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A Plan for the North American Bat Monitoring Program (NABat)

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Cover photo
Millions of Brazilian free-tailed bats emerge from
Bracken Cave in suburban San Antonio, TX.

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Brazilian free-tailed bats emerge from Bracken Cave in suburban San Antonio, TX.

Abstract

The purpose of the North American Bat Monitoring Program (NABat) is to create a continent-wide program to monitor bats at local to rangewide scales that will provide reliable data to promote effective conservation decisionmaking and the long-term viability of bat populations across the continent. This is an international, multiagency program. Four approaches will be used to gather monitoring data to assess changes in bat distributions and abundances: winter hibernaculum counts, maternity colony counts, mobile acoustic surveys along road transects, and acoustic surveys at stationary points. These monitoring approaches are described along with methods for identifying species recorded by acoustic detectors. Other chapters describe the sampling design, the database management system (Bat Population Database), and statistical approaches that can be used to analyze data collected through this program.

Keywords: Acoustic surveys, bat detectors, bats, chiroptera, climate change, hibernaculum counts, monitoring, occupancy models, population trends, white-nose syndrome.

Contents

Preface

Currently, there is no program, public or private, that conducts standardized monitoring of bat species across multiple taxa in North America. The North American Bat Monitoring Program (NABat) is a multiagency, multinational effort designed to address this need. It grew out of the document “A National Plan for Assisting States, Federal Agencies, and Tribes in Managing White-Nose Syndrome in Bats” (hereafter National Plan) (U.S. Fish and Wildlife Service 2011). The National Plan established seven working groups, including the Conservation and Recovery Working Group. Goal 1 of the Conservation and Recovery Working Group is to develop and validate rapid-assessment monitoring plans to determine differences in susceptibility among species and to identify which species are most vulnerable to extinction due to white-nose syndrome (WNS). To achieve this goal, the working group was charged with three action items: (1) seek consensus on feasible monitoring techniques and protocols that would gauge impacts of WNS on bat species, (2) develop and implement monitoring plans to establish the degree to which different species of bats are vulnerable to WNS, and (3) establish best management practices for population monitoring on a rangewide scale for bat species of greatest conservation concern. However, it became evident while working on these action items that others in the bat research and management community were trying to tackle similar goals to address such issues as the impacts of wind energy development on bats. Because bats and the factors that threaten them cross international and intranational borders, it became readily apparent that there was a need for the development of a comprehensive bat monitoring program for all 47 North American bat species shared among the United States, Canada, and Mexico. This monitoring program is needed not only to provide information about the impacts of WNS, but also to inform management and policymakers regarding the impacts of wind energy development, climate change, habitat loss, and unanticipated threats that may arise in the future.

Following recommendations of Gitzen and Millspaugh (2012) and Reynolds (2012), the development of NABat incorporated the expertise of bat biologists, wildlife managers, policymakers, statisticians, and data managers throughout the process. The first step in the development of NABat was to build consensus within the community of North American bat researchers and biologists on feasible monitoring techniques and protocols to assess species responses to WNS (Goal 1, Action Item 1 of the Conservation and Recovery Working Group). To this end, a workshop was held in April 2012 that brought together a wide variety of scientists, including bat field biologists, population geneticists, population modelers, statisticians, and database experts. The workshop was sponsored by the U.S. Fish and Wildlife Service; Forest Service, U.S. Department of Agriculture; Bureau of Land Management; U.S. Geological Survey; and Bat Conservation International, and was attended by 26 invited participants from 5 Federal agencies, 7 universities, and 1 nongovernmental organization. The major impetus for the meeting was the need to measure the impacts of WNS on bat populations, but measuring the effects of other stressors such as climate change and wind energy development was also of concern. The intent of the workshop was to build on the outcomes and recommendations of a workshop held in 1999 (O’Shea and Bogan 2003) and incorporate new techniques and analyses that had been developed since that workshop. Addressing data management needs was also a high priority and was considered in all discussions of monitoring needs and protocols. After reviewing existing protocols, participants made recommendations for monitoring bat populations in maternity and hibernation colonies, estimating vital rates, using acoustic detectors and mist nets as monitoring techniques, and modeling the spatial distribution and occurrence of bats across large

Gray myotis, Hubbards Cave survey.

spatial scales. Participants also discussed the need for developing a sampling frame before a national monitoring program could be established, and briefly outlined such a sampling frame. However, time was not available to fully develop this sampling frame. Thus, workshop participants recommended that a small group of experts in the field of sampling design convene to draft a national sampling frame that could be scaled from site to continental scales.

In summer 2012, funding was obtained from the National Landscape Conservation Cooperative network through a national grant opportunity offered by the U.S. Fish and Wildlife Service and from the National Institute of Mathematical and Biological Synthesis (NIMBioS) to convene three workshops to develop the sampling framework for NABat. The objectives of the first workshop, held in February 2013, were to gather information on other large-scale monitoring programs and learn from their successes and failures. Monitoring program sampling designs for birds, amphibians and reptiles, and water quality at national levels, as well as for bats in the United Kingdom, Pacific Northwestern United States, and Eastern United States, were presented and discussed. Based on these presentations and discussions, it was agreed that some type of grid-based finite sampling frame would be the most efficient approach for NABat. The second workshop, held in May 2013, was sponsored by NIMBioS and held at the NIMBioS laboratory at the University of Tennessee, Knoxville. Participants concentrated on fleshing out the details of the grid design, how it would be applied to acoustic monitoring and colony counts, and the analytical approaches that could be used to analyze resulting data. Additional topics included the appropriate covariates that should be collected, the need for standardization of protocols, data management, and Geographic Information System support. The third workshop, held in November 2013, focused on refining protocols and analyses and preparing the current report. Throughout the process, feedback was gathered from potential users through presentations in webinars and at scientific meetings (e.g., the International Bat Research Conference in August 2013 and the White-Nose Syndrome Workshop in September 2013).

All the authors of this report participated in two or more of the workshops and many participated in all four. We thank the following people for their participation in one or more workshops and providing guidance and expertise: Sybill Amelon, Kate Barlow, Eric Britzke, Brian Cade, Kevin Castle, Matthew Clement, Steve Corn, Paul Cryan, Peter Dratch, Winifred Frick, Cris Hein, Kate Jones, William Kendall, Marm Kilpatrick, Subash Lele, Kirk Navo, Anthony Olsen, Pat Ormsbee, Sarah Oyler-McCance, Luis Viquez Rodriguez, Amy Russell, Robin Russell, Patrick Sullivan, Jennifer Szymanski, Maarten Vonhof, Ted Weller, and Craig Willis. Technical reviews of this document were obtained from a variety of professionals. We thank the following individuals for the time, expertise, and valuable input on one or more chapters: Eric Britzke, Matthew Clement, Chris Corben, Gordon Dicus, Allysia Park, Laura Eaton, Robert Gitzen, Al Hicks, Vivian Hutchison, Andrew King, David Miller, Robyn Niver, Anthon Olsen, Craig Stihler, Patrick Sullivan, Steven Thomas, Janet Tyburec, and Michael Whitby.

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1. Introduction

1.1 Purpose, Mission, Goals, and Objectives of the North American Bat Monitoring Program 1.1

A Brazilian free-tailed bat with a moth.

North American bats face unprecedented risks from continuing and emerging threats including habitat loss and fragmentation, white-nose syndrome (WNS), wind energy development, and climate change. Thus, there is an urgent need to document changes in bat populations in response to these threats as well as to assess management actions aimed at mitigating these threats. The need to monitor bats in North America has been recognized for many years (O'Shea and others 2003), but no coordinated program exists to monitor most bat species in North America, although such programs have been designed and implemented for birds (Ziolkowski and others 2010) and amphibians (Adams and others 2013). The North American Bat Monitoring Program (NABat) is being established to fulfill this need. The purpose, mission, goals, and objectives of NABat are below.

PURPOSE: The purpose of NABat is to create a continent-wide program to monitor bats at local to rangewide scales that will provide reliable data to promote effective conservation decisionmaking and the long-term viability of bat populations across the continent.

MISSION: The mission of NABat is to provide the biological, administrative, and statistical architecture for coordinated bat population monitoring to support regional and rangewide inferences about changes in the distributions and abundances of bat populations facing current and emerging threats, and to provide guidance for monitoring at the local scale.

GOALS: To achieve the purpose and mission as stated above, NABat has established two specific goals:

- Develop and maintain a long-term continental program to monitor bat distributions and indices of abundance at rangewide, regional, and local scales.

- Provide regular analyses and reporting on the status and trends of bat populations to inform managers and policymakers so that they can manage bat populations effectively.

OBJECTIVES: The objectives of NABat are to (1) provide the infrastructure needed for a coordinated bat monitoring program across national, State, Provincial, tribal/aboriginal, and private lands boundaries; (2) provide a centralized database to house and manage data collected under the NABat program as well as additional data on bats of North America; (3) define a statistically robust continent-wide sampling framework for the collection of bat monitoring data; (4) provide recommended field protocols for colony count and acoustic monitoring data collection; (5) provide statistical analyses of status and trends in populations at national and regional scales using the most appropriate and robust methods available; (6) provide periodic "State of North America's Bats" reports that assess the status and trends of bats in relation to current and emerging threats; and (7) continually assess the monitoring program and adjust protocols, sampling designs, and analyses as necessary.

1.2 1.2 Background and Need

1.2.1 1.2.1 The Bats of North America and Their Importance

Bats are the second most diverse order of mammals with approximately 1,240 species worldwide (Simmons and Gunnell 2011). Currently, there are 150 species of bats recognized in North America, including 138 that are found in Mexico, 47 in the United States, and 17 in Canada. NABat will focus on the 47 species that are found in the United States and shared with Canada or Mexico (table 1.1) (sec. 1.3.1). In Canada, three species are listed as endangered, one species is considered threatened, and another species is considered a species of special concern (table 1.1). In the United States, eight species or subspecies are listed as endangered and one species is listed as threatened. Three species are considered threatened and two species are provided special protection in Mexico (Ceballos and others 2002).

Bats are important to the maintenance of healthy ecosystems and provide many other benefits to humans. One of the most important services that bats provide is insect consumption. Approximately 70 percent of all bat species are obligate or facultative insectivores, and these bats consume large numbers of insects throughout the growing season (Kunz and others 2011). For example, Brazilian free-tailed bat (*Tadarida brasiliensis*) colonies in Texas often contain over 1 million bats (Betke and others 2008), and it has been estimated that colonies of this size can eat 8.4 metric tons of insects in one night during the peak of lactation (Kunz and others 1995). Several studies in the tropics have shown that bats can significantly depress the number of insects feeding on important agricultural crops and forest trees (Kalka and others 2008, Morrison and Lindell 2012, Williams-Guillén and others 2008). While it is difficult to measure the economic impact of insect consumption by bats, the mean annual value of Brazilian free-tailed bats in an eight-county region of Texas is estimated at $12.2 million (range = $4.9 million to $24.0 million) (López-Hoffman and others 2014). Another model has estimated that bats across the United States provide approximately $4 billion to $53 billion worth of pest control services to agriculture per year (Boyles and others 2011).

Some species of bats are also important pollinators of native and commercial plants (Kunz and others 2011). For example, bats pollinate *Agave tequilana*, which is the principal component used in the distillation of tequila, an economically important product of Mexico. Fruit-eating bats in the tropics and subtropics are important seed dispersers and aid in forest and fruit crop regeneration. Bats also redistribute nutrients across the landscape. Accumulation of nitrogen from guano piles at the base of northern myotis (*Myotis septentrionalis*) and Indiana myotis (*M. sodalis*) maternity roosts in dead trees fertilize the soil and may be important for forest regeneration and gap dynamics (Duchamp and others 2010). Bat guano may also be an important source of chitin, a polymer that is used in cosmetics, pharmaceuticals, bioengineering, agriculture, textiles, and environmental engineering (Kaya and others 2014).

Biologist counts hibernating little brown myotis in Wisconsin's Bay City Mine. (© Mylea Bayless, Bat Conservation International, www.batcon.org)

Bats provide many other benefits to humans, some of which are just becoming known. They have served as important models in medical research and aerodynamics, and compounds from their bodies are being used in new medical treatments. Because bats live much longer than would be expected based on their body size, they provide a good model for studies of the aging process (Brunet-Rossinni and Austad 2004), and studies of their metabolism have provided insight into some causes of aging (Brunet-Rossinni 2004). Desmoteplase, a compound found in the saliva of the common vampire bat (*Desmodus rotundus*), is being tested as a treatment for stroke in humans and shows particular promise because it provides faster restoration of blood flow with reduced risk of bleeding and can be administered later than other stroke treatments (Pugsley and others 2006). Bats also provide small but measurable economic stimuli for several communities in the United States and elsewhere. For example, bat watching at caves such as Carlsbad Caverns or the Congress Avenue Bridge in Austin, TX, brings visitors to these areas and may contribute millions of dollars to local communities (Bagstad and Wiederholt 2013, Kunz and others 2011). Bats are also considered to be good bioindicators for monitoring ecosystem health because of their longevity and their sensitivity to stressors that may also affect many other organisms (Jones and others 2009).

1.2.2 Threats to Bats 1.2.2

Bats have been experiencing population declines for many decades, and approximately 24 percent of all bats worldwide are considered critically endangered, endangered, or vulnerable (Mickleburgh and others 2002). Because of their unique life history strategies, bats are particularly vulnerable to external stressors. North American bats have very low reproductive rates compared to other mammals their size, producing only one litter of young per year that usually ranges from one to three young per litter (Barclay and Harder 2003). They also have long lifespans (up to 38 years in some species) (Brunet-Rossinni and Austad 2004) for their body size, associated with delayed maturity and the ability to accumulate toxicants over a long period of time. Many bat species aggregate in large numbers (thousands to hundreds of thousands of individuals) during hibernation and rearing of young, often in relatively few caves or mines. For example, 80 percent of the known Indiana myotis population is found in just 16 hibernacula (Thogmartin and others 2012), and 95 percent of the known gray myotis (*M. grisescens*) population hibernates in 15 caves or mines (Harvey and others 2011). Thus, disturbance to even one of these hibernacula has the potential to affect a large proportion of the population.

Bats have been facing many threats for decades, including habitat loss and fragmentation; disturbance and destruction of roost sites, particularly caves and mines; pesticides and other contaminants; persecution; and climate change (Jones and others 2009, Mickleburgh and others 2002, Racey and Entwistle 2003). Cave disturbance and destruction have been cited as the major threats contributing to the endangered status of the gray myotis, Indiana myotis, and Mexican long-nosed bat (*Leptonycteris nivalis*) (U.S. Fish and Wildlife Service 1982, 1994, 2007), and loss of mature bottomland hardwood forest is thought to be the major factor contributing to the putative declines of Rafinesque's big-eared bats (*Corynorhinus rafinesquii*) and southeastern myotis (*M. austroriparius*) in the coastal plains of the Southeastern United States (Bat Conservation International and Southeastern Bat Diversity Network 2013, Miller and others 2011). Gating may mitigate the effects of disturbance on some populations, but not all (Crimmins and others 2014, Ludlow and Gore 2000). Warming temperatures associated with climate change are predicted to result in shifts in the hibernating distribution for species such as the little brown myotis (*M. lucifugus*) (Humphries and others 2002) and a reduction and shift in maternity distribution of the Indiana myotis (Loeb and Winters 2013). Drier conditions and increased drought associated with climate change may significantly impact bat reproductive success (Adams 2010, Adams and Hayes 2008).

Since the beginning of the 21st century, two additional threats, WNS and wind energy development, have greatly impacted North American bats. WNS is an emerging infectious disease caused by the psychrophilic fungus, *Pseudogymnoascus destructans* (formerly *Geomyces destructans*) (Lorch and others 2011, Minnis and Linder 2013). The disease was first discovered in North America on bats near Albany, NY, in 2006

Table 1.1—The bats of North America that are shared among Canada, the United States, and Mexico and their national conservation/legal status within the respective countries

		Canada		United States		Mexico	
Scientific name	**Common name**	**Presence**	**Status**[a]	**Presence**	**Status**	**Presence**	**Status**
Antrozous pallidus	Pallid bat	+	SARA Threatened	+	—	+	—
Artibeus jamaicensis	Jamaican fruit-eating bat	-	—	+	—	+	—
Choeronycteris mexicana	Mexican long-tongued bat	-	—	+	—	+	Threatened
Corynorhinus rafinesquii	Rafinesque's big-eared bat	-	—	+	—	-	—
Corynorhinus townsendii	Townsend's big-eared bat	+	CESCC Sensitive	+	*C. t. ingens* and *C. t. virginianus* Endangered	+	—
Eptesicus fuscus	Big brown bat	+	CESCC Secure	+	—	+	—
Euderma maculatum	Spotted bat	+	SARA Special Concern	+	—	+	Special Protection
Eumops floridanus	Florida bonneted bat	-	—	+	Endangered	-	—
Eumops perotis	Greater bonneted bat	-	—	+	—	+	—
Eumops underwoodii	Underwood's bonneted bat	-	—	+	—	+	—
Idionycteris phyllotis	Allen's big-eared bat	-	—	+	—	+	—
Lasionycteris noctivagans	Silver-haired bat	+	CESCC Secure	+	—	+	Special Concern
Lasiurus blossevillii	Western red bat	-[b]	—	+	—	+	—
Lasiurus borealis	Eastern red bat	+	CESCC Secure	+	—	+	—
Lasiurus cinereus	Hoary bat	+	CESCC Secure	+	*L. c. semotus* Endangered	+	—
Lasiurus ega	Southern yellow bat	-	—	+	—	+	—
Lasiurus intermedius	Northern yellow bat	-	—	+	—	+	—
Lasiurus seminolus	Seminole bat	-	—	+	—	-	—
Lasiurus xanthinus	Western yellow bat	-	—	+	—	+	—
Leptonycteris nivalis	Mexican long-nosed bat	-	—	+	Endangered	+	Threatened
Leptonycteris yerbabuenae	Lesser long-nosed bat	-	—	+	Endangered	+	Threatened
Macrotus californicus	California leaf-nosed bat	-	—	+	—	+	—
Molossus molossus	Pallas' mastiff bat	-	—	+	—	+	—
Mormoops megalophylla	Peter's ghost-faced bat	-	—	+	—	+	—
Myotis auriculus	Southwestern myotis	-	—	+	—	+	—
Myotis austroriparius	Southeastern myotis	-	—	+	—	-	—
Myotis californicus	California myotis	+	CESCC Secure	+	—	+	—
Myotis ciliolabrum	Western small-footed myotis	+	CESCC Secure	+	—	+	—

Continued

Scientific name	Common name	Canada		United States		Mexico	
		Presence	Status[a]	Presence	Status	Presence	Status
Myotis evotis	Long-eared myotis	+	CESCC Secure	+	—	+	—
Myotis grisescens	Gray myotis	-	—	+	Endangered	-	—
Myotis keenii	Keen's myotis	+	CESCC May be at Risk	+	—	-	—
Myotis leibii	Eastern small-footed myotis	+	CESCC May be at Risk	+	—	-	—
Myotis lucifugus	Little brown myotis	+	SARA Endangered	+	—	-	—
Myotis melanorhinus	Dark-nosed small-footed myotis	+	Not assessed	+	—	+	—
Myotis occultus	Arizona myotis	-	—	+	—	+	—
Myotis septentrionalis	Northern myotis	+	SARA Endangered	+	Threatened	-	—
Myotis sodalis	Indiana myotis	-	—	+	Endangered	-	—
Myotis thysanodes	Fringed myotis	+	CESCC May be at Risk; SARA Special Concern	+	—	+	—
Myotis velifer	Cave myotis	-	—	+	—	+	—
Myotis volans	Long-legged myotis	+	CESCC Secure	+	—	+	—
Myotis yumanensis	Yuma myotis	+	CESCC Secure	+	—	+	—
Nycticeius humeralis	Evening bat	-	—	+	—	+	—
Nyctinomops femorosaccus	Pocketed free-tailed bat	-	—	+	—	+	—
Nyctinomops macrotis	Big free-tailed bat	-	—	+	—	+	—
Parastrellus hesperus	Canyon bat	-	—	+	—	+	—
Perimyotis subflavus	Tri-colored bat	+	SARA Endangered	+	—	+	—
Tadarida brasiliensis	Brazilian free-tailed bat	-	—	+	—	+	—

+ = Species present, - = Species not present, — = No special status.

