Censusing Bats: Challenges, Solutions, and Sampling Biases

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Abstract. Historically, four methods have been used for censusing bats: roost counts, evening emergence counts, evening dispersal counts, and disturbance counts. Accurate and reliable estimates of the number of bats present in roosting situations are seldom feasible except for relatively small, gregarious species. In other situations, estimates of relative abundance may be the most appropriate data that can be obtained using a reasonable amount of time and effort. Mark-recapture methods can be used only if certain assumptions are met, including: (1) no differences in mortality between marked and unmarked animals; (2) marked and unmarked individuals have the same probability of being recaptured; (3) marks are not lost or overlooked; and (4) marked animals mix freely and randomly with the study population. Questions have been raised about the validity of this technique when applied to most bat species. There are numerous challenges associated with censusing bats, due largely to the wide range of roosting habits. Species that form large aggregations or that roost solitarily in cavities and crevices will be difficult to census. Censuses of hibernating bats must be designed to reduce disturbance and minimize the incidence of arousals. Recent technological advances offer promise for improving our ability to census bats reliably.

Key Words: Commuting bats, disturbance counts, emergence counts, foraging, hibernacula, mark-recapture, maternity roosts, roost counts.

Introduction

Methods suitable for censusing bats vary depending on the size and mobility of the species, the relative numbers of individuals present, access of investigators to roosting sites, and the availability and applicability of devices used for censusing (Mitchell-Jones, 1987; Kunz and Kurta, 1988; Thomas and LaVal, 1988; Frantz, 1989; Sabol and Hudson, 1995; Kunz and others, 1996a,b). A basic knowledge of the species to be censused is important before selecting one or more methods. This knowledge should include a general understanding of roosting habits, foraging behavior, seasonal movements, and how environmental factors may affect local abundance and distribution. Knowledge of temporal and spatial patterns associated with a particular species or population is also important. If devices such as binoculars, video cameras, night-vision devices, or ultrasonic detectors are used to extend the sensory capabilities of an observer while censusing, researchers must be thoroughly familiar with their operation, limitations, and potential biases (Kunz and others, 1996b).

Roost sites that are relatively easy to locate and house relatively small to moderately sized colonies of bats (<1,000) offer the greatest potential for conducting a reliable census (e.g., Kunz and Anthony, 1996; Hoying and Kunz, 1998; O’Donnell, 2000). Species that roost alone or in small groups in foliage, rock crevices and tree cavities, and species that form large colonies pose the greatest challenges for censusing (Constantine, 1966; Humphrey, 1971; Sabol and Hudson, 1995).
Historically, four methods have been used for censusing bats (Kunz and others, 1996b). These include roost counts, evening emergence counts, evening dispersal counts, and disturbance counts. Accurate and reliable estimates of the number of bats present in roosting situations are seldom feasible except for relatively small, gregarious species. Many solitary bats are cryptic and thus difficult to locate. Highly gregarious species often require the coordinated efforts of several individuals or use of sophisticated imaging devices. Some species are highly susceptible to disturbance in roosting situations, and may abandon these sites in response to census efforts (Tuttle, 1979). In other situations, lack of observer access to a roost or low visibility may preclude making reliable estimates during evening emergences.

In situations where direct access to the interior of a roost area is precluded or inadvisable (based on safety risks to observers), evening emergence counts offer the best alternative for censusing (Kunz and Anthony, 1996; Hoying and Kunz, 1998). In other situations, estimates of relative abundance may be the most appropriate data that can be obtained using a reasonable amount of time and effort. Disturbance counts may be of value in some limited situations (Racey, 1979), but in general they are not reliable and may increase mortality, especially of non-volant young.

**Visual Counts of Roosting Bats**

In some roosting situations, where a species forms small, compact, clusters, direct visual counts can provide reliable estimates of colony size (Tuttle, 1979; Hoying and Kunz, 1998; Fig. 1A). In other situations, where the probability of disturbing adults in maternity roosts is high, the number of lactating females can be estimated by counting the number of non-volant young in the roost after adults have departed to feed (Kunz, 1974; Tuttle, 1979; Fig. 1B). This method requires knowledge of litter size and an assumption that all females have given birth.