Note: Scientific and common names follow Wilson and Reeder (2005) except for those species whose taxonomy has been revised since publication of that document.

[a] SARA = Species at Risk Act, Schedule 1; CESCC = Canadian Endangered Species Conservation Council assessment of the state of biodiversity nationally, considering provincial status ranks (CESCC 2011). This latter ranking system affords no protection to bats federally, but is indicative of expert assessment of the status of each species. In addition, some species are protected under provincial legislation.

[b] Recent genetic evidence confirms this species has not been found in Canada (Nagorsen and Paterson 2012).


A pallid bat with a katydid.

and has been estimated to have killed over 5.7 million bats (U.S. Fish and Wildlife Service 2012). As of spring 2015, WNS had spread to 26 States and 5 Canadian Provinces (U.S. Fish and Wildlife Service 2015). Winter colony counts have revealed major declines associated with WNS for four of the seven affected species (Turner and others 2011). Although several treatment methods are being tested and show promise (e.g., Cornelison and others 2014), it will be many years before these may be implemented on a large scale.

The first bat fatalities at wind energy facilities in the United States were reported in the late 1990s, but significant numbers of fatalities were not reported until 2003 when numerous fatalities were observed in the Appalachian Mountains (Cryan and Barclay 2009). Since 2003, the widespread occurrence of bat mortality at wind turbine facilities across North America has become evident (Arnett and others 2008). Causes of mortality include direct impact with the blades as well as barotrauma. Mitigation strategies such as deterrents (Arnett and others 2013) or altering the threshold wind speed at which the rotors begin to rotate (Arnett and others 2011, Baerwald and others 2009) can reduce the number of mortalities by approximately 2 to 64 percent and 50 to 65 percent, respectively. However, deterrents are still in the experimental stage, and reducing cut-in speeds as a mitigation strategy is used only at a subset of sites. Estimates of mortality at wind energy developments vary widely. Arnett and Baerwald (2013) estimated that cumulative bat fatalities in the United States and Canada from 2000 through 2011 ranged from approximately 840,000 to 1,691,000 bats,[1] whereas Hayes (2013) and Smallwood (2013) estimated that the number of bats killed at wind turbine facilities in the United States during 2012 alone was approximately 684,000 and 880,000, respectively.

New threats are also likely to emerge. For example, toxicants and chemicals associated with new technologies such as hydraulic fracking and produced water ponds (by-products of oil and gas drilling) also have the potential to impact bats. Additional emerging diseases may affect bats in the future, particularly during the winter when their immune systems are suppressed (Bouma and others 2010) or as the result of pesticides, such as neonicotinoid pesticides, that can suppress animal immune systems (Mason and others 2014).

1.2.3

1.2.3 Need for Monitoring

Given the myriad known and unknown threats to bats and our lack of baseline data on bat distributions across North America, an effective and efficient monitoring program is needed to (1) document the impact of stressors on bat populations, (2) identify priority species for conservation actions, and (3) measure the effectiveness of agencies' conservation and management actions to mitigate stressors. Monitoring data are also critical for determining species' risks of extinction, providing an early warning sign for species that may be experiencing declines from unknown causes, and managing for healthy bat populations. Because bats are wide ranging and can travel over hundreds of kilometers annually, an effective monitoring program to document changes in their populations and distributions must be extensive in geographic scope (e.g., rangewide to continental). Local land managers also need methods to monitor bats on their properties to determine the effectiveness of their conservation and management at smaller spatial scales (e.g., national park, State forest). Thus, a monitoring program that meets the needs of users must be scalable from local to continental scales. NABat will help to (1) determine species distributions, (2) focus conservation efforts, (3) provide

[1] Revised data on file with: Erin Baerwald, Department of Biological Sciences, University of Calgary, 2500 University Drive N.W., Calgary, AB T2N 1N4, Canada.

analysis of trends and assessment of impacts, and (4) monitor efficacy of conservation and adaptive management efforts.

1.3 Scope of NABat 1.3

1.3.1 Scope and Species 1.3.1

One of the main goals of NABat is to establish a long-term monitoring program for bats across North America. We define monitoring as assessing one or more population state variables (e.g., abundance or distribution) at various points in time to draw inferences about changes in those state variables (e.g., trends) (Yoccoz and others 2001). Because bats have long life spans and some stressors such as climate change may have subtle effects, this effort will require a long-term commitment (i.e., multiple decades). For example, Roche and others (2011) estimated that 8 to 38 years of monitoring using mobile driving transects would be necessary to document declines of 25 to 50 percent in common bat species in Ireland, and Meyer and others (2010) estimated that at least 20 years of monitoring are needed to detect a 5-percent change in tropical bat species using capture data.

The geographic scope of NABat is the area of North America occupied by bats. Although there are 150 species of bats currently recognized in North America, NABat will concentrate on the 47 species that are found in the United States and shared with either Canada or Mexico (see table 1.1). The bat fauna of Mexico is quite distinct from that of the rest of North America, being predominantly made up of Neotropical species (Ceballos and others 2002). Some of these Neotropical species may also be monitored by the same approaches recommended here, but others may be monitored more efficiently with techniques that are outside the scope of NABat.

The focus of NABat will be regional to continental (e.g., State, Province, ecoregion, Landscape Conservation Cooperatives, rangewide). However, we intend to provide the guidance and infrastructure (e.g., data management) for managers and biologists to conduct monitoring projects at the scale appropriate to managing and conserving bats on their properties and jurisdictions. It is the intention of NABat to enable data collection efforts to be aggregated up to support regional and rangewide syntheses.

1.3.2 The Role of Demographic Studies in NABat 1.3.2

Interpretation of long-term monitoring data will be greatly aided by detailed studies of demographic parameters (e.g., reproductive rate, survival rate, population growth rate). While these focused studies are not currently included in NABat, the organization of NABat will be able to facilitate selecting the location of these studies and provide data management support.

1.4 Putting NABat Into Practice 1.4

The sampling framework, protocols, analysis methods, and database structure of NABat were developed with input from experts in many relevant fields as well as preliminary pilot studies and analyses of existing data. Additional pilot studies are ongoing. Some changes to the protocols and analytic methods may be necessary based on the results of ongoing field studies, input from field biologists implementing the program, and results of the first few years of data. However, because of the conservation crisis facing North American bats, it is critical that a continental bat monitoring program be initiated immediately and that the program be fine-tuned as necessary (see sec. 1.5).

1.4.1

1.4.1 General Structure of NABat

A detailed description of the proposed organizational structure and the responsibilities of individual positions within that structure are given in chapter 10. Although dedicated staff will be necessary, the success of NABat will rely primarily on the participation of biologists, resource managers, and the public. These participants will gather the data that will be used to determine changes in bat populations at regional and continental scales. We envision that the States and Provinces will organize bat monitoring programs within their jurisdictions and work with partners (e.g., Federal agencies, tribes, First Nations, nongovernmental organizations, industry, and private landowners) to conduct monitoring and submit the data to the Bat Population Database (BPD) (see ch. 8). This includes a large role for citizen scientists.

1.4.2

1.4.2 Products and Expected Outcomes

We expect that the outcome of NABat will be statistically robust data that can be used by scientists, managers, and policymakers to make informed decisions about conservation and management of North America's bat species. Initially, reports will be produced on the status (e.g., distribution and indices of abundance) of bats at State or Province, regional, and rangewide scales. Once several years of consecutive data have been collected, NABat will begin to produce periodic reports on trends in abundances and distributions of bats across North America (e.g., "State of North America's Bats"). Periodic detailed reports focused on individual species of specific concern will also be produced. Some of the questions that can be addressed by NABat include:

- What are the summer distributions and indices of abundance of little brown myotis, northern myotis, and other hibernating species in areas affected and unaffected by WNS, and how do these change over time?

- What are the summer distributions and indices of abundance of migratory bats [e.g., hoary bats (*Lasiurus cinereus*)] and other species affected by wind energy development, and how do these change over time?

- How do the sizes of wintering populations of little brown myotis, Indiana myotis, northern myotis, and other at-risk species change following the onset of WNS?

- How do populations of summer maternity colonies of species affected by WNS change following the onset of the disease?

- What are the trends in bat distributions along gradients of climate and climate proxies, including latitude and elevation, relative to patterns of climate change across North America?

- What are baseline distributions and indices of abundance patterns of North American bats that will allow detection of emerging threats?

Over time, NABat will provide a means to analyze and draw inferences about these and other questions and issues, including those related to unanticipated future stressors.

1.4.3 Next Steps and Implementation 1.4.3

This technical guide represents the first step in the establishment of NABat and provides guidance for conducting bat monitoring programs across North America. The next steps include providing the infrastructure necessary to support NABat (see ch. 10) and initiating bat monitoring programs on the ground. Feedback from participants will be gathered to improve the execution of NABat both from a logistical and organizational standpoint.

1.5 Adaptive Monitoring Approach 1.5

Questions and objectives of NABat may change over time as new threats are encountered and more is learned about bats and their ecology. Further, techniques for acoustically detecting and identifying bats have advanced greatly over the past several decades (Parsons and Szewczak 2009) and are likely to continue to improve, and new techniques are being developed to allow more accurate enumeration of bats in caves and mines (Azmy and others 2012, Meretsky and others 2010). Thus, even though a long-term monitoring program requires consistency across space and time in techniques and protocols, NABat will need to adapt to both changes in technology and changes in objectives and questions. Lindenmayer and Likens (2009) outlined an adaptive monitoring approach that involves an iterative process of defining questions; designing the monitoring approach to answer those questions; data collection, management, and analysis; and feedback based on a reevaluation of questions or changes in technology or analytical methods. However, even though changes in techniques or questions will be required, it will be critical to maintain the long-term integrity and utility of the existing data, such as by calibrating new methods with the old.

A hoary bat fatality at a wind energy facility in West Virginia. (© Cris Hein, Bat Conservation International, www.batcon.org)

2. Primary Monitoring Methods of NABat and Introduction to Protocols

2.1

2.1 Introduction and Species-Specific Methods

Four approaches will be used to gather monitoring data to assess changes in bat populations: winter hibernaculum counts, maternity colony counts, mobile acoustic surveys along transects, and acoustic surveys at stationary points. Selection of these methods was based on discussions among bat biologists and statisticians at the 2012 bat population monitoring workshop (Loeb and others 2012). Because of the diversity of North American bat life histories and behavioral characteristics (e.g., colonial roosters versus solitary tree bats, migratory species versus year-round residents, low-intensity versus high-intensity echolocation calls), method selection will vary by species and season (tables 2.1 and 2.2). Further, the most appropriate methods for a species or group of species may vary geographically. For example, hibernaculum counts are a commonly used method for assessing populations of bats that hibernate in large aggregations such as many species of *Myotis* in eastern North America. However, winter hibernaculum counts will not be as useful in areas where hibernacula are not known or for species which do not form large aggregations.

Table 2.1—Preferred methods for monitoring bats in eastern North America

	Spring, summer, fall			Winter		
Species	Acoustic point	Mobile transect	Roost	Acoustic point	Mobile transect	Hibernaculum or roost
Artibeus jamaicensis	—	1	—	—	1	—
Corynorhinus rafinesquii	2	—	1	2	—	1
Corynorhinus townsendii	—	—	1	—	—	1
Eptesicus fuscus	3	2	1	—	2	1
Eumops floridanus	2	3	1	2	3	1
Lasionycteris noctivagans	2	1	—	2	1	—
Lasiurus borealis	2	1	—	2	1	—
Lasiurus cinereus	2	1	—	2	1	—
Lasiurus intermedius	2	1	—	2	1	—
Lasiurus seminolus	2	1	—	2	1	—
Molossus molossus	2	3	1	2	3	1
Myotis austroriparius	2	3	1	2	3	1
Myotis grisescens	3	2	1	—	—	1
Myotis leibii	1	2	—	—	—	1
Myotis lucifugus	3	2	1	—	—	1
Myotis septentrionalis	1	2	—	—	—	1
Myotis sodalis	1	2	—	—	—	1
Nycticeius humeralis	1	2	—	1	2	—
Perimyotis subflavus	2	1	—	—	2	1
Tadarida brasiliensis	3	2	1	3	2	1

1 = primary/preferred method, 2 = less preferred, 3 = least preferred, — = method not applicable.
See table 1.1 for common names.
Rankings were based on input from bat biologists working in eastern North America.

Table 2.2—Methods for monitoring bats in western North America

	Spring, summer, fall			Winter		
Species	**Acoustic point**	**Mobile transect**	**Roost**	**Acoustic point**[a]	**Mobile transect**[b]	**Hibernaculum or roost**
Antrozous pallidus	X	X	?	—	—	X
Choeronycteris mexicana	—	—	?	—	—	?
Corynorhinus townsendii	—	—	X	—	—	X
Eptesicus fuscus	X	X	—	X	X	X
Euderma maculatum	X	X	—	—	—	X
Eumops perotis	X	X	—	—	—	—
Eumops underwoodii	X	X	—	—	—	—
Idionycteris phyllotis	X	X	—	—	—	X
Lasionycteris noctivagans	X	X	—	X	X	—
Lasiurus blossevillii	X	X	—	—	—	—
Lasiurus borealis	X	X	—	—	—	—
Lasiurus cinereus	X	X	—	—	—	—
Lasiurus xanthinus	X	X	—	—	—	—
Leptonycteris nivalis	—	—	X	—	—	—
Leptonycteris yerbabuenae	—	—	X	—	—	—
Macrotus californicus	—	—	?	—	—	X
Mormoops megalophylla	X	X	X	—	—	—
Myotis auriculus	X	X	—	—	—	X
Myotis californicus	X	X	—	X	X	X[c]
Myotis ciliolabrum	X	X	—	X	—	X
Myotis evotis	X	X	—	X[d]	—	X
Myotis keenii	X	—	X	—	—	X
Myotis lucifugus	X	X	?	X	—	X
Myotis occultus	X	X	—	—	—	X
Myotis septentrionalis	X	X	—	—	—	X
Myotis thysanodes	X	X	—	—	—	X
Myotis velifer	X	X	X	—	—	X
Myotis volans	X	X	—	—	—	X
Myotis yumanensis	X	X	?	X	—	X
Nyctinomops femorosaccus	X	X	—	—	—	X
Nyctinomops macrotis	X	X	—	—	—	—
Parastrellus hesperus	X	X	—	—	—	X
Tadarida brasiliensis	—	X	X	X	X	X

Note: Due to lack of knowledge for many species, the ranking approach used for eastern bats was not used.

Methods are designated as: X = appropriate method, ? = possibly appropriate method, and — = not appropriate or not known. Designations are based on input from bat biologists working in western North America.

[a] Acoustic points in winter generally entail passive detectors at a source of open winter water (standing) such as the entrance of a creek to a lake, or a detector mounted as close as possible to terrain with rock crevices/mines/caves/outcrops that remain relatively snow free.

[b] Road transects in winter should be conducted near open winter water sources in areas of high-density rocky terrain during weather conditions that support high bat activity.

[c] This species is active at low-elevation mines even though they often do not roost in these mines.

[d] Acoustic point should be within a few hundred meters of potential or known rock crevice hibernacula.

2.2

2.2 Overview of NABat Methods

2.2.1

2.2.1 Colony Counts

Many bat species form conspicuous and accessible hibernating colonies that allow counts of bats on a periodic basis during the winter season (Kunz and others 2009, O'Shea and Bogan 2003). These hibernacula are usually in caves and mines that have stable temperatures and relative humidity levels. When conducted at regular intervals, population counts allow the estimation of population change (e.g., Ingersoll and others 2013, Langwig and others 2012, Thogmartin and others 2012). The relatively stable environment of caves and mines allows a surveyor to assume that year-to-year variability in winter population counts largely reflects real changes in bat numbers if surveys are conducted during the same time of year (Ingersoll and others 2013).

Traditionally, surveyors have either counted individual bats or determined the area of the hibernaculum wall that was occupied by a species and multiplied this area by the number of bats per unit area (LaVal and LaVal 1980). However, new techniques such as digital photography provide more accurate counts and cause fewer disturbances to the bats (Meretsky and others 2010). Other methods for counting bats include infrared beam-break technology, thermal imaging of bats as they leave the hibernaculum, and passive integrated transponder (PIT) tags. Some of these techniques and others are discussed in more detail in chapter 7. Long-term datasets from a large number of sites are already available for a number of species, particularly endangered species such as Indiana myotis (*Myotis sodalis*) and gray myotis (*M. grisescens*). These datasets will form the basis for much of the hibernaculum count monitoring program. However, where hibernaculum locations are not known, emphasis will be placed on locating sites for monitoring to be added to the sample frame as they are discovered.

In addition to forming large hibernating colonies, some species such as Townsend's big-eared bats (*Corynorhinus townsendii*), gray myotis, Mexican long-nosed bats (*Leptonycteris nivalis*), and Brazilian free-tailed bats (*Tadarida brasiliensis*) form large maternity colonies in caves and mines and are highly faithful to these sites, returning year after year. Other species form smaller colonies in long-term stable structures such as bat boxes, buildings, or other artificial structures (Dobony and others 2011, Frick and others 2010). As with hibernaculum counts, regular counts of bats in maternity colonies can provide estimates of population trends (e.g., Sasse and others 2007, Stihler 2011). Methods for surveying bats in maternity colonies are described in chapter 7.

2.2.2

2.2.2 Acoustic Surveys

Many species such as the tree bats [e.g., hoary bats (*Lasiurus cinereus*) and eastern red bats (*L. borealis*)] do not form summer or winter colonies, and other species such as the pallid bat (*Antrozous pallidus*) and silver-haired bat (*Lasionycteris noctivagans*) form small and inconspicuous colonies that are not easily accessible. For these species, colony counts are not feasible, and mist netting and acoustic surveys are the only methods available for assessing distributions and occupancy. Mist netting has many drawbacks that preclude it from being part of a large-scale long-term monitoring program such as NABat. These include: (1) it is costly and labor intensive (Coleman 2013); (2) it can be carried out only by trained professionals who have received pre-exposure prophylactic rabies vaccinations; (3) there are many biases associated with mist netting related to mist net placement, the ability of some species to successfully avoid nets, and environmental conditions at the time of netting (Carroll and others 2002, Geluso and Geluso 2012, MacCarthy and others 2006); (4) data from mist netting cannot be used to estimate abundance, although it is useful for collecting presence/absence data and some demographic information such as breeding status, presence of volant young, and sex ratios; (5) only certain habitats can be sampled (e.g., flyways with sufficient canopy cover and small ponds and streams); (6) there is a risk of disease transmission among bats, including *Pseudogymnoascus destructans* spores; and (7) there is risk of injury or stress to bats. Although mist-netting data will not be used as part of the standard protocols to estimate trends in bat populations, capture data can be submitted to the Bat Population Database (BPD) and may be useful in the interpretation of acoustic and colony count data to verify species presence in the area.

Two approaches to acoustic surveying will be used in NABat: stationary point surveys and mobile transects. Stationary point surveys involve bat detectors placed for multiple nights at various features across the landscape (see ch. 4 for information on survey site selection). Mobile transects are usually conducted with a bat detector fixed to the roof of a vehicle that is driven slowly along a predetermined route (see ch. 5 for more details). Resulting call files of sufficient quality will be identified to species or species group using at least two methods (see ch. 6). Response variables will be detection/nondetection of each species for both mobile transects and stationary point surveys and the number of bat passes per species along a given transect for mobile transects. In addition, indices of activity can be calculated for stationary point surveys that may be valuable indicators in future analyses (see ch. 9).