Direct visual counts of some gregarious megachiropterans may be possible in situations where the colonies are relatively small or where roost trees have been fully or partially defoliated, making it possible to see all or most of the bats (Fig. 2A). However, because colonies (camps) of many gregarious species are so large and diffuse or obscured by surrounding vegetation (Fig. 2B), a roost census may only yield estimates in orders of magnitude. For example, in very large colonies of pteropodids, incremental counts (e.g., 1–100, 100–1,000, 1,000–10,000, and 10,000 plus) have been used for extrapolating to larger areas occupied by the colony (Vardon and Tidemann, 1997, 1999). If numbers of roosting bats cannot be assessed reliably, "flyout" or dispersal counts (described below) may be more appropriate.

As with highly gregarious, tree-roosting megachiropterans, reliable visual censuses of large, active colonies of cave-roosting bats pose several challenges. Estimates of cluster density averaged from capture or

![Image A](image1.jpg)

![Image B](image2.jpg)

Fig. 1. (A) Small maternity colony of eastern pipistrelles (*Pipistrellus subflavus*) during late pregnancy, roosting near the ridgepole of a barn. The number of adult bats present in a colony can be censused by direct observation, assuming that all bats are visible. (B) Young cave myotis (*Myotis velifer*) roosting on the beam of a barn. The number of lactating females in a colony may be estimated by counting the number of non-volant young present in the roost after adults depart to feed. If the litter size is known for a given species being censused, and all females have produced young, the number of lactating females can be estimated. Photographs by T.H. Kunz.
Fig. 2. (A) A colony of giant flying foxes (*Pteropus giganteus*) roosting in a partly defoliated tree near Pune, India (Photograph by T.H. Kunz.). Bats may be censused from ground level, assuming that all bats can be observed.

(B) A colony of gray-headed flying foxes (*P. poliocephalus*), roosting in the crown of a tree in eastern Australia that is relatively densely foliated (photograph by P. Birt, from Hall and Richards, 2000; copyrighted by Krieger Publishing Company, used with permission). Dense foliage and sensitivity of bats to disturbance may preclude direct censusing from ground level. Evening dispersal or exit counts of large colonies of *Pteropus* spp. are sometimes possible if observers position themselves with an unobstructed view of dispersing bats silhouetted against a clear sky.

Photographic methods (Fig. 3A) have been used to extrapolate to the total area occupied by roosting bats (Tuttle, 1979). However, this approach may cause considerable disturbance to the roosting bats, especially during maternity periods. Moreover, irregularities in roost substrates, variations in cluster density, and dispersion
(Fig. 3B) will lead to biased estimates when cluster densities are extrapolated to the areas occupied by bats that are not uniformly distributed on the cave substrate. At best, the latter method will yield estimates of colony size in orders of magnitude. Estimates of colony size based on amounts and distribution of guano beneath roosting areas or stains deposited on roost substrates left by bats have been determined by extrapolating estimates of cluster density of roosting bats to the entire colonies (Tuttle, 1979). However, this method has not been validated and promises to be highly unreliable. At best, stained areas on ceilings and areas covered by guano may be useful for evaluating areas of caves that were previously occupied by bats.

**Evening Emergence Counts**

Evening emergence counts are the most effective for censusing bats that depart from buildings, caves, mines, and tree cavities (Speakman and others, 1992; Kunz and Anthony, 1996; Rydell and others, 1996; Jones and Rydell, 1998; O’Donnell and Sedgeley, 1999). An emergence count may be the only suitable method for censusing bats that roost in physically hazardous or inaccessible places. In situations where roosts are unknown, a census can be accomplished by capturing bats while they are feeding or commuting, fitting selected individuals with radio transmitters, and tracking the bats to their roosts (Kurta and others, 1993; Vonhof, 1996; O’Donnell and Sedgeley, 1999). After roosts have been located it may be possible to conduct evening emergence counts.

The number of observers needed to conduct an emergence count at caves, buildings, and tree cavities will depend on the size, configuration, and spatial distribution of the roost openings, the number of openings from which bats depart, and the relative numbers of bats present (Kunz and others, 1996b). Observers should be assigned specific exits or fields of view for which they are responsible, and should be present at their stations before the onset of emergence to ensure that the earliest departing bats are counted.