There are several advantages and disadvantages of mobile transects compared to point surveys. On mobile transects, each bat pass should represent a different individual, as most bats do not fly faster than 32 km/h (Grodzinski and others 2009, Hayward and Davis 1964, Kennedy and Best 1972, Patterson and Hardin 1969, Schaub and Schnitzler 2007). Thus, the number of passes of each species can be used as an index of relative abundance (Roche and others 2011). Road transects are also more cost effective than stationary point surveys (Whitby and others 2014) and may be easier to implement in areas that are dominated by private land. However, some species may be overrepresented whereas others may be underrepresented, depending on their affinities for roads and roadside habitat (Roche and others 2011, Whitby and others 2014). Stationary point surveys remove the road bias associated with mobile transects, and it is easier to control for factors that may affect call quality and quantity (see ch. 4). However, stationary points also require more time to deploy, and it may be difficult to find sites in areas that are primarily in private ownership.

2.3 Focal Demographic Studies 2.3

Demographic studies on focal populations are very useful for understanding the importance of different parameters, such as survival and reproductive rates, to population growth rates and for predicting potential extinction risk of species or populations given particular stressors. They require long-term (≥5 years) data on marked individuals (O'Donnell 2009). Because of the logistics of capturing and recapturing bats (either physically or through dataloggers), only a limited number of sites are appropriate for this type of study. Although focal demographic studies are not currently a formal part of NABat, data on colony locations and counts gathered within NABat can be used to assist researchers in establishing focal demographic studies, and data housed in the BPD can provide baseline data on long-term population trends. Data gathered from focal demographic studies will be valuable in helping to interpret population trends observed through the foundation methods of NABat.

Profile of a spotted bat. (© Daniel Neubaum, Colorado Parks and Wildlife)

3. The NABat Sampling Design

3.1 3.1 Overview and Purpose


Portrait of a Mexican long-tongued bat.

The use of probability-based sampling is widely recognized as being important for environmental monitoring where valid statistical inference from a sample to a population of interest is desired (Cochran 1977, Gitzen and others 2012, Green 1979, Olsen and others 1999, Thompson 2002). This is particularly critical for bat monitoring because of the inherent difficulties in describing the status and trends of bat populations (Hayes and others 2009, Rodhouse and others 2011) and the need for statistically robust status and trend data to inform management and policy decisions such as Endangered Species Act petitions for bat species affected by white-nose syndrome (e.g., Federal Register 2013). Similar considerations apply to other conservation issues such as bat fatalities at industrial wind facilities and long-term population changes in abundance and distribution from climate change and habitat loss. Because bats are so difficult to survey, nonprobabilistic approaches have typically been favored over more formal probabilistic survey designs (Rodhouse and others 2011). However, monitoring to assess the status and trend of bat populations will be much more useful and justifiable if undertaken with a coherent statistical underpinning. Though nonprobabilistic surveys can contribute information to monitoring programs, sampling based solely on nonprobabilistic surveys can produce misleading results and conclusions that are not scientifically defensible, and findings from nonprobabilistic surveys are more likely to be dismissed by skeptics (McDonald 2012). Given the costs and effort associated with implementing bat surveys, every attempt should be made to maximize the level of valid inference drawn from such efforts. Accordingly, NABat has adopted a grid-based sampling frame that can support the probabilistic selection of survey locations across North America. Indeed, the establishment of a formal grid-based sampling framework for coordinating bat monitoring across major portions of North America will be one of the primary contributions of NABat. Similar approaches have been successfully used for monitoring bats across broad geographic extents in the United States and United Kingdom (Hayes and others 2009, Roche and others 2011, Rodhouse and others 2012).

A central challenge for NABat is to balance the need for "bottom-up" flexibility with top-down consistency and quality control. Data collected outside the formal sampling frame of NABat will be utilized to encourage the broadest participation possible from the bat conservation community at large, but the fundamental emphasis will be on promoting implementation of the probabilistic sampling design. Legacy data (i.e., nonprobability data provided by contributors following quality protocols prior to the development of NABat) and found data (i.e., nonprobability data collected concurrently with NABat but not within the sampling framework) (Olsen and others 1999, Overton and others 1993) can be weighted to allow incorporation with the probabilistic sample data and can also be used to validate models (Olsen and others 1999). It is important to emphasize to potential partners and data contributors that data collected within the probabilistic sampling framework will be of much greater value and utility.

3.2 3.2 The Grid-Based Sampling Frame

The statistical target populations of NABat are the summer populations of the North American bat species with geographic ranges that overlap Canada, the United States, and Mexico (excluding tropical species that do not range north of the Mexican border) and the winter hibernacula and summer maternity colonies of several of these same bat species (see table 1.1). Such a large and complex spatial domain of interest requires a flexible, multipurpose sampling frame. The NABat sampling frame is a grid-based finite-area frame spanning Canada, the United States, and Mexico consisting of *N* total number of 10- by 10-km (100-km^2) grid cell sample units (fig. 3.1). For example, there are 133,307 cells in the continental United States. (See appendixes A and B for the number of full and partial cells contained in each State and Canadian Province, respectively.) These 100-km^2 sample units are the focal analytical unit for regional and rangewide assessments. This grain size is biologically appropriate given the scale of movement of most bat species, which routinely travel many kilometers each night between roosts and foraging areas and along foraging routes (e.g., Chambers and others 2011, Lacki and others 2007, Norberg 1990, Pierson 1998). The grid was developed by the Forest Service, U.S. Department of Agriculture for use in the interagency "Bat Grid" monitoring program in the Pacific Northwest (Hayes and others 2009, Ormsbee and others 2006, Rodhouse and others 2012) and was expanded across Canada, the United States, and Mexico in anticipation of an eventual program such as NABat. The 100-km^2 grain of the sampling frame is also an appropriate resolution for modeling and mapping bat species distributions (e.g., Rodhouse and others 2012). Finer grain sizes may be informative for local-scale questions but are inefficient for broad, regional syntheses. However, it will be possible to nest finer grained secondary and tertiary sampling units within the 100-km^2 primary unit for local research and management purposes. This should be done in consultation with NABat to ensure that these efforts will produce data that can be successfully aggregated back up to the 100-km^2 unit.

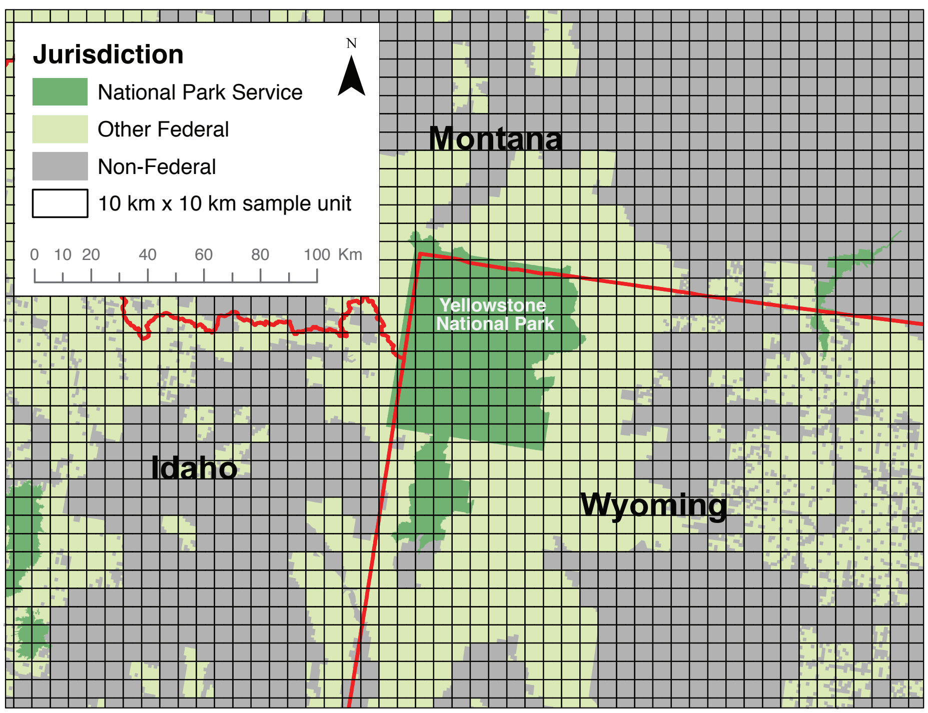

Figure 3.1—Part of the finite grid-based sampling frame of the North American Bat Monitoring Program. Sample units are 100-km^2 grid cells. Northwestern U.S. Federal lands are shown here for illustrative purposes only. The frame extends through Canada and Mexico as well.

3.3

3.3 The Spatially Balanced Master Sample

NABat will use a master sample approach (Larsen and others 2008) with a grid-based frame. Larsen and others (2008) describe several examples of how this has been done for other regional and national programs. For NABat, the approach begins by assigning a spatially balanced and randomized ordering of all 100-km^2 units from the finite grid-based sampling frame using the generalized random-tessellation stratified (GRTS) survey design algorithm (Stevens and Olsen 2004). Subsamples of 100-km^2 units can then be made following the GRTS order, ensuring both randomization and spatial balance.

The GRTS design provides solutions to several practical challenges faced by bat surveyors that are not provided by more familiar designs such as simple random, stratified, and systematic sampling. The GRTS design allows for sample site additions and deletions, supports unequal-probability selection of survey locations, and provides an approximately unbiased neighborhood-weighted variance estimator that takes advantage of the spatial structure present in the surveyed population (Stevens and Olsen 2003, 2004). These features have made the GRTS design an increasingly popular choice for natural resource monitoring programs (Fancy and others 2009, Johnson and others 2009, Olsen and others 2009), and it has recently been shown to be useful for bat acoustic surveys as well (Rodhouse and others 2011). The hallmark of the GRTS design is its flexibility and applicability to the master sample strategy. For example, because of changes in financial resources from year to year, it may be possible to increase or, if necessary, decrease the number of grid cells surveyed. Other common problems include the loss of access to sample units as ownership status changes. The GRTS design will accommodate these changes in realized sample size as resources and logistical conditions ebb and flow over the life of a monitoring program. By working through the spatially balanced ordered list of sample units generated through the GRTS ordering of the master sample, sample units not meeting a priori criteria (e.g., access) can be passed over (dropped) and subsequent units further down the list can be added (fig. 3.2).

Unit	Status
111	Dropped – no access
12	Sample
189	Sample
26	Dropped – mapping error
103	Sample
115	Sample
17	Sample
200	Sample
89	Sample
1	Sample
3	Added to replace 111
54	Added to replace 26
6	Additional oversample
217	Additional oversample
29	Additional oversample

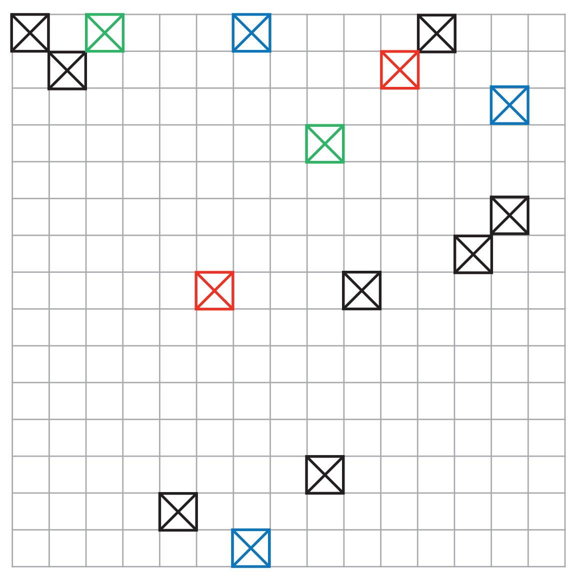

Figure 3.2—An example of a generalized random-tessellation stratified (GRTS) draw. Fifteen grid cells were drawn with the intention to sample 10 cells. Two cells were replaced because of lack of access and mapping errors. Three other grid cells are available for additional sampling if resources allow increased sampling in the future.

A draw of sample units from a finite sampling frame using the GRTS design produces an ordered list of units such that any ordered subset of that list is also randomized and spatially balanced. Therefore, GRTS ordering of all units within the frame (a de facto exhaustive sample of all units, the so-called "master sample") (Larsen and others 2008) allows for ordered subsampling by jurisdiction of the entire list of sample units that meet specific design criteria. This flexibility provides the crucial capability to integrate continental-scale monitoring across multiple partner jurisdictions (e.g., across Federal, State, and Provincial boundaries). Each jurisdiction uses the same common master sample and a priori criteria to meet common objectives (see ch. 1) but can tailor sample sizes in response to their own available resources. The master sample also allows the development of an economy of scale, where neighboring partners can collaborate on surveys of grid cells that overlap jurisdictions (e.g., a Forest Service team surveys a grid cell that also contains a substantial amount of Bureau of Land Management land).

Brazilian free-tailed bats emerge at sunset under the Congress Avenue bridge in Austin, TX. (© Karen Marks, Bat Conservation International, www.batcon.org)

An example of unequal probability subsampling of the master sample is illustrated in figure 3.3. In this scenario, a lower sampling intensity was supported on non-Federal lands (e.g., perhaps because of fewer resources available by State and nongovernmental partners), very high sampling intensity for National Park Service (NPS) lands (e.g., under a scenario in which NPS plans to invest a considerable amount of resources into bat monitoring), and intermediate intensities for other Federal lands. These varying intensities were achieved by attributing the master sample into jurisdictional groups

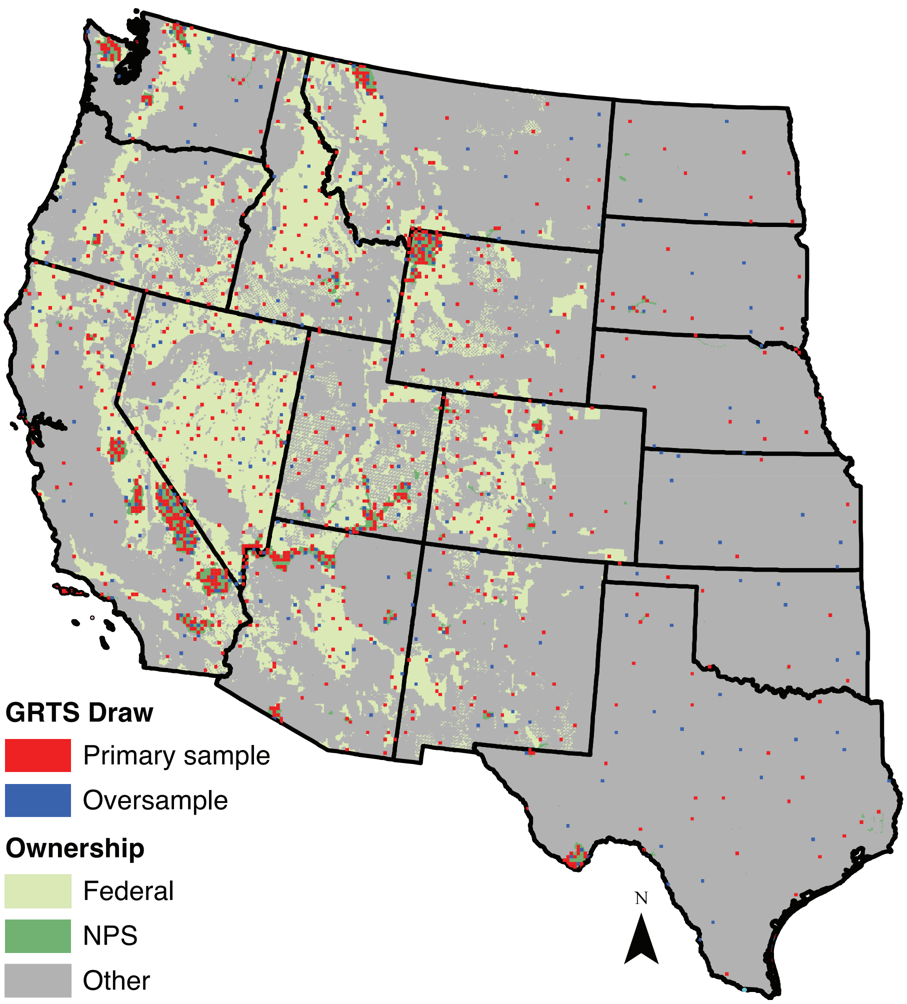

Figure 3.3—An example of subsampling of the spatially balanced randomized GRTS master sample of 100-km² grid cells (sample units) from the Western United States, with 500 sample units each selected from the non-Federal list subset, the National Park Service (NPS) subset, and the subset of units that overlap other (non-NPS) Federal lands. Oversamples of 500 from each subset are also included (see sec. 3.3). (GRTS = generalized random-tessellation stratified)

and then picking n_i sites from each jurisdictional subset *i* following the spatially balanced random GRTS order. Remaining sample units not included within the initial n_i units are retained for future use as "oversamples" in the event that increasing resources allow for greater sampling effort. In the case of the master sample approach, the oversample list contains all remaining sample units, although figure 3.3 shows only the first 2*n* for illustrative purposes. This strategy allows multiple partners to work from a common probability sample rather than from separate disparate samples.

3.4

3.4 Design Criteria and Implementation of the Master Sample

In an effort to reduce complexity and maintain as much flexibility as possible (Larsen and others 2008, Olsen and others 1999), the NABat master sample assigns an inclusion probability of 1 (100 percent) to all sample units across the entire continental United States and those portions of Canada and Mexico that are overlapped by the range of at least one of the target species. This unstructured (e.g., no a priori stratification) master sample allows multiple partners to select units according to a priori (e.g., accessibility, jurisdiction) NABat criteria as well as in response to local conditions and resource constraints. Also, in the case of frame errors that may result in units being inaccessible (e.g., mapping inaccuracies), replacement units can be selected, and spatial balance will be maintained. This will result in an unequal-probability realized sample in which inclusion probabilities and design weights (inverse inclusion probabilities) vary among jurisdictional domains. Whereas the creation of the master sample is straightforward using widely available statistical tools (e.g., Kincaid and Olsen 2012), its successful implementation depends on very careful tracking of the specific criteria used to establish jurisdictional sample subsets and the resulting adjustment of initial design weights to realized design weights that will be used in analysis (Larsen and others 2008). This important component of the data management system is provided by the Bat Population Database and is described further in chapter 8.

Careful attention needs to be given to the sample sizes of individual jurisdictions for which robust statistical inference is desired. No formal power analysis will be conducted until 2 years of pilot data collection have been completed. During this start-up pilot period, we recommend that at least 30 sample units (grid cells) be surveyed each year within each jurisdiction until further guidance is available. In some instances (e.g., State of Rhode Island), this may require an exhaustive sample of all units. This level of sampling may not be necessary when only broader regional syntheses and inferences are planned. The Pacific Northwest Bat Grid program achieved sample sizes of ~50 to 70 each year for two adjacent large Western States (Oregon and Washington) using a combination of trained volunteers and a small team of full-time technicians; precision of occupancy model estimates was sufficient to detect important spatiotemporal variation with common species over 4 years (Rodhouse and others 2012). Precision of temporal trend estimates will improve over time, even with modest initial sample sizes (MacKenzie and others 2006, Urquhart and others 1998).

3.5 Response Designs

3.5

Within selected 100-km^2 sample units from the master sample, acoustic recording of bat calls will be accomplished using stationary deployment of detectors and mobile deployment of detectors mounted on the roofs of motor vehicles for 25- to 48-km driving transects. Two to four stationary bat detectors should be placed within each grid cell, ideally in each 5- by 5-km quadrant, to adequately represent the entire sample unit. Stationary detectors should be run for multiple days. Current recommendations for NABat participants are to deploy detectors for four nights (e.g., deploy on Monday and retrieve on Friday). Note that firmer guidelines about subsampling of grid cells will be provided after pilot study results have been evaluated. Driving transects should be run twice within the same week as the stationary surveys to permit estimation of detection probabilities and integration of data from both methods. Colony count effort may also be allocated following the ordered GRTS sample, particularly as a way to organize efforts to discover new roosts and hibernacula. Additional details of the response designs and sampling procedures are provided in chapters 4, 5, and 7.

3.6 Temporal Revisit Design

3.6

The temporal revisit design defines the survey effort of sample units over time. NABat will use an "always revisit" design (McDonald 2003) in which the same grid cells are surveyed every year for acoustic surveys and external colony counts, and every year or every other year for internal roost surveys. This design is considered optimal for trend detection (MacKenzie and Royle 2005, Urquhart and others 1998) and has been successfully used for temporal trend detection of bat populations in Oregon and Washington within a dynamic occupancy modeling framework (Rodhouse and others 2012). Importantly, some amount of missing data can be accommodated in analyses proposed for these data, providing ad hoc flexibility to this design (MacKenzie and others 2003, Rodhouse and others 2012, Royle and Dorazio 2008). For example, it is acceptable for some number of sample units to be skipped in some years (e.g., as a result of funding shortfalls). However, these missing observations must be assumed to be random and unbiased; consistent deviation (i.e., the same grid cells are consistently not revisited) from the always-revisit strategy should be avoided and should not be based on lack of data or species presence/absence. Providing specific guidance on how many missing data can be accommodated without unduly compromising the efficacy of the program will depend on results of initial pilot efforts and overall sample sizes achieved among the primary partners. Note that other revisit strategies are also possible, such as a split-panel design where a small subset of units (a panel) are revisited annually, while other subsets (i.e., other panels of sample units) are visited in alternating years (e.g., see Urquhart and others 1998). However, NABat is pursuing an always-revisit design because of statistical power and, importantly, to avoid the concomitant added complexity of logistical coordination and analysis that would be associated with these more complicated revisit designs.

A palid bat captures a scorpion.

4. Stationary Point Acoustic Survey Protocols

4.1 4.1 Types of Detectors

Side view of a long-eared myotis. (© Daniel Neubaum, Colorado Parks and Wildlife)

Many types of bat detectors are available for continuous recording of bat echolocation calls. Britkze and others (2013) and Parsons and Szewczak (2009) reviewed differences among types and present advantages and disadvantages. Detector technology is continuously improving over time, and because each detector type has different limitations, NABat does not specify a particular type of detector to be used. However, whatever detector is used must be capable of recording continuously for the required number of nights and detecting species anticipated to be present in the region that can be detected acoustically (see tables 2.1 and 2.2). If it becomes necessary to change technology or settings, it is important to carry out calibration trials to compare detectability with the old and the new technologies or settings. Model types discussed below are the most commonly used detectors in North America to date.

Detector types most commonly used for species identification are zero-crossing frequency division (e.g., Anabat™ CF–ZCAIM, SD1/SD2, Express; Wildlife Acoustics® SM2BAT+™ or SM3BAT™ on ZC mode), time expansion full-spectrum (e.g., Pettersson D240X), and direct recording full-spectrum detectors (e.g., Binary Acoustic Technology AR125™, FR125™, iFR-IV™, Pettersson D500x, Wildlife Acoustics® SM2BAT+™, SM3BAT™, or EM3+™). Time expansion systems stretch the signal out by a factor of n while transferring the data to the recording device (Britzke and others 2013, Parsons and Szewczak 2009), and the system cannot record new sounds while this is occurring. Because future analytical approaches may be able to estimate abundance by using the number of files or passes recorded (see ch. 9), the use of time expansion detectors is not recommended. Thus, any frequency division zero-cross or full-spectrum direct recording bat detector that has a time-date stamp for each file can be used for stationary point surveys. However, because acoustic technology changes rapidly, new detector types may be available in ensuing years that may also be suitable for stationary point surveys.

When choosing a detector type, the type of microphone must also be considered. Microphones can be classified as omnidirectional or directional depending on how they are constructed and how they are deployed. An omnidirectional microphone that is not placed into a housing or shield will pick up bat activity in all directions, but it may also record more noise because it picks up sound from a greater volume of space, particularly from the ground and surrounding vegetation. A more directional microphone (either by design or by using a housing, horn, or shield) will mainly record bats in front of the detector, with some “side lobes” of detection of lower frequencies. Directional microphones often detect bats at a greater distance on the central axis of the microphone than omnidirectional microphones. In general, the larger the microphone diameter, the more directional it tends to be. For example, the Anabat™ SD2 has a much larger diameter microphone than the Anabat™ Express, so the Express detector is far more omnidirectional, especially when the microphone is mounted on a cable away from the body of the detector. In addition, some detector manufacturers offer microphones with different frequency response curves, specifically varying sensitivities at low or high frequencies. For example, the Anabat™ “lo” (white) microphone is more sensitive in the audible range than is the standard (black) microphone; the green “hi” microphone has the same frequency response as the standard microphone, but should be used when using the microphone off the detector body (e.g., when mounting it on an extendible pole). The Wildlife Acoustics® SMX–UT™ microphone for the SM2Bat+™ records higher frequencies and is more sensitive than the SMX–US™; the SMM–U1™ is more sensitive than either of the SMX microphones. Some microphones are manufactured within more consistent ranges of sensitivities than others. For example, the Anabat™ stainless microphones are factory calibrated so that each microphone is within a narrow range of sensitivities. Whatever microphone is used, it is critical that they are used consistently at sites over time. Using the same type of microphone and periodically checking for microphone performance will help to ensure this consistency (see sec. 4.2.1).

4.2 Detector Sensitivity and Settings 4.2

Long-term monitoring requires the surveyor to minimize and account for variability among detectors and settings. Therefore, it is critical that settings be consistent within and between years, and documented in the Bat Population Database (BPD).

4.2.1 Sensitivity 4.2.1

The sensitivity of bat detectors can vary both within and among detector types (Adams and others 2012, Larson and Hayes 2000). Full-spectrum recording is inherently more sensitive than frequency division zero-cross because full-spectrum detectors record signals within the ambient noise, whereas zero-cross detectors record only the loudest signal above the noise floor (Corben 2002). However, during deployment of full-spectrum detectors, sensitivity is often lowered to reduce the number of files recorded with no bats and to reduce recording extraneous noise, thus reducing memory requirements (i.e., a louder signal above the noise floor is required to initiate recording).

For full-spectrum detectors, gain and signal-to-noise ratio settings affect sensitivity of the detector. Sensitivity can be adjusted manually with a dial for all Anabat™ models except the Anabat™ Express, but the numbers on this dial are not consistent among units or models and thus should not be used as a way of equalizing sensitivities (see below). The sensitivity (low, medium, or high) for the Anabat™ Express can be set through Anabat™ Toolbox utility software. Some detectors also allow frequency band filters to target some frequencies; these filters should be adjusted for the local bat community, be documented in the BPD, and be used consistently from year to year at a monitoring site.

The signals of bat calls must exceed the noise floor for zero-cross detectors (e.g., Wildlife Acoustics® detectors set on ZC mode or SMZC; Anabat™ II, SD1, and SD2) to record them. The ambient level of noise can vary over time (e.g., wind or rain increases the noise floor), and detectors that track the ambient noise level and adjust accordingly will have varying sensitivity over time (auto-level). For example, Wildlife Acoustics® SM2BAT+™ and SM3BAT™ detectors auto-level when in zero-cross mode, and thus their sensitivity can vary daily or even within the night depending on how the detector is programmed. Anabat™ detectors use a consistent noise floor as long as the sensitivity knob is not changed or the internal digital setting has been applied in the automated equalization process (Anabat™ Equalizer, see below).

Calibrating detectors among each other by adjusting their recording sensitivities can reduce variation in detection volumes among detectors. Some manufacturers provide hardware and software that allow the user to calibrate across and within detectors (e.g., Anabat™ Equalizer for Anabat™ SD1 and SD2), while others provide equipment that allows the user to test the performance of their equipment against system standards

(e.g., Wildlife Acoustics® Ultrasonic Calibrator™). Larson and Hayes (2000) described a method for calibrating Anabat™ II detectors against each other. Currently, there is no method for testing the performance of Anabat™ Express microphones, but a method is expected in the near future.[1]

Microphone sensitivity can vary over time, making detector calibration and performance tests very important, particularly for a long-term monitoring program. Testing the performance of microphones and detectors before and during the recording season is important to detect any loss in sensitivity. When loss of sensitivity occurs, microphones may need to be replaced. Environmental conditions can also affect microphone sensitivity. For example, if Wildlife Acoustics® SMX microphones with mesh windscreens get soaked with water, their sensitivity diminishes.[2]

To ensure consistency, it is imperative that the same detector or detector type, microphone, and settings are used at a site each year to reduce variation caused by equipment differences. However, if equipment needs to be replaced or if new detectors are used, they need to be calibrated against the older equipment. Having old and new equipment recording side by side for at least one season is the most effective way to develop correction factors and allow monitoring to continue with new equipment after calibration.

4.2.2

4.2.2 File Recording Settings

A “triggered” bat detector does not record constantly, but starts and stops based on input. A triggered detector begins recording when it detects an ultrasonic signal. If a trigger window has been set, recording will end after a specified amount of time has passed in which no signal is detected. For example, Anabat™ defaults to 5 seconds unless the time between calls (Max TBC) setting is changed in CFCRead utility software. In contrast, Wildlife Acoustics SM2BAT+™ and SM3BAT™ and Binary Acoustics AR125™, FR125™, and iFR-IV™ allow the user to specify the trigger window. To standardize recordings, it is recommended that a 2-second trigger window and a maximum file length of 15 seconds be used. Each detector may refer to these settings differently. The Binary Acoustics Technology AR125™ and FR125™ refers to “Duration” for max file length and “Idle setting” for trigger window. For Anabat™ detectors, the trigger window is the “Max TBC;” the file size is set at 15 seconds and cannot currently be changed.

With full-spectrum recorders, it is also possible to record continuously through the night and then use software to scan the recordings to detect bat calls. This approach takes advantage of the full sensitivity of the recorder and can lead to substantially increased detection probabilities. However, it also has much larger memory requirements and requires increased processing time to analyze the data. As with other methods, this approach is acceptable provided that the same approach is used consistently over time. In this case, not only the recording parameters but also the algorithms used to extract calls from the recordings can affect detection probabilities, and both need to be standardized. However, if the original recordings are retained, it may be possible to reanalyze them in the future if improved detection algorithms become available.

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[1] Personal communication. 2014. K. Livengood, Office Manager, Titley Scientific USA, 601 Business Loop 70 W, Suite 110, Columbia, MI 65203.

[2] Personal communication. 2014. S. Snyder, Product Manager, Wildlife Acoustics, Inc., 3 Clock Tower Place, Suite 210, Maynard, MA 01754-2549.

The division ratios for frequency division zero-cross detectors can be adjusted. Because a frequency division detector considers only every n^{th} wave, the lower the division ratio (n) the more information is recorded. However, file sizes will also be larger. A low division ratio is recommended (e.g., ≤8) in areas with target species that have audible, low frequency components to their echolocation calls such as the spotted bat (*Euderma maculatum*). However, a division ratio of 8 or 16 should be used in areas where bat species produce high frequency calls [e.g., Californian myotis (*Myotis californicus*)] because of the risk of inaccurate high frequency representation with low division ratios.[3] Division ratio settings should be consistent between years.

4.3 Site Selection and the Influence of Clutter on Bat Echolocation 4.3

With only two to four detectors in a cell, it is not cost effective, practical, or desirable to position detectors randomly within the cell. Rather, detectors should be placed in areas that maximize the number and quality of recordings. In areas with heterogeneous habitats suitable for bats, detectors should be placed to maximize the diversity of species likely to be detected. Whenever possible, one detector should be placed in each 5- by 5-km quadrant of the cell.

Site selection for deployment of detectors can affect the quantity and quality of echolocation calls recorded (Britzke and others 2013). It is important that biologists consider the bat species in the area and their habitat associations when selecting sites for stationary point samples. Because sites will be surveyed each year of the monitoring program (see sec. 3.6), it is critical that good sites are selected. Thus, knowledgeable biologists should put considerable thought into the site selection process and conduct on-the-ground reconnaissance.

Several features in the environment affect the quality and quantity of calls recorded by bat detectors (table 4.1). One of the most important features is the amount of clutter, defined as the density of obstacles in the flight environment (e.g., tree branches, leaves, or water surfaces) (Fenton 1990). For example, transmission of 25 kHz sounds is lower in intact forests than in thinned forests (Patriquin and others 2003), and detectors oriented away from clutter record more calls than those oriented towards clutter (Weller and Zabel 2002) due to multiple reflections off of vegetation. Further, bats adjust their echolocation calls while in clutter. Echolocation calls in clutter are

[3] Personal communication. 2014. C. Corben, Acoustic Biologist, Titley Scientific USA, 601 Business Loop 70 W, Suite 110, Columbia, MI 65203.

Table 4.1—Factors that may impact the quantity and quality of bat echolocation calls recorded by acoustic detectors, the problems associated with each factor, and ways to reduce the effects

Factor affecting call quality	Associated problems	Ways to reduce effects
Dense vegetation (classic "clutter")	Poor quality calls (e.g., fragments) Bats change their call structure	Place detectors in more open areas Orient microphone toward more open areas
Other bats	Bats change their call structure	Place detectors in areas where there are not dense concentrations of bats (e.g., avoid recording directly at watering holes or close to a roost)
Echoes off hard surfaces	Diffuse or spectral echoes	Place detectors so that they are not directly over hard surfaces such as still water, pavement, or bridges

shorter duration, higher frequency, and have greater bandwidths than those produced in more open areas (Broders and others 2004, Wund 2006). Thus, identification of calls recorded in cluttered environments based on known calls from open areas could be erroneous (Britzke and others 2013). Other bats in the area can also represent a form of clutter to echolocating bats, and bats will adjust their individual calls for echo recognition when many other bats are in their foraging space (Obrist 1995).

Echoes off surfaces can also affect the quality of recorded calls by distorting the sound (Parsons and Szewczak 2009). Bat detectors generally record two basic types of echoes: diffuse echoes and specular echoes (fig. 4.1). Ultrasound reflected off a rough surface, such as a tree trunk, will produce a diffuse echo; smooth surfaces produce a specular echo, which is a near-perfect reflection of the original bat pulse. Echoes can make species identification more difficult and inflate the number of calls in a file. This is especially a concern for automatic species-identification software. Thus, when recording occurs in close proximity to flat, reflective surfaces (e.g., still water, pavement, or bridges), call quality may be reduced.

Bats use various types of habitats to forage, drink, roost, and commute. Ponds or wetlands are often used for drinking and foraging (Seibold and others 2013, Stahlschmidt and others 2012), and edge habitats such as along trails and forest roads, forest openings, and rock cliffs are often used by bats that are commuting between foraging and roosting areas (Jantzen and Fenton 2013, Morris and others 2010, Verboom and Huitema 1997). Areas with suitable roosting sites such as mature trees, snags, rock crevices, anthropogenic structures (e.g., homes, barns, and log cabins), caves, and mines are also potential habitats. Bats are less likely to be found in wide-open places, such as the middle of a cultivated field (Crampton and Barclay 1996, Grindal and Brigham 1999). They also avoid very fast flowing streams or creeks that produce too much competing noise (Mackey and Barclay 1989, von Frenckell and Barclay 1987) or creeks and wetlands with dense vegetation that reduces access to prey and water (Ober and Hayes 2008).

Bat species vary in habitat use due to differences in maneuverability, foraging mode, ecology, and properties of echolocation call structure (Aldridge and Rautenbach 1987,

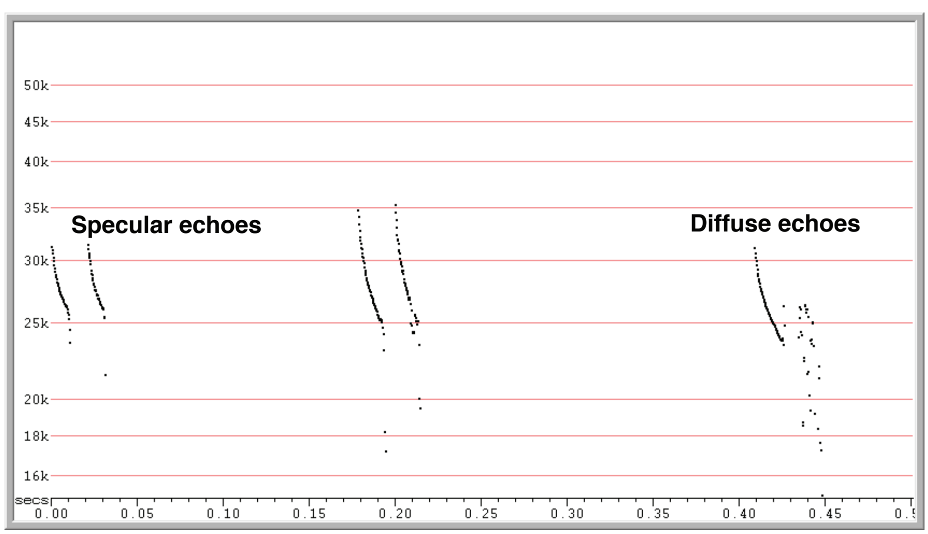


Figure 4.1—Specular and diffuse echoes of Brazilian free-tailed bat (*Tadarida brasiliensis*) echolocation calls recorded with an Anabat™ detector. (recording courtesy of C. Corben, Titley Scientific)

Fenton 1990). In general, large fast-flying bats use habitats that are more open, whereas smaller, more maneuverable species use more cluttered or edge habitats. Thus, it is important to consider the composition of the bat community in the survey area when selecting suitable sampling sites.

When placing detectors in the 100-km^2 grid cells, it is desirable to monitor bats in a variety of habitats. For heterogeneous landscapes, place up to four detectors such that they sample different habitat features, preferably one within each quadrant of the cell (fig. 4.2). For example, if a cattle watering tank is selected for one sample point, consider selecting other habitat types such as larger bodies of water, small roads, or a forest opening. Although fewer individual bats may be recorded by deploying detectors away from areas where bats may concentrate or other sources of clutter such as water tanks or roosts in buildings, a higher percentage of calls may be identifiable (fig. 4.3).

If the habitat within a grid cell is more homogeneous, fewer detectors (minimum of two) may be sufficient to capture the potential bat diversity in the cell. However, if the surveyor is not familiar with the area or the bat community, we suggest setting up three or four detectors to ensure capturing as much of the species diversity in the area as possible. Although it is good to place detectors so that a high number of species are recorded, sampling should be conducted to maximize detection of all species within cells across all detectors. Thus, in some cases it may be desirable to place one or two detectors in habitats that may be used only by one or two species if those habitats are the most likely area to host those species. For example, northern myotis (*M. septentrionalis*) are more likely to forage in closed canopy forests (Henderson and Broders 2008), and placing at least one detector in these habitats may increase the probability of detecting them, although doing so may lower the probability of detecting other species (Carroll and others 2002).

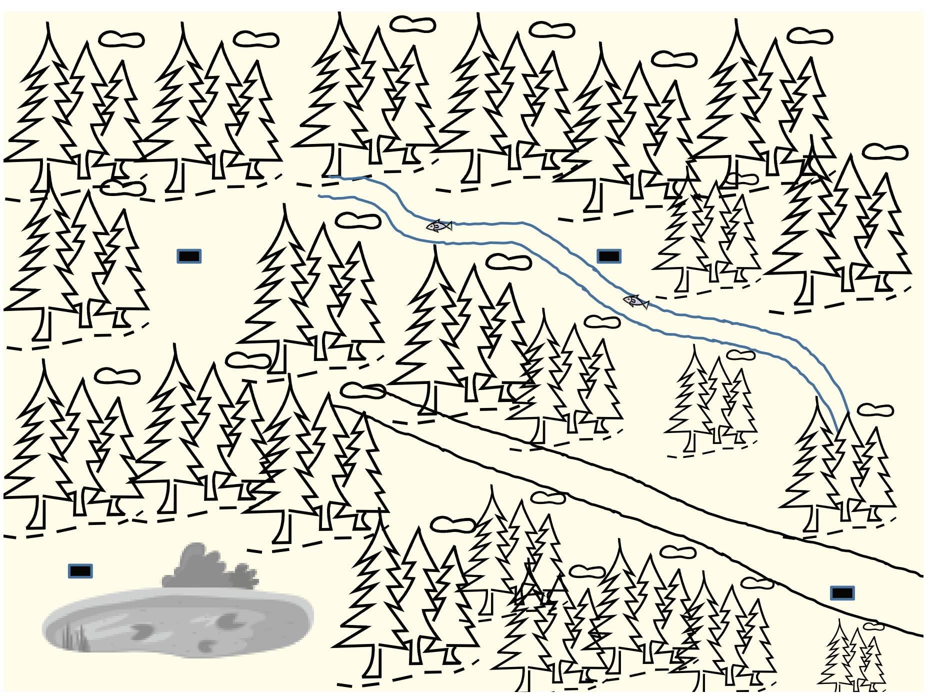


Figure 4.2—Example of stationary detector placement in a 100-km^2 grid cell. Detectors (black rectangles) have been placed in four diverse habitat types (clockwise from top left): a forest opening, along a stream, along a forest road, and near a pond.