Ideally, evening emergence counts should be made repeatedly to establish intra-colony variation in the number of bats present (Kunz and Anthony, 1996; Hoving and Kunz, 1998; Fig. 4). If time is limited, evening emergence counts should be conducted for at least three consecutive nights during periods of maximum adult colony size (late pregnancy and early lactation). For maternity colonies, evening emergence counts should be made when all adults are present but before young have become volant. More frequent censusing is advisable if time and personnel are available, and if there is interest in assessing seasonal changes in colony size associated with the reproductive phenology of the colony. If a census is made after young begin to fly, it is important to acknowledge that newly volant individuals may depart later in the evening than adults (Kunz, 1974; Kunz and Anthony, 1996), thus making it necessary to extend the census period past the time when the emergence of adults has ceased.

**Evening Dispersal or “Flyout” Counts**

Evening dispersal or “flyout” counts are commonly used to estimate numbers of megachiropterans that roost in trees (Thomas and LaVal, 1988; Kunz and others, 1996b; Eby and others, 1999; Garnett and others, 1999; Vardon and others, 2001). As bats disperse from their diurnal roosts, they can be counted by observing their silhouettes against the sky. However, visibility of bats at the time of nightly dispersal and the experience of observers can greatly influence the reliability of the census. In general, reliability decreases with increasing numbers of bats, the distance of the observer from bats, and the light conditions at the time of emergence (Richards, 1990; Kunz and others, 1996b). Evening dispersal counts may be underestimated if some individuals delay departure from the roost (e.g., lactating females), depart after dark.
(young-of-the-year), or observers cannot adequately see individuals due to the density of surrounding foliage (Kunz and others, 1996b).

Several observers should be positioned at least half an hour before nightfall at designated stations near a colony that is to be censused. Individuals or teams of individuals should be assigned to count bats as they depart within a pre-assigned arc surrounding the roost. Because decreasing light levels can reduce the ability of observers to see, use of light-gathering binoculars or low-light level cameras may facilitate censusing in some situations. The size of nomadic colonies of megachiroptrans can be assessed by making simultaneous censuses over large areas. To be successful, this approach requires large numbers of observers and strong coordination among teams of observers.

**Disturbance Counts**

Disturbance counts have been used with limited success to census some large megachiroptrans (Racey, 1979). Typically, this method requires one or more persons to enter a roost area (causing bats to take flight during the day) and make loud noises while other individuals count the bats. Assuming that all individuals in the colony take flight, individuals may be counted directly, photographed, or videotaped. The success of disturbance counts, however, depends on several factors, including the sensitivity of bats to the type of disturbance, the skill of the individuals causing the disturbance, whether all bats simultaneously take flight, and the position of the observers or photographers relative to the flying bats (Racey, 1979). Because some megachiroptrans habituate to extraneous noises, the reliability of this method is highly questionable. More importantly, because abandonment of adults and deaths of dependent young have been reported following such disturbances at roosts (Garnett and others, 1999), this method is not recommended.

**Estimates Based on Mark-Recapture**

Mark-recapture methods can be used successfully only if certain assumptions are met. A major assumption of the mark-recapture method is that the population or colony to be censused is "closed". A colony of adults may be considered "closed" only during a brief period in late pregnancy and early lactation when females show the strongest fidelity to their roosts and before young become volant. In principal, a population is considered closed when recruitment, mortality, emigration, or immigration are non-existent during the census period. Some recent models have relaxed the latter assumption, but other assumptions of this method, including: (1) no differences in mortality between marked and unmarked animals; (2) marked and unmarked individuals have the same probability of being recaptured; (3) marks are not lost or overlooked; and (4) marked animals mix freely and randomly with the study population, raise questions about the validity of this technique when applied to most bat species. A detailed review of mark-recapture methods is beyond the scope of this chapter, but relevant discussion and evaluation of mark-recapture models can be found in White and others (1982) and Thompson and others (1998). For a review of published mark-recapture studies on bats, the reader is referred to Thomas and LaVal (1988).