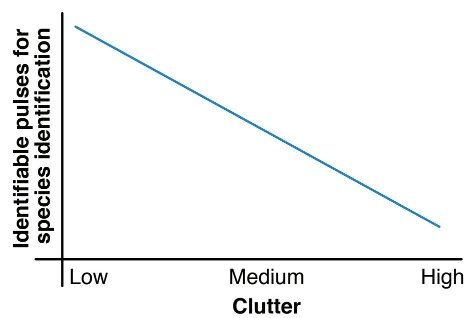


Figure 4.3—Relationship between clutter and probability of successful species identification for species that are difficult to acoustically differentiate from others. Note: clutter may be reduced by increasing horizontal set-back from clutter and/or vertical height of microphone.

4.4

4.4 Equipment Setup

4.4.1

4.4.1 Placement Relative to Clutter, Height above Ground, and Orientation

Bats tend to respond to clutter within a few meters. Thus, detectors should be a sufficient distance and oriented away from clutter such as forest edges, buildings, cliff faces, and the ground to reduce echoes and the effects of clutter on bat behavior and sound quality. Unfortunately, little research has been done on an ideal set-back distance of microphones from clutter. In general, 3 to 5 m is likely to be enough to reduce the effect of clutter when a directional microphone is used and is oriented away from the clutter. A greater set-back distance will be needed for omnidirectional microphones unless they are contained in housings that make them more directional and are oriented away from the clutter. The set-back distance from clutter depends on the sensitivity and range of the microphone being used. It is recommended that microphones be elevated as high as possible off the ground; directional microphones should be at least 1.4 m above ground (Weller and Zabel 2002), and omnidirectional microphones should be placed even higher to reduce background noise and echoes from the ground. Detectors or microphones can be mounted on tripods or elevated on poles (fig. 4.4). Caution should be used when elevating some microphones on fiberglass poles, as they may short out due to static electricity unless the poles are grounded.

The suggested microphone orientation depends on directionality and weatherproofing (see sec. 4.4.2). Orientation relative to the horizontal plane may be important for detectors with directional microphones. For example, Anabat™ II microphones oriented horizontally record fewer calls than those oriented at 45° or greater (Britzke and others 2010). Omnidirectional microphones can be angled horizontally or even below horizontal without use of a reflector plate.

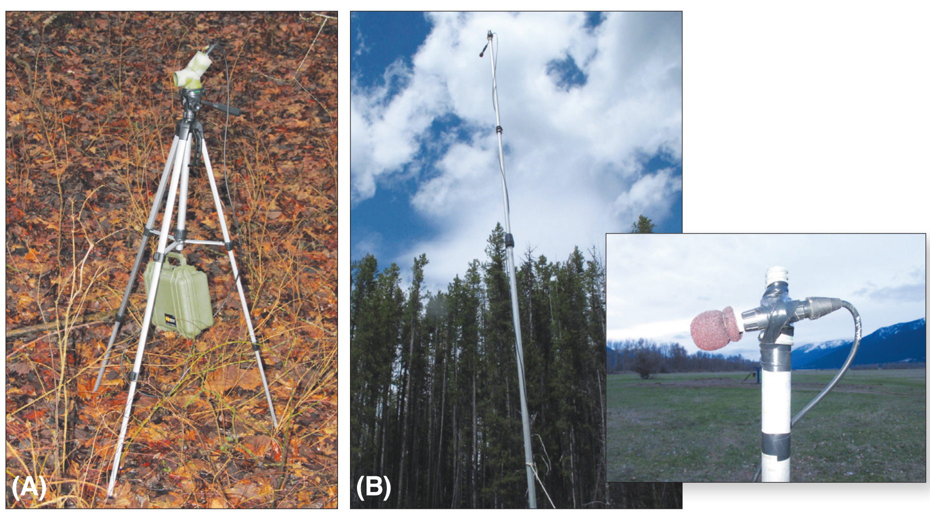
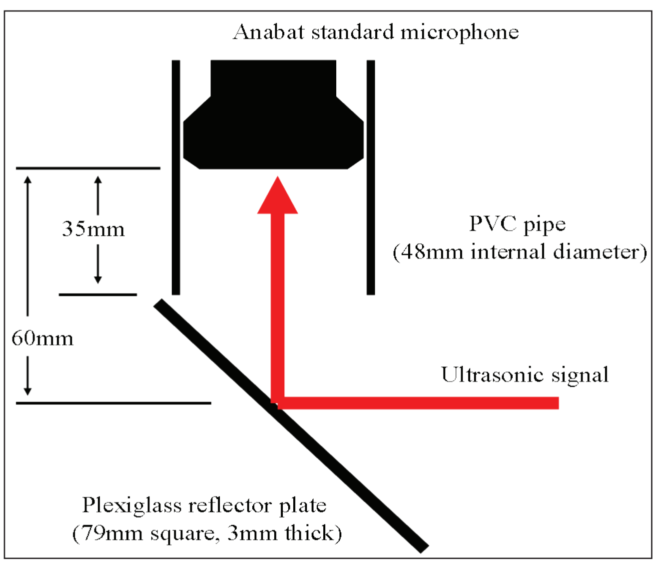


Figure 4.4—An example of a microphone mounted on (A) a tripod (Anabat™ system), and (B) a painter pole (inset: Wildlife Acoustics® SMX-US™ microphone on top of pole). (fig. 4.4A photo courtesy Titley Scientific, other photos by C. Lausen)

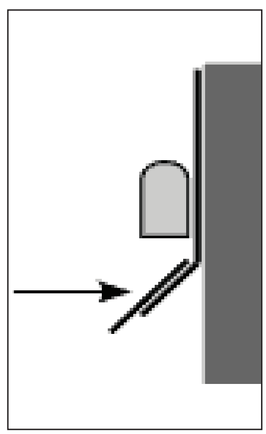
4.4.2 Weatherproofing 4.4.2

Some detector systems have water-resistant microphones (e.g., Wildlife Acoustics® SM3BAT™, EcoObs Batcorder, Pettersson D500x), and a few have waterproof microphones (e.g., Anabat™ Express). For long-term recording under unpredictable weather conditions, weatherproofing is necessary for microphones that are not water resistant. However, even water-resistant microphones such as the Wildlife Acoustics® SMX–US/UT™ microphones should not be angled above horizontal in inclement weather (see footnote 2) and should be oriented downwards if rain is anticipated. A reflector plate can be used with a directional microphone that allows the microphone to face down and thus be protected from rain (e.g., the Bat-Hat system). The detector records reflected ultrasound, not the original signal, in this case. Generally, reflector plates are 45° to horizontal when the microphone is facing directly down (fig. 4.5). Alternatively, the detector and microphone can be placed in a waterproof box with the microphone at the base of a PVC tube with drain holes and oriented at 45° or 90° to horizontal (fig. 4.6).

The type of weatherproofing system (e.g., reflector plate, PVC pipe) can affect the number and quantity of calls recorded, although comparisons of the effects of weatherproofing have yielded mixed results (Britzke and others 2010, Gruver and others 2009). Thus, it is difficult at this time to say which type of weatherproofing is best. Although some protocols, such as the Indiana myotis (*M. sodalis*) summer survey guidelines (U.S. Fish and Wildlife Service 2014), suggest using weatherproofing only if weather conditions call for it on a particular night, this is not appropriate for long-term monitoring programs such as NABat. The decision to use weatherproofing with bat detectors needs to be made at the onset of the monitoring program, and the same procedure must be followed throughout to ensure consistency in data collection.



(A)



(B)

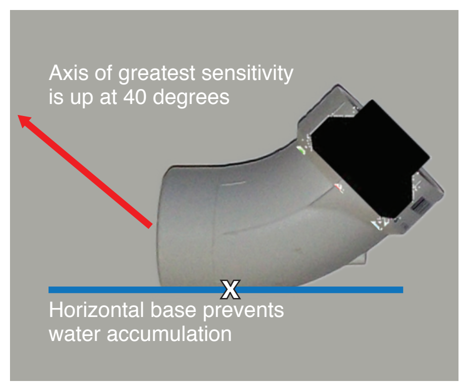


Figure 4.6—Schematic of an Anabat™ microphone with a PVC pipe as a weatherproof housing. The arrow shows the axis of greatest sensitivity. A drain hole exists at the "X." (schematic courtesy of C. Corben and K. Livengood, Titley Scientific)

Figure 4.5— (A) Schematic of an Anabat™ microphone in a weatherproof housing and oriented down towards a reflector plate (figure courtesy of C. Corben and K. Livengood, Titley Scientific); (B) the Bat-Hat system from EME Systems (http://www.emesystems.com/bat-hat.htm).

4.5

A silver-haired bat roosts on a tree trunk.

4.5 Frequency and Timing of Surveys

Surveys should be conducted during the summer active period prior to the young becoming volant. Associated driving transects (see sec. 5.5) should be conducted while the stationary points are being surveyed. The weeks when this occurs will vary with location (e.g., later in the northern parts of North America and at higher elevations) and possibly with species. Detectors should run the entire night, from 15 minutes prior to sunset to 15 minutes after sunrise, for a minimum of four nights. Stationary acoustic surveys should be conducted at least once per year. When possible, surveys should be conducted when weather conditions are optimal for bat activity: (1) seasonally warm temperatures, (2) low wind, and (3) little or no rain. Specific limits will change depending on the location. For example, in south-central Alaska (lat. 60° N.), bat activity declines below 10 °C (Loeb and others 2014), whereas in Massachusetts (lat. 42° N.), bat activity declines below 15 °C (Brooks 2009). In typically rainy locations, bats may fly in light rain.

4.6

4.6 Collection of Covariates and Ancillary Data

Bat activity and habitat use can be affected by numerous factors, including habitat type, temperature, relative humidity, rainfall, wind, and moonlight. As discussed in sections 4.2 through 4.4, many factors related to equipment placement and setup can also affect the data. Many of these factors can be controlled during the analysis phase if they are known. Thus, it is critical that a number of variables are recorded during the surveys and submitted with the data in the BPD. Variables that should be collected are listed in tables 8.1 and 8.2, and an example data sheet is provided in appendix C.

5. Mobile Acoustic Transect Survey Protocols

5.1 Types of Detectors

5.1

Many types of bat detectors are available for continuous recording of bat echolocation calls. Britkze and others (2013) and Parsons and Szewczak (2009) reviewed differences among types and present advantages and disadvantages. Detector technology is continuously improving over time, and because each detector type has different limitations, NABat does not specify a particular type of detector to be used. However, the detectors selected for mobile acoustic transects must be able to detect all of the species anticipated to be present in the region that can be detected acoustically (see tables 2.1 and 2.2). If it becomes necessary to change technology or settings, it is important to carry out calibration trials to compare detectability with the old and the new technologies or settings. Model types discussed below are the most commonly used detectors in North America to date.

Detector types most commonly used for species identification are zero-crossing frequency division (e.g., Anabat™ CF–ZCAIM, SD1/SD2, Express; Wildlife Acoustics® SM2BAT+™ or SM3BAT™ on ZC mode), time expansion full-spectrum (e.g., Pettersson D240X), and direct recording full-spectrum detectors (e.g., Binary Acoustic Technology AR125™, FR125™, iFR-IV™; Pettersson D500X; Wildlife Acoustics® SM2BAT+™, SM3BAT™, or EM3+™). Time expansion recorders cannot be used for mobile transects because a time expansion system does not record when expanding the signal to the recording device (Britzke and others 2013, Parsons and Szewczak 2009). Thus, a considerable amount of recording time (>50 percent) could be lost during a 1.5-hour mobile transect. Any zero-cross frequency division or full-spectrum direct recording detector that provides a time-date stamp for each file is acceptable. Mobile transects can also make use of microphones and digitizers connected directly to a tablet, smartphone, or computer. These systems may be less expensive than dedicated recorders, especially for volunteers or others who already own a suitable device. Options currently available include the Pettersson M500 and Binary Acoustics AR125™, which connect through a USB port, or the Wildlife Acoustics® Echo Meter Touch®, which connects through the Lightning Connector to Apple devices such as an iPad or iPhone. However, because the Echo Meter Touch™ has an omnidirectional microphone, it is not recommended for mobile acoustic transects at this time. Other options will likely be available in the near future.

Additional considerations need to be taken into account when choosing a detector or recording mode for mobile transects beyond those for stationary detectors (see ch. 4). Detectors that auto-level, such as SM2BAT+™ and SM3BAT™ detectors (see sec. 4.2.1), should not be used in zero-cross mode because the sensitivity level could vary during the recording session, between nights, and between years. For example, ambient noise such as that caused by tires on different surfaces (e.g., gravel, pavement, and dirt) may change throughout the transect, and the sensitivity of the detector may vary accordingly. Until there is a tested method to compensate for varying sensitivities when using these detectors in zero-cross mode, it is recommended that these detectors be used in full-spectrum recording mode only. Further, the EM3+™ also should not be used in zero-cross mode because it has a low gain setting that does not perform well in this mode; this detector should only be used in full-spectrum mode.[1]

[1] Personal communication. 2014. I. Agranat, President and CEO, Wildlife Acoustics, Inc., 3 Clock Tower Place, Suite 210, Maynard, MA 01754-2549.

When choosing a detector for mobile transects, the type of microphone must also be considered. Microphones can be classified as omnidirectional or directional depending on how they are constructed and how they are deployed. An omnidirectional microphone that is not placed into a housing or shield is likely to pick up bat activity in all directions, but it will also record more noise. A more directional microphone (either by design or by using a housing or shield) mainly records sounds in front of the microphone, but often can detect bats at a greater distance than omnidirectional microphones. It is recommended that detectors used for mobile transects have a directional microphone to minimize road noise and reflections off the top of the vehicle. Because the Anabat™ Express has an omnidirectional microphone that currently cannot be made directional, it should not be used for driving transects.

Each bat file that is submitted to NABat must be georeferenced (see sec. 5.6), so the detector must also be able to record the location of each bat file. Most detectors provide global positioning system (GPS) metadata through the attachment of a GPS unit that is calibrated to the local time zone (e.g., Binaray Acoustics FR125™ and iFR-IV™) or manufacturers may provide an optional GPS accessory (e.g., Wildlife Acoustics® SM2BAT+™ and EM3+™, Anabat™ SD1 and SD2).

5.2

5.2 Detector Sensitivity and Settings

Use of relative abundance in the analysis of mobile transects for trend estimates requires that the surveyor minimizes and accounts for variability among detectors. It is critical that settings are consistent along individual transects within and between years and are documented in the Bat Population Database (BPD).

The sensitivity of bat detectors can vary both within and among detector types (Adams and others 2012, Larson and Hayes 2000). Full-spectrum recording is inherently more sensitive than frequency division zero-cross because full-spectrum detectors record signals within the ambient noise, whereas zero-cross detectors record only the loudest signal above the noise floor (Corben 2002). However, during deployment of full-spectrum detectors, sensitivity is often lowered to reduce the number of files recorded with no bats and to reduce recording extraneous noise, thus reducing memory requirements (i.e., a louder signal above the noise floor is required to initiate recording).

For full-spectrum detectors, gain and signal-to-noise ratio settings affect sensitivity of the detector. Sensitivity can be adjusted manually with a dial for all Anabat™ models except the Anabat™ Express, but the numbers on this dial are not consistent among units or models, and thus should not be used as a way of equalizing sensitivities (see below). The sensitivity (low, medium, or high) for the Anabat™ Express can be set through Anabat™ Toolbox utility software. Some detectors also allow frequency band filters to target some frequencies; these filters should be adjusted for the local bat community, be documented in the BPD, and be used consistently from year to year at a monitoring site.

Calibrating detectors among each other by adjusting their recording sensitivities can reduce variation in detection volumes among detectors. Some manufacturers provide hardware and software that allow the user to calibrate across and within detectors (e.g., Anabat™ Equalizer for Anabat™ SD1 and SD2) while others provide equipment that allows the user to test the performance of their equipment against system standards (e.g., Wildlife Acoustics® Ultrasonic Calibrator). Larson and Hayes (2000) described a method for calibrating Anabat™ II detectors against each other. Currently there is no method for testing the performance of Anabat™ Express microphones, but a method is expected in the near future.[2]


Portrait of a Peter's ghost-faced bat.

Microphone sensitivity can vary over time, making detector calibration and performance tests very important, particularly for a long-term monitoring program. Testing the performance of microphones and detectors before and during the recording season is important to detect any loss in sensitivity. When loss of sensitivity occurs, microphones may need to be replaced. Environmental conditions can also affect microphone sensitivity. For example, if Wildlife Acoustics® SMX microphones with mesh windscreens get soaked with water, their sensitivity diminishes.[3]

To ensure consistency, it is imperative that the same detector or detector type, microphone, and settings are used on a transect each year to reduce variation caused by equipment differences. However, if equipment needs to be replaced or if new detectors are used, they need to be calibrated against the older equipment. Having old and new equipment recording side by side for at least one season is the most effective way to develop correction factors and allow monitoring to continue with new equipment after calibration.

Most detectors allow the user to adjust the sensitivity. The sensitivity must be high enough that the detector picks up low-intensity bat calls. However, if the sensitivity is set too high, the detector will record too much extraneous noise (e.g., insects). The appropriate sensitivity setting may vary with the bat community and the environment, so detectors should be adjusted accordingly. Division ratios for frequency division detectors can also be adjusted. Because a frequency division detector only uses every n^{th} wave pass, the lower the division ratio (n) the more information is recorded. While file sizes will also be larger, this should not be an issue with current storage abilities of most frequency division detectors. A division ratio of 4 or 8 is recommended in areas with target species that have low frequency, audible calls such as the spotted bat (*Euderma maculatum*). However, a division ratio of 8 or 16 should be used when bats that use high frequency calls are expected to be recorded, as a division ratio of 4 can result in inaccurate high frequency representation which can sometimes confound species identification.[4]

5.3 Route Selection 5.3

5.3.1 Safety Considerations 5.3.1

One of the first considerations when choosing a route is safety. The route should be safe to drive at 32 km/h (20 miles per hour) with minimal stopping. Thus, roads that receive heavy traffic during the survey period should not be used, as this will require pulling off the road to let other vehicles pass or endanger the surveyor and other drivers as they try to pass the survey vehicle. Further, very rough roads where speeds of 32 km/h are dangerous should not be used. Drivers should use their hazard lights to warn others of their slow speed. Although lights may attract or repel bats (Hickey and Fenton 1990, McGuire and Fenton 2010, Polak and others 2011), headlights should always be used while driving the transect.

[2] Personal communication. 2014. K. Livengood, Office Manager, Titley Scientific USA, 601 Business Loop 70 W, Suite 110, Columbia, MI 65203.

[3] Personal communication. 2014. S. Snyder, Product Manager, Wildlife Acoustics, Inc., 3 Clock Tower Place, Suite 210, Maynard, MA 01754-2549.

[4] Personal communication. 2014. C. Corben, Acoustic Biologist, Titley Scientific USA, 601 Business Loop 70 W, Suite 110, Columbia, MI 65203.

5.3.2

5.3.2 Road Types

In general, roads should be two-lane secondary or tertiary roads with few if any stops. Roads with gates that require opening and closing should not be used. Secondary roads include State highways and county roads, and tertiary roads include county roads and forest roads. Some gravel and dirt roads that are well maintained and allow consistent travel at 32 km/h can also be used. The route should be driven prior to the first survey to ensure that the road can be safely driven at the appropriate speed and the driver is familiar with the route. The test routes should be driven at the proposed start time and speed.

5.3.3

5.3.3 Route Configuration

Routes should be approximately 25 to 48 km in length and fit primarily within the 100-km^2 grid cell (e.g., fig. 5.1). If the route extends beyond the grid cell edges due to its length, the beginning and end of the transect can be in adjacent grid cells. One of the assumptions of the mobile transect method is that individual bats are not counted more than once, allowing calculation of an index of relative abundance (Roche and others 2011). Thus, the route should not cross back into the likely travel route of a bat, as this may result in the same bat being counted more than once. Sections of the route should be >100 m from each other if the route contains many curves or switchbacks. The surveyor should maintain a speed of ~32 km/h as consistently as possible throughout the survey period. If a stop is required, the detector should be paused and this should be noted.

5.3.4

5.3.4 Habitat Types

The route should pass through common habitat types of the area as much as possible. Depending on the location, this may include agricultural areas, forests, wetlands, and residential areas and small towns if traffic is not too congested. Urban areas can be important areas for some species of bats but may need to be surveyed with stationary point surveys due to the difficulty of maintaining a constant speed. When selecting the route, areas with dense forested corridors and a low canopy should be avoided or minimized to decrease the chance of recording high-clutter calls. There should be at least 3 m between the vehicle and the overhanging canopy (see sec. 4.4.1). Roads that parallel waterways (e.g., along a river or lakeshore) are often adequate to pick up species associated with water.

5.4

5.4 Equipment Setup

Detectors can be mounted on the vehicle in a variety of ways. For example, a unit can simply be placed in a low-cost container and strapped firmly to the center of the vehicle rooftop (figs. 5.2A and 5.2B). Alternatively, the microphone can be detached from the unit, placed in a mount, and attached with a cable to the detector housed in the vehicle (figs. 5.2C and 5.2D). It is suggested that the bat detector be oriented straight up. Although the microphone can be also pointed down to receive reflected signals off the roof of the car (fig. 5.2D), similar to a reflector plate described in section 4.4.2., it may be difficult to orient the microphone the same way each time the transect is run. Thus, this technique should only be used if the position of the microphone can be exactly replicated each survey (e.g., using an Anabat™ suction car mount). Once an orientation is selected (i.e., up or down), it should be used consistently throughout the survey period (Britzke and others 2010). Because mobile transects should not be conducted during poor weather, weatherproofing is not necessary and should not be used, as it can reduce microphone sensitivity.

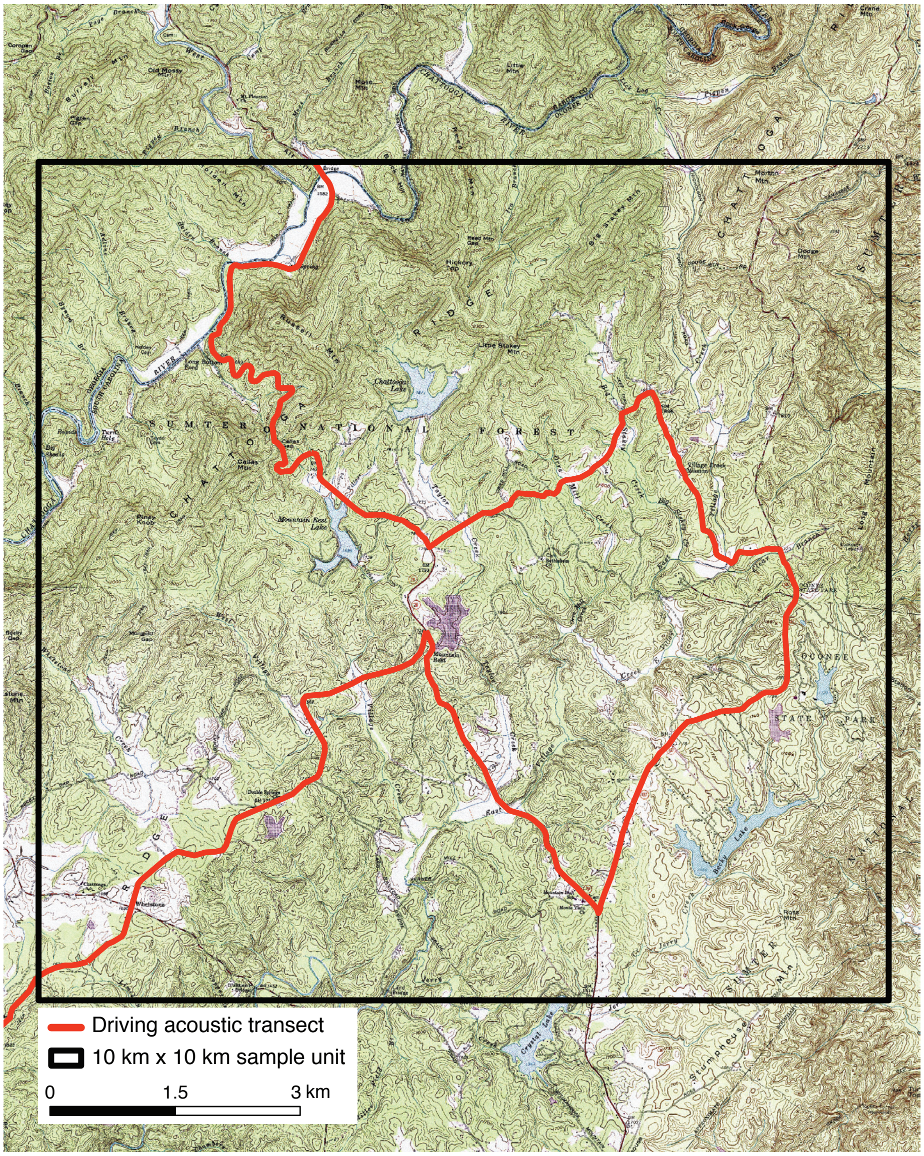


Figure 5.1—Example of a mobile acoustic transect in a 100-km² grid cell.

Figure 5.2—Examples of bat detector attachments on top of vehicles. (fig. 5.2A by the author; fig. 5.2B courtesy of Michael Whitby, fig. 5.2C courtesy of Carl Herzog, and fig. 5.2D courtesy of Titley Scientific)

5.5 Frequency and Timing of Surveys 5.5

Surveys should be conducted twice during the maternity season to allow estimates of detection probability. Both surveys should be conducted within a week if possible to reduce violations of the closure assumptions in the proposed analytical models. In subsequent years, surveys should be conducted within 1 to 2 weeks of the original survey to align with similar weather conditions and stages of the life cycle. The most appropriate dates for the surveys will vary depending on the phenology of bats in the region, but the period from June 1 through July 30 will exclude most migrants. It is best to conduct the transect earlier in the survey window rather than later in case inclement weather or other issues prevent surveying at the end. Additional runs outside of the maternity season may be desirable for local monitoring efforts and can be used to focus on other points in the bats' life cycle such as migration or winter activity. These data are not required for NABat, but can be entered into the BPD with appropriate documentation.

Surveys should begin 45 minutes after sunset. Driving should commence as soon as the detectors are set to "Record," and detectors should be stopped as soon as the end of the transect is reached. The equipment should be tested by rubbing fingers or jangling keys in front of the microphone immediately prior to the beginning of the transect run and just before the detector is shut off. This allows surveyors to determine if the equipment was functional throughout the survey, especially if no bats are recorded at the end of the transect. Surveys should occur on nights when there is no rain or fog, low wind speed (< ~10 km/h), and, if possible, during a new or quarter moon. Wet roads and puddles can affect quality of calls recorded because of increased road noise from tires. Thus, these conditions should be avoided if possible, or noted. Because the effects of moonlight are equivocal (Ciechanowski and others 2007, Erickson and West 2002, Hayes 1997), moonlight should be a low-priority criterion when selecting survey nights unless it is known that moonlight is a significant factor in the survey area. Nights that are exceptionally cool for the area should also be avoided.

5.6

5.6 Marking the Route

The route should be recorded with a GPS and submitted as metadata in the BPD as an ArcGIS® shapefile. In addition, the latitude/longitude of each acoustic file should be recorded and embedded in the file itself, if possible. Detectors such as the Anabat™ SD2, Wildlife Acoustics® SM2BAT+™ or SM3BAT™, and Binary Acoustics Technology FR/AR125™ accommodate accessory GPS attachments that allow this to be done. Other options are available for detectors that cannot record the location directly to the file (e.g., Pettersson D500x) such as Myotisoft TransectPro (http://myotisoft.com/products/transectpro/); in this case, associated shapefiles of tracks and waypoints of recorded files should be submitted to the BPD along with the acoustic files. The start and end GPS locations should also be recorded and submitted. As with all GPS utilities, the time zone needs to be set to ensure the times match those of the study area, and GPS and bat detector times should be synchronized each night the transect is surveyed.

5.7

5.7 Covariates and Ancillary Data

Portrait of a pallid bat. (© Daniel Neubaum, Colorado Parks and Wildlife)

Bat activity and habitat use can be affected by a large variety of factors including habitat type, temperature, relative humidity, rainfall, wind, and moonlight. As discussed in sections 5.2 and 5.4, many factors related to equipment placement and setup can also affect the data. Many of these factors can be controlled for during the analysis phase if they are known. Thus, it is critical that a number of variables be recorded during the surveys and submitted with the data in the BPD (see ch. 8). Data that should be collected are listed in tables 8.1 and 8.2 and an example datasheet is provided in appendix D.

6. Species Identification of Acoustic Recordings

There are many methods and tools for species identification of acoustic recordings, and these methods and tools are continually evolving. Their utility and efficacy may vary with equipment type, geographic location, and experience of the user. NABat does not recommend specific methods or programs for analyses. However, as explained below, at least two methods should be used for verification.

6.1 Responsibility for Species Identification 6.1

Individual agencies and biologists will be responsible for identifying acoustic recordings to species. Because overall coordination will likely occur at the State or Provincial level (see sec. 10.3), ultimately the coordinators at this level will be responsible for ensuring that species identification of all acoustic files is conducted according to the guidelines given below. Because identification of bats can be challenging, it is recommended that whoever conducts the identification has experience in bat acoustic species identification. The level of expertise of the person(s) who conduct the identification needs to be documented at the time of submission of data into the Bat Population Database (BPD).

6.2 Definitions 6.2

In North America, a *pulse* of sound produced by an echolocating bat navigating through its environment tends to sweep from a high frequency to a lower frequency, although in some cases a pulse of relatively constant frequency may be produced (Fenton and Bell 1981). A pulse is sometimes also referred to as a *call*. A series of calls or pulses made by an echolocating bat is referred to as a *call sequence* or *bat pass*. Much confusion surrounds the use of the phrase bat pass. Fenton (1970) defined a bat pass as a series of calls produced by a bat passing by a microphone, and this was later made more specific by Hayes (1997) as a sequence of pulses separated from another sequence of pulses by ≥1 second. However, the utility of this more specific definition has been questioned, particularly as it applies to lower frequency bats that can have long periods of silence between their calls. For example, pulses of hoary bats (*Lasiurus cinereus*) can be ≥1 second apart, which would misleadingly equate one pulse to one pass. Consequently, a single hoary bat making one pass across the detection area of the microphone could be misinterpreted as many bat passes. As such, for NABat a pass is defined as sequence of pulses separated by ≥2 seconds. For trigger-based recording, setting the trigger window (“Idle Setting or “Max TBC”) to 2 seconds (see sec. 4.2.2) allows each file to be considered a separate pass.

Length of a call sequence that is captured in a file produced by a bat detector is dependent on the type of detector, its settings, and the recording scenario. For example, Wildlife Acoustics SM2BAT+™; Binary Acoustics AR125™, FR125™, and iFR-IV™; and Pettersson D500x allow a maximum file recording length to be set when recording in full-spectrum mode, whereas Anabat™ systems have a fixed maximum recording length of 15 seconds before beginning a new file. Recommended settings are presented in section 4.2.2. If a different file length or trigger window is used, this should be reported in the BPD data submission.

A sequence of calls can consist of different pulse shapes, depending on the behavior of the bat (Siemers 2002). Search phase pulses are produced while the bat is navigating its environment (fig. 6.1). A series of search phase pulses is recognizable by the consistent shape of calls over time, and it is these types of pulses that are generally used for species identification (Fenton and Bell 1981). As a bat approaches an object, such as an insect, it changes the shape of its pulses and echolocates more quickly, often sweeping through a broader range of frequencies to resolve distance to the insect (approach phase); this intensifies in the terminal phase of the approach as the insect is captured (feeding buzz) (Fenton and Bell 1979, Griffin and others 1960). In most cases, approach and terminal phase pulses are not useful for species identification because of the high degree of overlap of pulse shape among species. Pulse shapes of many species of bats converge when flying in clutter (e.g., close to or within vegetation), confounding species identification (Fenton 1990, Limpens 2002, Siemers 2002). Efforts to reduce the likelihood of recording high-clutter calls made during deployment (see secs. 4.3 and 5.3.4) will aid in species identification.

Differentiation among some species of bats relies on examination of the pattern associated with a sequence of pulses (O'Farrell and others 1999). For example, an evening bat (*Nycticeius humeralis*) and an eastern red bat (*Lasiurus borealis*) can have similar pulse shape and frequency, but the minimum frequencies of evening bat calls oscillate relatively consistently, whereas the minimum frequencies of eastern red bat calls change randomly (fig. 6.2). Similarly, tri-colored bat (*Perimyotis subflavus*) calls can resemble the higher frequency calls of the eastern red bat, but tri-colored bat pulses have constant (non-undulating) minimum frequencies (fig. 6.3). Thus, by having a sequence of many pulses, it is often possible to differentiate acoustically similar species with frequency overlap. Conversely, species identification may be confounded if only one or two pulses are recorded. It is thus recommended that a minimum of three search phase pulses be present to use a recording for species identification. Files with fewer pulses should be assigned to a broader acoustic category (see below).

6.3

6.3 Process of Species Identification

The goal of the acoustic analysis is to identify as many files as possible to the species level. Spreadsheets from various automated species identification programs or personally created spreadsheets that are uploaded to the BPD (see sec. 8.4) should use the standardized codes provided in table 6.1. Because of poor quality recordings such as short call sequences, incomplete pulse recordings, recording of high-clutter pulses, non-search-phase pulses, or overlap in species' call parameters, identification

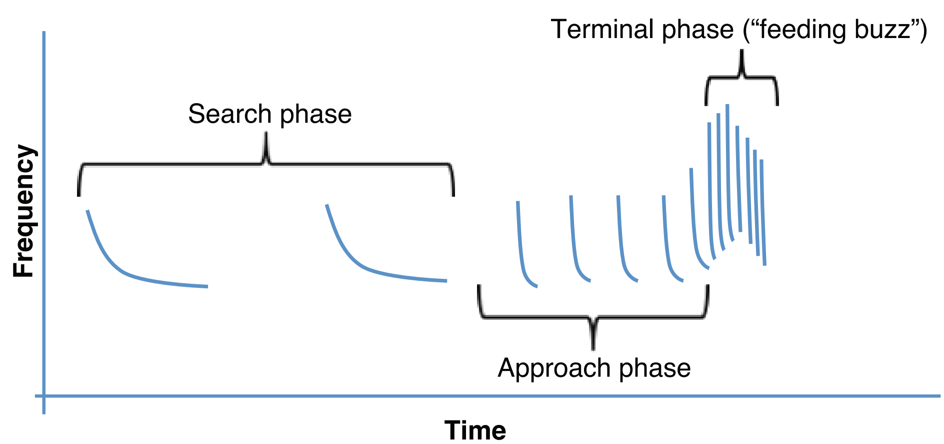


Figure 6.1—Search, approach, and terminal phases (feeding buzz) of a bat pass.

to the species level is not always possible. When identification is possible, files should be classified as narrowly as possible; for example, files may be classified to one of two species [e.g., big brown (*Eptesicus fuscus*) or silver-haired bat (*Lasionycteris noctivagans*) to EPFU/LANO], or broader categories when necessary [e.g., Low frequency bat (LowF)]. Recommendations for clustering of acoustically similar species and associated codes are presented in table 6.2. If alternate categories are used, definitions and associated codes should be submitted with the data to the BPD.

It is recommended that at least two methods be used to identify files to species. Analysis of acoustic recordings can be done in several ways, combining automatic species-identification (auto-ID) software and manual identification as appropriate. The advantage of using an auto-ID software package is that the data are analyzed objectively. Four auto-ID programs are currently available for North American bats within the scope of NABat: Sonobat™ (www.sonobat.com), Bat Call Identification (BCID) (http://www.batcallid.com/Software.html), Kaleidoscope® Pro (http://www.

A roosting Townsend's big-eared bat. (© Michael Durham/Minden Pictures, Bat Conservation International, www.batcon.org)

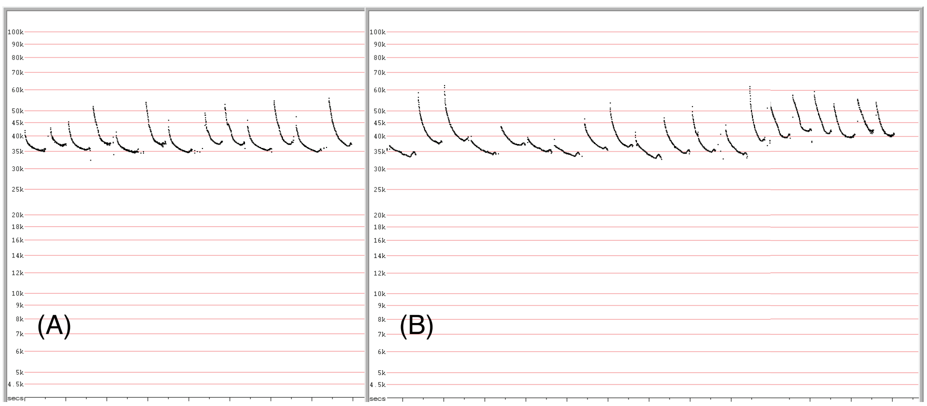


Figure 6.2—Example of the relatively consistent pattern of minimum frequency alternation in (A) an evening bat (*Nycticeius humeralis*) versus the more random pattern of alternating higher and lower minimum frequencies of (B) an eastern red bat (*Lasiurus borealis*). (screenshots from Anabat™ AnalookW software)

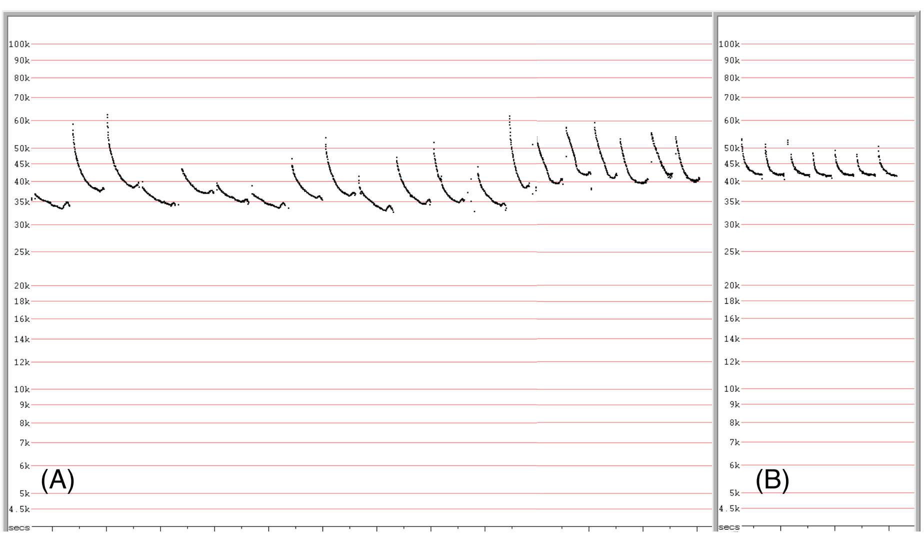


Figure 6.3—Example of the undulating minimum frequency pattern of (A) the eastern red bat (*Lasiurus borealis*) that sets it apart from the consistent minimum frequency pattern of (B) the tri-colored bat (*Perimyotis subflavus*). (screenshots from Anabat™ AnalookW software)