Unbiased capture and marking methods are essential for successful mark-recapture studies. Many species require different capture and marking methods (Barclay and Bell, 1988; Kunz and Kurta, 1988; Kunz and others, 1996a). Some species fail to tolerate traditional marking methods, whereas other species cannot be captured repeatedly without causing severe disturbance to colonies. Use of passive integrated transponders (PIT tags) for marking bats holds considerable promise for mark-recapture studies. To date, PIT tagging has been used successfully in a handful of studies on bats with minimal injury or loss of tags (Kerth and König, 1996, 1999; Brooke, 1997; Horn, 1998). Once animals are marked, potential biases associated with recapture, such as trap happiness or trap shyness can be ignored. Mark-recapture studies of bats that use PIT tags, however, do not obviate the need to satisfy other assumptions.

**Challenges and Recent Advances in Censusing Bats**

There are numerous challenges associated with censusing bats, due largely to the wide range of roosting habits, including foliage, tree cavities, caves (and mines), rock crevices, and an assortment of human-made structures. Species that form large roosting aggregations in caves, mines, buildings, or similar structures, pose special challenges for censusing. It is usually impractical to visually count large numbers of bats as they emerge nightly from caves (Fig. 5). Solitary bats and small groups that roost in dense foliage, rock crevices, and tree cavities also pose challenges for conducting a reliable census (see also Carter and others, 2003). In the final analysis, methods used to census bats should be designed to minimize disturbance and sample biases.

One of the greatest challenges for censusing bats is that nightly emergence periods may extend beyond the
time that visible light can be relied on when using conventional methods. Moreover, some colonies are so large (estimated in the thousands and millions) that traditional methods of censusing are impractical. Infrared thermal imaging offers considerable promise for censusing bats at colonies that range from a few hundred to millions (Sabol and Hudson, 1995; Frank and others, 2003). An important advantage of infrared thermal imaging is that individual bats can be detected and counted independent of ambient (visible) light, because this technology detects heat given off by the bats. However, for this method to be successful, a clear sky or uniform artificial background is required. Emerging bats are detected in the field of view as digital “hot spots” (Fig. 6A). Subsequently, the uniform background is digitally subtracted from the field of view to highlight the bats for analysis. Rates of emergence and the numbers of bats emerging per unit time can then be computed electronically (Fig. 6B).

An important advantage of infrared thermal imaging relative to other methods available for censusing bats is that it can yield reliable and consistent records independent of ambient light. In addition to the high cost, a principal limitation of this technology is that the camera and associated computer acquisition and analysis systems require an uninterrupted, stable, filtered source of electrical power (generator or battery) to obtain reliable results.

Methods for censusing foliage, crevice and cavity-roosting species (Fig. 7) are often limited to random searches or are confined to habitats based on previously established search images. In general, these approaches are labor intensive, biased, and unproductive. However, radiotelemetry is an invaluable technique for locating bats that roost in foliage and tree cavities (Barclay and others, 1988; Kurta and others, 1993; Betts, 1996; Kalcounis and Hecker, 1996; Sasse and Pekins, 1996; Vonhof, 1996; Menzel and others, 1998; O’Donnell, 2000). Once roost sites are located, a census based on emergence counts can be accomplished.

Censuses of hibernating bats should be designed to reduce disturbance and minimize the incidence of arousals. Ideally, a hibernaculum should not be censused more often than once every 2 years. Species that roost in small, discrete clusters can often be counted individually as they are encountered (Fig. 8). However, for species that
form large aggregations, numbers are best censused by estimating the cluster density at selected sites and extrapolating this value to the total area of the roost substrate covered by bats (Tuttle, 1979, 2003). Species identifications based on visual assessment, rather than handling, are preferred in order to reduce disturbance.

Personnel engaged in censusing hibernating bats should have experience with all types of caving techniques and knowledge of appropriate safety and rescue procedures. Considerations of size and complexity of the hibernaculum will dictate the number of personnel needed to conduct a census in caves and mines. Census teams should make every effort to minimize the amount of time conducting a census in order to reduce disturbance to the bats.

Fig. 8. Small hibernating cluster of cave myotis (Myotis velifer). Small clusters can be counted directly and large colonies sometimes can be estimated by extrapolating cluster density (assuming some average value) to areas of the roost substrate occupied by hibernating bats. To minimize disturbance, hibernating bats should not be censused more than once every two years. Photograph by T.H. Kunz.