Table 6.1—Species codes to be used when labeling acoustic files and submitting data to the Bat Population Database

Common name	Scientific name	Code
Pallid bat	*Antrozous pallidus*	ANPA
Jamaican fruit-eating bat	*Artibeus jamaicensis*	ARJA
Mexican long-tongued bat	*Choeronycteris mexicana*	CHME
Rafinesque's big-eared bat	*Corynorhinus rafinesquii*	CORA
Townsend's big-eared bat	*Corynorhinus townsendii*	COTO
Big brown bat	*Eptesicus fuscus*	EPFU
Spotted bat	*Euderma maculatum*	EUMA
Florida bonneted bat	*Eumops floridanus*	EUFL
Greater bonneted bat	*Eumops perotis*	EUPE
Underwood's bonneted bat	*Eumops underwoodii*	EUUN
Allen's big-eared bat	*Idionycteris phyllotis*	IDPH
Silver-haired bat	*Lasionycteris noctivagans*	LANO
Western red bat	*Lasiurus blossevillii*	LABL
Eastern red bat	*Lasiurus borealis*	LABO
Hoary bat	*Lasiurus cinereus*	LACI
Southern yellow bat	*Lasiurus ega*	LAEG
Northern yellow bat	*Lasiurus intermedius*	LAIN
Seminole bat	*Lasiurus seminolus*	LASE
Western yellow bat	*Lasiurus xanthinus*	LAXA
Mexican long-nosed bat	*Leptonycteris nivalis*	LENI
Lesser long-nosed bat	*Leptonycteris yerbabuenae*	LEYE
California leaf-nosed bat	*Macrotus californicus*	MACA
Pallas' mastiff bat	*Molossus molossus*	MOMO
Peter's ghost-faced bat	*Mormoops megalophylla*	MOME
Southwestern myotis	*Myotis auriculus*	MYAUR
Southeastern myotis	*Myotis austroriparius*	MYAUS
California myotis	*Myotis californicus*	MYCA
Western small-footed myotis	*Myotis ciliolabrum*	MYCI
Long-eared myotis	*Myotis evotis*	MYEV
Gray myotis	*Myotis grisescens*	MYGR
Keen's myotis	*Myotis keenii*	MYKE
Eastern small-footed myotis	*Myotis leibii*	MYLE
Little brown myotis	*Myotis lucifugus*	MYLU
Dark-nosed small-footed myotis	*Myotis melanorhinus*	MYME
Arizona myotis	*Myotis occultus*	MYOC
Northern myotis	*Myotis septentrionalis*	MYSE
Indiana myotis	*Myotis sodalis*	MYSO
Fringed myotis	*Myotis thysanodes*	MYTH
Cave myotis	*Myotis velifer*	MYVE
Long-legged myotis	*Myotis volans*	MYVO
Yuma myotis	*Myotis yumanensis*	MYYU
Evening bat	*Nycticeius humeralis*	NYHU
Pocketed free-tailed bat	*Nyctinomops femorosaccus*	NYFE
Big free-tailed bat	*Nyctinomops macrotis*	NYMA
Canyon bat	*Parastrellus hesperus*	PAHE
Tri-colored bat	*Perimyotis subflavus*	PESU
Brazilian free-tailed bat	*Tadarida brasiliensis*	TABR

Table 6.2—Possible groupings and associated codes for species that are acoustically similar and can occur sympatrically

Common name	Scientific name	Code
Pallid bat Big brown bat	*Antrozous pallidus* *Eptesicus fuscus*	ANPA/EPFU
Big brown bat Silver-haired bat	*Eptesicus fuscus* *Lasionycteris noctivagans*	EPFU/LANO
Western red bat Canyon bat	*Lasiurus blossevillii* *Parastrellus hesperus*	LABL/PAHE
Eastern red bat Tri-colored bat	*Lasiurus borealis* *Perimyotis subflavus*	LABO/PESU
Eastern red bat Little brown myotis	*Lasiurus borealis* *Myotis lucifugus*	LABO/MYLU
Eastern red bat Seminole bat	*Lasiurus borealis* *Lasiurus seminolus*	LABO/LASE
California myotis Yuma myotis	*Myotis californicus* *Myotis yumanensis*	MYCA/MYYU
Long-eared myotis Keen's myotis Northern myotis	*Myotis evotis* *Myotis keenii* *Myotis septentrionalis*	LEMY (long-eared myotis)
User-defined categories		
User-defined	Various species with pulses that have a minimum frequency of approximately 25 kHz.	25kHz
User-defined	Various species with pulses that have a minimum frequency in the range of 35-40 kHz.	40kHz
User-defined	Various species with pulses having a minimum frequency lower than ~30 kHz.	LowF
User-defined	Various species with pulses having a minimum frequency higher than ~30 kHz.	HighF
User-defined	Various myotis species with pulses having a minimum frequency higher than ~30 kHz.	Myotis

Note: For "User-defined" categories, species in these categories will be listed for the recording area upon submission to the Bat Population Database.

A lesser long-nosed bat pollinates an agave flower.

wildlifeacoustics.com/products/kaleidoscope-software), and Echoclass (http://www.fws.gov/midwest/Endangered/mammals/inba/surveys/inbaAcousticSoftware.html). Currently, all four programs can be used to identify species found in the Northeastern and Midwestern United States, but only Sonobat™ and Kaleidoscope® Pro can be used to identify western species (although BCID now includes the canyon bat, *Parastrellus hesperus*). Sonobat™ can only be used with full-spectrum calls and Echoclass and BCID can only be used with zero-cross calls; Kaleidoscope® Pro can be used with either full-spectrum or zero-cross calls. Some species found in the Southeastern United States, such as the northern yellow bat (*L. intermedius*) and Brazilian free-tailed bats (*Tadarida brasiliensis*) are only included in some programs; many western species are not included in either Kaleidoscope® Pro or Sonobat™ (appendix E). Other methods, such as filters in Anabat™ AnalookW call analysis and data management software, also provide an objective method for species identification. If using AnalookW filters for identification of species, the .abf files should be submitted to the BPD at the time of acoustic data submission. Processing of files that contain bats, but are not identified to species by an auto-ID program, may proceed using manual identification, use of filters, or some combination.

Files that are identified to species from auto-ID programs should be visually reviewed and verified by experienced personnel whenever possible, as this has been shown to successfully remove false positive identifications and allow the addition of species missed by the auto-ID program (Fritsch and Bruckner 2014). Because of variation in quality of recordings, the influence of clutter, and the changing performances of software packages over time, manual verification is currently recommended for, at minimum, unexpected classifications. For example, if a species that is not known to reside in the recording area is identified through an auto-ID program, files of this unexpected species need to be manually verified. Currently, most auto-ID packages are designed to identify only one species of bat per recorded file. Auto-ID software should provide some indication of files that may contain more than one species of bat. These files should be manually examined to determine species composition and labelled appropriately. The general procedure used in analysis of recordings should accompany the data when submitted to the BPD (see table 8.1).

How one determines the final identification of a bat recording will be up to the experienced biologist conducting the analysis. When depending largely on auto-ID programs and there is a discrepancy in the identification of a file between the programs, it is recommended that the two suggested species both be considered possible. For example, if one auto-ID program labels a file as a silver-haired bat (LANO) while another determines it to be a big brown bat (EPFU), the final identification should be assigned a combined species category of EPFU/LANO unless the experienced biologist, upon manual examination, has reason to agree with one of the auto-ID programs.

6.4

6.4 Storage of Acoustic Files

In the early stages of NABat, both acoustic analysis summary data and files containing bat calls will be submitted to the BPD.

7. Colony Counts

7.1 Introduction 7.1

Monitoring wildlife populations using direct count data is central to many research and management activities. However, conducting direct counts may be particularly challenging when populations are open (i.e., there is immigration, emigration, births, and deaths), have unknown ranges, or are difficult to observe (Anderson 2001, Royle and Nichols 2003, Williams and others 2002). These challenges are highly relevant to surveys of roosting bats. Kunz and others (2009: 136) warned: “Efforts to infer population trends by comparing current and historical estimates of roosting bats are often based on the invalid assumption that availability and quality of roosts is static and that bats exhibit high rates of fidelity to roosts through time.” Thus, a continental framework for monitoring bat populations with colony counts, whether during summer or winter, is recommended only for species or populations having ecological and behavioral characteristics conducive to these types of surveys. The following characteristics identified by Kunz and others (2009) are important for species monitored via colony counts: (1) reasonable geographic limits are placed on the area to be monitored, (2) the number of roosts in the area are known, (3) locations of roosts within the area are known, (4) potential daily and seasonal movement distances of individuals of the species within the area are understood, and (5) information about immigration and emigration in the area is available. While colony counts for species that do not exhibit these characteristics (e.g., those using ephemeral roost trees or forming complex metapopulations) may reveal important biological information about them, these methods are not recommended for monitoring population trends for NABat.

Counts of bats at hibernacula have been used for decades to monitor abundance of some species, such as the Indiana myotis (*Myotis sodalis*), and have provided reasonable estimates of regional population sizes (Thogmartin and others 2012). For many colonial hibernating species, these counts provide a robust method for estimating population sizes but have limitations associated with incomplete knowledge and accessibility of winter sites. In summer, colony counts may be the only feasible method for determining presence and estimating abundance for some species. For example, whispering bats such as Rafinesque’s big-eared bats (*Corynorhinus rafinesquii*) and Virginia big-eared bats (*C. townsendii virginianus*) are not readily detected with acoustics, so identifying available roosts and conducting colony counts is the best way to assess presence and abundance on the summer landscape (Clement and Castleberry 2011, Stihler 2011). Species such as the Brazilian free-tailed bat (*Tadarida brasiliensis*) pose different challenges for acoustic monitoring. These bats often form aggregations of 100,000 or more during the summer, fly at altitudes above the range of ground-based bat detectors, and disperse broadly across the landscape, making counts at maternity colonies the most reliable estimates of abundance in an area.

Accurate estimates from colony counts depend on both availability (animals are present at the time of the survey) and detectability (animals are observed during the survey) of individuals in the colony. Both of these factors vary temporally and spatially and can also be affected by methodology. Because bats may move readily within and among roosts in both winter (Elder and Gunier 1978, Ingersoll and others 2010, Tuttle 2003) and summer (Johnson and others 2013, Lewis 1995, Watrous and others 2006), establishing population-level estimates of abundance can be difficult. Furthermore, it is difficult to locate alternate roosts, so colony counts likely represent only a partial survey of the population. Nevertheless, colony counts represent the best available information on the status and trends of species not well sampled by other methods.

Methods discussed in this chapter standardize surveys of colonies to reduce variation in occurrence and abundance estimates caused by availability and to facilitate adjustments for variation in detectability. They are designed to allow hierarchical or state-space models for monitoring colonies (de Valpine and Hastings 2002) (see ch. 9) and to allow data collected via different methods or observers or under different survey conditions to be combined into a single model. They also allow for adjustments between differing survey conditions to estimate absolute abundance or occupancy instead of merely providing a proxy of abundance. Use of these models will be possible through multiple visit or multiple observer survey methods recommended in this chapter. Furthermore, it is important to note that methods discussed in this chapter are not intended for focal studies on behavior, demographics, or phylogenetics. There are numerous methods for exploring these factors including capture-mark-recapture and genotyping. Although understanding these factors may contribute to an understanding of abundance and occupancy of a species, these methods have limited application for rangewide monitoring programs such as NABat.

7.2

7.2 Multiple Visit and Multiple Observer Methods

Imperfect detection (i.e., detection probabilities <1) results in undercounting the number of bats present in a colony. Detection probabilities are influenced by numerous factors, including time of surveys (e.g., day, week, month, year); environmental conditions; roosting and clustering behavior; physical characters of the roost; survey method; and experience of surveyors (Ingersoll and others 2013, Tuttle 2003). Using multiple visit or multiple observer methods allow estimation of species detectability, which may then be used for producing reliable estimates of occurrence and abundance (Royle and Dorazio 2008).

Hierarchical models can use data from multiple visit or multiple observer methods to separate detection probabilities from estimates of the variable of interest, such as abundance or occupancy (Royle and Dorazio 2008). To provide unbiased abundance estimates, temporally repeated measures must be conducted across a time period when abundance is unchanging. Unfortunately, this is not typically practical or permissible for hibernating bats that should be surveyed no more than once per winter or for summer colonies whose composition may change nightly. However, multiple records may be produced simultaneously by more than one observer or method at each location, an approach described as multiple independent observers (Williams and others 2002). It is critical that data collected in this fashion be independent (i.e., on discrete data sheets, no communication between observers, and no changing or supplementing data with the observations of others). Furthermore, observers should make every effort to minimize additional disturbance to bats that may be caused by additional people, noise, and light associated with duplicated effort.

Multiple observer methods produce two or more independent sets of observations at each sampling location. For example, two or more individuals may separately conduct manual counts of bats roosting in the same hibernaculum, of bats exiting at evening emergence, or of bats roosting in a summer colony. This approach can be extended to instrument-based survey methods as well. Two or more separate sets of photographs of roosting bats or video of emerging bats may be collected, ideally by changing the camera angle between sets. The multiple sets of photographs or videos should be made and analyzed by different observers. Alternatively, different observation methods may be combined, e.g., a manual count paired with a photographic count or video or thermal imaging survey (fig. 7.1). Using multiple observer methods allows for continuity and comparability of data through changes in surveyors, methods, and environmental conditions and greatly increases the utility and longevity of population data.

Figure 7.1—Double-observer setup for pairing manual exit count at a bat house with infrared thermal recording of the same emergence activity. (photo by Jonathan Reichard)

7.3 Colony Count Site Selection 7.3

NABat is an adaptable system of data collection that accommodates variation in resources, personnel, methods, and survey locations with careful recording of covariates that affect survey effort and bat detection probabilities as well as those affecting bat abundance. The selection of which colonies to monitor should not be altered solely for the sake of inclusion in the NABat framework if they are providing reliable long-term trend information for particular species or regions. NABat will integrate these ongoing colony monitoring programs with the continental sampling framework to allow inference about trends (including prior to the implementation of NABat) while promoting consistency in methodology for future data collection, thus allowing for rangewide analyses of relative abundance and distribution. Identifying and monitoring summer and winter colonies can be very time and effort consuming, and many existing monitoring programs have prioritized sites that maximize benefits of these efforts.

The NABat sampling framework, through the generalized random-tessellation stratified (GRTS) master sample, provides a mechanism to modify or expand colony monitoring programs in a statistically sound manner. If it is feasible and practical to monitor all known colonies of a species in a particular region on a regular basis (e.g., every 1 to 3 years, though not necessarily all in the same year), it may be most appropriate to continue to monitor all colonies. However, if there are more colonies than can be sampled at a reasonable sampling interval, the GRTS master sample can be used to prioritize sample selection. An appropriate selection method is to start at the top of the list and pick the number of grid cells for which colonies can be surveyed with available resources. For selected cells, all known colonies within those cells should be surveyed. If a particular cell has no known colonies, or if those colonies are inaccessible (e.g., due to lack of permission on private land), the cell should be replaced with the next cell in the list, continuing until the target number of cells with known colonies is reached. If a cell is skipped, it is important to document the reason it was rejected. A similar approach could be used to guide searches for new colonies, for example, in regions or for species for which colonies are poorly known or which may move from one year to the next (e.g., breeding colonies). In this case, an appropriate number of cells at the top of the list could be selected for searching, including those with and without known colonies. However, cells could still be rejected if they do not contain appropriate types of habitat (identified a priori) or if too much of the cell is inaccessible. Such searches could potentially be informed by the results of acoustic surveys in the same grid cells.

7.4 Internal Roost Counts 7.4

Although there is potential to negatively impact roosting bats during internal surveys, such surveys are appropriate when (1) acoustic monitoring is insufficient to detect a particular species in the area, (2) exit counts cannot be conducted safely or effectively, or (3) species identification is unreliable either from acoustics or emergence counts. Internal surveys in winter are the preferred method for counting gregarious hibernating species when there is reasonable certainty that locations for most individuals of a species are known (at least within that region). Furthermore, surveys in hibernacula are likely the only method for assessing abundance of bats throughout most of North America during winter when bats' reduced activity makes acoustic monitoring impractical in many areas. Internal counts are especially useful when there is a need for winter-specific population estimates to assess threats associated with hibernacula, such as disease [e.g., white-nose syndrome (WNS)]. In summer, internal surveys may be necessary if emergence counts are exceedingly challenging or if the colony contains multiple species that cannot be distinguished without direct observation. However, because of the likelihood of disturbing bats during pup rearing, internal surveys of summer colonies are not recommended if other means of estimating the colony size are available.

Roost abandonment, decreased overwinter survival, physiological stress, and mortality of nonvolant young have all been linked to disturbance from humans (Barbour and Davis 1969; Boyles and Willis 2010; Hicks and Novak 2002; Lacki 2000; Mohr 1972; Thomas 1995; Thomas and others 1990; Tuttle 1979, 2003). Thus, limiting sizes of survey crews, using red lights, employing infrared lights and night-vision equipment, limiting amount of time in roosts, requiring quiet and efficient behavior of surveyors, and taking precautions to avoid introducing foreign material or chemicals to a roost can reduce the impact of the survey on the bat colony. Surveyors should be prepared to work efficiently to minimize time in the roost. Working in pairs helps to ensure safety of surveyors while moving efficiently and accurately through the survey. All surveyors should be capable of distinguishing species without handling bats if possible, although photographic records may be used for later identification or confirmation in some situations. New surveyors should conduct multiple surveys under the supervision of an experienced observer to ensure consistency among surveyors. Employing double-observer methods also helps to validate species identification. Although each roost survey is unique, whenever possible, surveyors should follow species-specific methods for internal surveys adopted from sources such as the recently published *Conservation Strategy for Big-Eared Bats and Southeastern Myotis* (Bat Conservation International and Southeastern Bat Diversity Network 2013) and the Indiana myotis draft recovery plan (U.S. Fish and Wildlife Service 2007). Other sources listed in table 7.1 provide good models for protocols. Guidance for conducting roost surveys outside of North America may also prove useful (e.g., Hundt 2012).

The guidelines recommended here are designed to encourage consistency among survey efforts to create comparable datasets throughout a species' range. However, we recognize that circumstances such as availability of equipment, clustering of bats, roost configuration, experience of the survey team, and many other factors may require deviations from either NABat recommendations or previous survey efforts. We do not recommend significant changes to existing roost survey programs unless there is reason to believe that reliability would be enhanced by adopting a new method. In recent years, developments in winter survey methodologies have improved winter survey efficiency and repeatability (Meretsky and others 2010), and we encourage surveyors to employ these or similar methods. When transitioning to new methods, replicated surveys conducted with both old and new techniques for several sessions will enhance the consistency of results over time.

7.4.1

7.4.1 Preferred Methods for Internal Surveys

The following sections do not provide an exhaustive review of internal survey methods, but represent the methods generally believed to be most effective. For more discussion and details of methods and techniques, we suggest consulting the references provided in table 7.1.