Relative numbers of flying bats may be estimated in some habitats by deploying mist nets, harp traps, night vision devices, infrared cameras (Fig. 9), and ultrasonic detectors (for some echolocating species). In regions where echolocating bats commute and forage (and where trapping is impractical or impossible), ultrasonic bat detectors have proven useful (in some situations) for identifying bats to species (or genera), and for estimating their relative abundance (Hayes, 1999, but see also Working Group reports, this volume).

Users of ultrasonic detectors should have a basic understanding of electronics, a thorough knowledge of echolocation and bioacoustics, experience in using modern methods of sound analysis (Kunz and others, 1996a; Fenton, 2000), and an understanding of the limitations of these devices for monitoring bat populations. Quantitative methods for identifying
echolocating species in the field are preferable to qualitative methods (Hayes, 1999, 2000). The ability of bat detectors and associated analysis software to discriminate between closely related taxa, however, varies with the type and quality of the instruments and the experience and skill of the observer (Fenton, 2000; Jones and others, 2000).

In general, learning to distinguish different bat species by their echolocation calls requires practice, good acoustic memory, and lots of patience (Hayes, 1999). Unique characteristics of echolocation calls, including frequency, changes in frequency with time, and pulse repetition rate may allow an observer to identify bats flying (feeding and commuting) in a given area (O’Farrell and Gannon, 1999; O’Farrell and others, 1999a, but see critique of Barclay (1999) and reply by O’Farrell and others (1999b)]. The most important attributes of a successful user of bat detectors are training and patience.

Aided with spotting lights, night vision devices, and flash photography, species that have distinct wing shapes and flight patterns can be visually identified with some degree of confidence (Ahlen, 1980, 1981). With exception of a few diurnal species (Speakman, 1995; Thomson and others, 1998), it is very difficult to identify bats by sight while they are flying. Capture and recordings of echolocation calls should confirm species that are provisionally identified by sight.

**Conclusions**

A combination of traditional census methods (roost counts and evening emergence counts) and recently developed remote censusing techniques offer the greatest promise for estimating colony sizes of most species. Where a given species forms relatively small colonies and roosts in open areas on walls and ceilings of caves, mines, and buildings, a direct count may be the most appropriate method as long as disturbance to roosting bats can be avoided or minimized. Disturbance to roosting bats can be minimized by using low light-level video cameras, night vision devices, or infrared thermal cameras and by reducing the number of visits to roost areas during the day.

Traditional methods used to census bats include visual counts within roosts and counts made during evening emergences and dispersals. While these methods remain as standards for censusing bats, improved capture and marking methods and the use of remote detection devices have increased our ability to more accurately and reliably census both roosting and flying bats. Mark-recapture methods have generally proven unsuccessful for censusing bat colonies, largely because colonies (and bat populations as a whole) are not “closed”, and because other assumptions often cannot be met. Moreover, application of the latter method may be compromised by the fact that some bat colonies often fragment into smaller groups and some individuals may shift to alternate roost sites.

For many bat species, evening emergence counts provide the most reliable method for estimating colony size, especially when observers cannot gain access to or choose not to enter roost areas. Emergence counts are most effective at small colonies, and where the emergence routes are known and can be monitored with an appropriate number of personnel. Limitations of conducting successful emergence counts include inadequate light and poor visibility.

Infrared thermal imaging holds considerable promise for censusing bats as individuals emerge from roosts. One of the advantages of infrared thermal imaging is that individuals can be censused independent of the ambient light at the time of emergence. However, successful application of infrared thermal imaging requires a uniform background (clear sky or artificial backdrop) behind the emerging bats so that this background can be digitally subtracted from the images of emerging bats.

Censusing hibernating bats is best achieved by counting each individual bat or group of bats as they are encountered, or by estimating the mean density of bats
in several representative clusters, and extrapolating this density to the total area of the cave wall or ceiling that is covered by bats. Censuses of hibernating bats should be limited to one census period every other year.

Methods used for censusing foraging and commuting bats are more problematic and generally limited to making relative estimates based on captures or remote sensing. Devices suitable for capture include mist nets and harp traps, whereas photography and videography using supplemental light sources, ultrasonic detectors, and infrared thermal cameras are valuable remote sensing devices for assessing relative abundance.

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References Cited

Horn, J.W., 1998, Individual variation in the nightly time budgets of the little brown bat, Myotis lucifugus, M.A. thesis; Boston University, Massachusetts, 64 p.