Table 7.1—Additional resources for conducting internal and external colony counts

Source	Description
Kunz and others (2009)	General review of bat survey methods
Thomas and LaVal (1988)	General review of bat survey methods
U.S. Fish and Wildlife Service (2014)	Emergence survey protocols for Indiana myotis
U.S. Fish and Wildlife Service (2007)	Indiana myotis hibernacula survey guidelines
Bat Conservation International and Southeastern Bat Diversity Network (2013)	Roost count guidance for two species
Wisconsin Department of Natural Resources (2013)	Roost monitoring Web site for Wisconsin Department of Natural Resources
Vermont Fish and Wildlife (2012)	Bat monitoring guidance from Vermont Fish and Game Department
New Hampshire Fish and Game Department (2014)	Bat monitoring guidance for summer maternity roosts
Pennsylvania Game Commission (2014)	Summer maternity roost monitoring protocols
Alaska Department of Fish and Game (2010)	Summer roost emergence count instructions from Alaska Fish and Game Department
New Zealand Department of Conservation (2012)	Discussion of internal roost survey methods for bats in New Zealand
Hundt (2012)	Guidance for bat surveys in United Kingdom

7.4.1.1 Visual counts and photographic methods

7.4.1.1

Direct counts such as visual or photographic counts are effective for estimating colony sizes for bats that roost conspicuously in single- or multispecies clusters. Direct counts are suitable for hibernating species during winter and gregarious species during summer, depending on roosting and clustering behavior. Direct counts are not appropriate for species that roost in crevices or otherwise inaccessible parts of a roost (Thomas and LaVal 1988). Under most circumstances, visual counts from internal surveys accompanied by digital photography offer the most reliable results where conditions allow (Meretsky and others 2010). Minimum camera specifications and photography methods will vary by roost and target species, but some recommendations are discussed in the Indiana myotis survey protocols (U.S. Fish and Wildlife Service 2007). Detailed discussion of photographic methods can be found in Meretsky and others (2010). Commonly used camera systems include a single lens reflex (SLR) digital camera with a minimum resolution of eight megapixels, a zoom lens for high ceilings, adequate flash and flash extender for high ceilings, and spot metering capabilities for survey photographs. For more details on conducting surveys with digital SLR cameras see: http://workspace.whitenosesyndrome.org/sites/default/files/ny_camera_equipment_and_hibernacula_photography_guide.pdf. Less elaborate systems such as simple point-and-shoot digital cameras may be adequate for sites where surveyors are relatively close to bats, and waterproof point-and-shoot cameras facilitate decontamination before use at another site. Laser pointing devices can aid in low-light auto-focusing and ensure the correct bat cluster is photographed (Meretsky and others 2010) (fig. 7.2).

Figure 7.2—Hibernating *Myotis* cluster photographed for survey purposes. A laser pointer (dot on image) was used to aid autofocusing in low light conditions. (photo courtesy Vesper Environmental, LLC)

It may be necessary to photograph multiple sections of large clusters of bats to achieve sufficient resolution for accurate species identification and counting. This approach facilitates distinguishing individuals that may be less conspicuous in dense clusters. The percentage of a cluster to be targeted in high-resolution digital photographs will depend on the overall size of the cluster, the focal length of the camera lens, and the resolution of the camera's sensor. Surveyors should subsample at a level that ensures targeted bats are clearly distinguishable in each photograph. It is critical that reference points (e.g., a laser pointer held in one position for multiple photos) are included in every image so that adjacent fields of view can be spliced together without double counting or missing bats.

In addition to producing a permanent record of the survey, high-quality photographs allow individual bats to be counted or densities estimated after surveyors have left the roost, thus reducing the amount of time surveyors spend in the roost. However, photography may not be appropriate for counting bats in hibernacula with complex roosting surfaces where the observer must process multiple angles of observation to account for bats in the cluster. In these cases, photographic methods should be paired with visual counts to estimate detection probabilities with the two methods. Surveyors should take special care to identify clusters and record photograph numbers so that estimates from the two methods may be directly compared for each cluster rather than for the colony as a whole.

7.4.1.2

7.4.1.2 Estimating cluster density for visual counts

When bats form large clusters, estimates of abundance from visual counts are achieved by measuring the dimensions of a roosting cluster and conducting counts on subsets of the cluster to estimate the packing density. The estimated packing density is then extrapolated over the entire area of the cluster to estimate total colony size. Because packing densities often vary across a cluster, this method may produce large errors in colony estimates (Thomas and LaVal 1988). If density estimates from visual counts are to be used, packing density should be estimated for each cluster and for multiple subsets of larger clusters. However, Meretsky and others (2010) have shown that visual density estimates produce less consistent results than photographic methods, and thus they are not recommended for the purposes of NABat when photographic methods are possible.

7.4.1.3

7.4.1.3 Other methods

Numerous other options are available to estimate colony sizes from internal surveys. However, a complete discussion of these methods is beyond the scope of this document because these methods are sometimes more narrowly applicable, too labor intensive, or too expensive for rangewide monitoring of most species. For example, three-dimensional laser scanning has been proposed as an alternative to digital photography (Azmy and others 2012). Three-dimensional laser scanners provide a topographical map of the cave surface and can be used with very low light, thus reducing disturbance to the bats. However, like other methods, bats that are in crevices or covered by other bats will not be counted, and this method offers no advantages in species identification. Reflectance infrared and thermal infrared imaging have also been used inside roosts (Boyles and others 2008), but they are more useful for monitoring behavior and physiology than for estimating numbers of roosting bats. Modeling abundance using traditional mark-recapture (e.g., O'Shea and others 2004) and related molecular methods (e.g., Oyler-McCance and Fike 2011, Puechmaille and Petit 2007) are additional tools that may be applied in some situations. Any of these alternative methods should be coupled with photographic counts to help validate estimates and scale them appropriately for inclusion in rangewide estimates. We recommend pairing historic methods with photography for several surveys to transition to photographic counts as the primary method.

7.4.2 Preferred Timing for Internal Surveys 7.4.2

7.4.2.1 Internal surveys in winter 7.4.2.1

Detection probabilities of hibernating bats in roosts are seasonally heterogeneous, even in the best cases when bats are in conspicuous clusters. Cluster densities change with date so that some bats are obscured or covered entirely by other bats (Tuttle 2003). Fissure-roosting bats such as northern myotis (*M. septentrionalis*) may periodically emerge from a cluster or crevice depending on date or conditions and potentially move to another spot, resulting in substantial within-winter variation in counts. Ideal timing for surveys likely varies by species and region and has yet to be established except in a few special cases. For example, in the Appalachian region, northern myotis are more detectable in late February, but counts vary considerably on a day-to-day basis (Ingersoll and others 2013). Indiana myotis counts are least variable during January, and little brown myotis (*M. lucifugus*) counts are least variable at the end of January; tri-colored bat (*Perimyotis subflavus*) counts show little variation throughout the winter (Ingersoll and others 2013). We recommend that, whenever possible and when specific guidance for endangered species does not preclude it, winter surveys be conducted between late January and early March, which is also appropriate for identifying field signs and collecting samples for WNS surveillance (WNS Surveillance Working Group 2010). At hibernacula with multiple species, survey timing might be selected based on species of greatest concern or for those for which the most reliable results are expected. Until optimal dates are determined at local scales, survey timing should be based on consistency with historic records and knowledge of species detectability. Although some sites may become inaccessible as ice and snow accumulate, seasonal effects on survey data can be modeled and scaled if appropriate covariates are also recorded (Ingersoll and others 2013). Hibernaculum surveys should not be conducted more frequently than once every year to minimize disturbance (Kunz 2003, Tuttle 1979, U.S. Fish and Wildlife Service 2007). Weller and others (2014) detected no measurable effect of annual surveys on colony sizes of Townsend's big-eared bats (*Corynorhinus townsendii*). For some species, however, surveys should be no more frequent than every other year. Maintaining reasonably regular intervals for bat counts reduces the influence of outliers on subsequent modeling and analysis and improves the precision of estimates. Use of automated equipment to conduct surveys may allow for annual surveys with negligible disturbance to bats, but so far these methods are somewhat limited due to cost, supplies, safety of equipment, and other considerations.

Brazilian free-tailed bats emerge from Bracken Cave in suburban San Antonio, TX.

7.4.2.2 Internal surveys in summer 7.4.2.2

Conducting internal roost surveys during the summer maternity season should be avoided if emergence counts of bats can be used. If internal surveys are to be used, they should be timed to minimize detrimental impacts on bats while maximizing the probability that inhabitants represent a relatively stable colony, preferably composed mostly of adult bats (Kunz and others 2009). Although exact timing will vary among species and geographic region, we recommend that, whenever possible, internal roost surveys be conducted during the final 2 weeks of pregnancy. While early lactation also represents a period of relatively stable colonies, risk of disturbing neonates may be greater at this time. Thus, the preferred window for internal surveys at summer roosts is more restrictive than the window for conducting emergence counts. Internal roost surveys should be conducted in the afternoon once bats have settled from early morning foraging activity and prior to increased evening activity in preparation for emergence (O'Donnell 2002). As with winter surveys, repeated visits into summer roosts may disturb resident bats (Fenton 1997, Kunz and others 2009, Lacki 2000, Mann and others 2002). Thus, we recommend using multiple observer methods to conduct a single internal survey annually to estimate colony size. Furthermore, use of red lights or night vision helps reduce disturbance. Remotely operated cameras may also be installed in the roost during the night while bats are absent from the roost and operated from outside on subsequent days to obtain internal counts.

7.4.3

7.4.3 Spatial Variability Among Surveys

A persistent problem of cave and mine surveys is inconsistent sampling within sites over time. For example, surveyors may cover different or additional portions of a site depending on variation in resources or accessibility from year to year. Important new bat colonies may be discovered in previously unexplored portions of caves or mines (Tuttle 2003). Spatially inconsistent survey routes may render data useless for analysis if differences in survey route are not well documented. To accommodate route changes, count locations should be topographically referenced or subdivided into rooms and passageways to facilitate analysis of location-specific changes from year to year. Topographic referencing underground is best achieved with a detailed cave or mine map (often available from local National Speleological Society chapters or State cave surveys) indicating the survey route and cluster locations. Stihler (2005) provided an excellent example of survey effectiveness in a very large roost used by multiple bat species. When maps are not available, surveyors should make drawings of the roost and indicate all areas surveyed as well as known but unsurveyed areas.

7.5

7.5 External Roost Counts

Emergence counts can produce reliable estimates of volant bats at a wide variety of roost types (Kunz and others 2009). They also create minimal disturbance and provide excellent opportunities for including citizen scientists in monitoring bat populations. Suitability of emergence counts varies among species and, for some species, among regions. Emergence counts are appropriate when (1) all exits from the roost are known and observable; (2) there are sufficient resources to monitor all exits simultaneously; (3) emergence trajectories of bats are not obscured by clutter outside the roost; (4) density of bats during emergence is low enough that individuals can be distinguished; (5) emergence occurs while light is sufficient to observe the duration of the emergence or technology is used to facilitate observation; (6) emergence is complete prior to increased circling activity at the entrance of the roost and prior to bats returning to the roost after foraging; (7) emergence activity is not disturbed by noise, weather, or other factors; and (8) species composition and relative abundance of the species in the roost are known.

A hoary bat perched in a deciduous oak tree in autumn.

Accuracy of emergence counts relies in part on the assumption that all bats leave the roost on the survey date and that they are visible to observers or recording devices as they emerge. In northern latitudes, it is recommended that observers be in place and monitoring roosts at least 30 minutes before sunset; however, emergences may begin hours before sunset for some species in some regions (e.g., Brazilian free-tailed bats in Texas) (Frick and others 2012). We recommend that observers spend at least one afternoon and evening monitoring emergence behavior at each site immediately prior to the survey to establish timing, flight patterns, optimal observation positions, and other factors that may affect the ability to obtain accurate estimates of emerging bats. If possible, conducting simultaneous emergence counts at all known roosts in an area will reduce error caused by bats moving among nearby roosts. As with internal surveys, multiple observer methods or repeated surveys are encouraged.

7.5.1 Preferred Methods for External Surveys 7.5.1

7.5.1.1 Visual counts 7.5.1.1

Counting bats emerging at dusk is a long-established technique for monitoring roosting populations of bats that has been well described (Battersby 2010, Elliot and others 2006, Jones and Rydell 1994, Kunz 2003, Kunz and others 2009, Thomas and La Val 1988). During midsummer in temperate zones, ambient light is often sufficient to observe enough of an evening emergence to account for most bats in a colony. This method is inexpensive, but may produce inaccuracies associated with limitations of unaided observation or incomplete counts if bats continue to emerge as light fades, or double counting if bats exit and return to the roost multiple times during the emergence.

When conducting emergence counts, it is important that a sufficient number of observers are present to continuously monitor all possible exits from the roost. Where multiple exits are used, observers must identify boundaries to the field of view each will count to avoid double counting (Kunz and Anthony 1996, Kunz and others 1996). If resources are limited and monitoring all exits is not possible, some exits can be temporarily obstructed. For example, windows or doors of a house or barn roost can be closed or sheets can be draped over openings to deter bats from using openings that are not being monitored. To avoid potential harm to bats, primary exits should not be obstructed. Modification to a site should be completed well before the expected time of emergence and all exits returned to original states as soon as the emergence count is complete.

To conduct counts, each observer should use two clickers, one to tally emerging bats and one to tally returning bats passing through his or her field of view during the emergence period. However, if observers are situated close to flying or roosting bats, high frequency sounds from clickers may change bat behavior. Use of audio recorders to record recited observations with time stamps may also be appropriate. Counting should continue until it is determined that all volant bats have left the roost. In many cases, an interval of at least 10 minutes during which no bats emerge indicates that the majority of bats have left the roost. However, some larger colonies may exhibit multiple emergence pulses, and intervals with no activity may last much longer than 10 minutes (Lee and McCracken 2004, Reichard and others 2009). A bat detector near roost openings can sometimes be used to determine when activity inside the roost has ceased. Diminishing light conditions may preclude the observers' abilities to continue counting bats as they emerge. In these cases, a clear note about the rate at which bats are emerging (number of bats per minute) as observation becomes impossible is informative, but the results of that survey may be unreliable. Alternatively, night vision goggles or viewers can be employed with infrared light sources to allow the observer to continue tallying emerging bats after dark. Spotlights, headlights, or other light sources should not be used to observe emerging bats, as they may affect bat behavior.

Under some conditions, an emergence count will not provide an accurate estimate of the true colony size. These conditions include extreme temperatures, high wind, heavy rain, or pressure changes on the survey night. Extended periods of drought or nearby wildfires may also affect emergence timing. Anthropogenic factors such as noise near the roost; habitat modification; unnatural light sources; and odors from vehicles, foggers, or other sources can also alter bat behavior. Whenever possible, surveys should be postponed if any of these conditions occur or if there is any other reason to suspect that the emergence behavior would be disturbed in some way.

7.5.1.2

7.5.1.2 Digital video methods

Numerous digital video methods for estimating colony size may be applied if resources permit. The use of digital video cameras creates a physical record of the emergence and enables subsequent manual or automated counting of individuals leaving a roost. Combining automated programs (see below) and manual processes to analyze recorded footage (i.e., a multiple observer method) can be used to validate estimates. Video methods are particularly useful for larger colonies where human error is likely to lead to inaccurate estimates, and footage can be slowed to facilitate counting especially busy periods of the emergence.

Either thermal infrared (TIR) or near infrared (NIR) cameras can be employed for emergence counts (fig. 7.3). Although these technologies are expensive, both allow surveyors to "see in the dark" and record activity long after darkness has eliminated the ability to observe bats with the unaided eye. There are several trade-offs between the two technologies. NIR is less expensive, but it can underestimate colony sizes (Elliott and others 2011). Utility of TIR for surveying bat emergences can be limited due to a lack of thermal contrast between the target and the background, too large a distance between the camera and the subject, and thermal clutter (e.g. clouds, ground, and foliage) (Melton and others 2005). NIR imaging is often enhanced with a secondary integrated or external infrared light source to illuminate subjects. Infared light is unlikely to alter bat behavior, especially if oriented perpendicular to the bats' flight path; however, these light sources require additional power and may have limited range and intensity that may diminish their utility for some applications.

Automated methods of counting bats have been developed for TIR (Betke and others 2008, Frank and others 2003, Hristov and others 2008, Melton and others 2005, Sabol and Hudson 1995) and NIR (Elliott 2006, Elliott and others 2006) footage of emerging bats. These methods are capable of distinguishing emerging and returning bats to avoid recounting most individuals that pass through the field of view more than once. We recommend that automated tallies and manual counts of the same footage be used to estimate error and detection probabilities. As with direct visual emergence counts, it is important that each exit be monitored by at least one camera and that areas of possible overlapping fields of view are well defined and accounted for when bats are tallied.

7.5.1.3

7.5.1.3 Other methods

Numerous other methods have been proposed for conducting external surveys. Beam-break technology (Redell 2005), Doppler radar (Horn and Kunz 2008), and vertical profiler radar (Kelly and others 2009) have all been used to estimate colony sizes. Although these and other methodologies may develop into convenient survey methods,

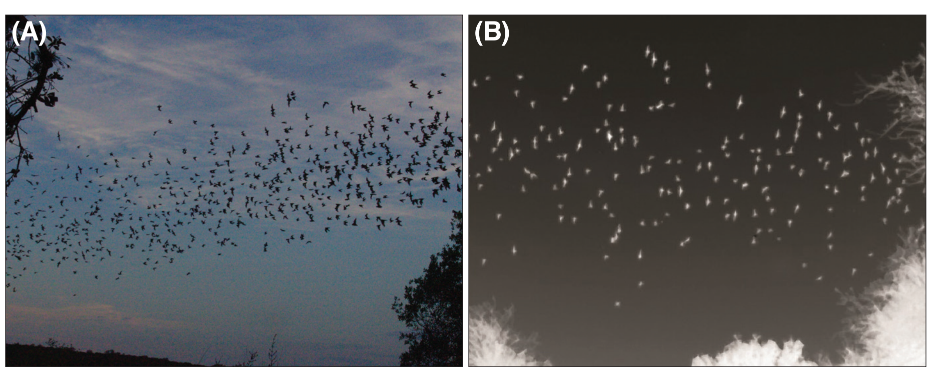


Figure 7.3—(A) Visible light and (B) thermal infrared image of Brazilian free-tailed bats (*Tadarida brasiliensis*) emerging from a cave in Texas. (photo and image by Nickolay Hristov)

they are currently not sufficiently well developed to recommend as general methods for assessing colonies to meet the objectives of NABat.

Bats drinking from a water tank.

7.5.1.4 Determination of roost species composition 7.5.1.4

Multispecies roosts can complicate external survey estimates. Several ancillary methods are available to determine the species in a roost when species cannot be distinguished through the applied survey method. Internal surveys during a non-sensitive time period (e.g., after the young are volant), mist netting or harp trapping outside of the roost (e.g., Kunz and Kurta 1988, Whitaker and Rissler 1992), acoustic monitoring (e.g., Stihler 2011), and DNA analysis of guano (Zielinski and others 2007) all provide means of estimating species composition and, to some extent, relative abundance of species in a roost. In some cases, body shape or size can be used to distinguish among species (e.g., Ammerman and others 2009). In other cases, species may segregate themselves temporally or spatially during emergence, allowing surveyors to produce discrete species-specific estimates. If relative abundance of species in a colony is used to estimate numbers for each species, the associated error must be acknowledged, if not quantified. Estimates of associated error or acknowledgment that the measure of abundance is deemed relative rather than absolute by the surveyors should accompany the data in the BPD for potential use as a covariate in subsequent analyses.

7.5.2 Preferred Timing of External Surveys 7.5.2

The timing of external surveys is an important factor to consider when planning surveys so that comparable estimates of colony sizes are collected across sites and years. The best time to conduct surveys is when the adult colony is relatively stable and prior to volancy of the young. Kunz and others (2009) recommend conducting emergence counts for two to three nights during the period of maximum adult colony size, which often occurs during late pregnancy and early lactation. In general, a 2- to 3-week period around the summer solstice often corresponds with these reproductive stages in many temperate species (e.g., Hristov and others 2008, Humphrey and Cope 1976, O'Farrell and Studier 1973, Reichard and others 2009, Schowalter and others 1979). For larger colonies, scheduling counts closer to late pregnancy reduces the likelihood of lactating females returning to the roost to nurse young before all bats have emerged. In the later stages of the lactation period, increased flight activity around the roost may complicate emergence counts as young bats come and go throughout the night and adults return periodically to nurse their young (Stihler 2011). Because exact dates of parturition vary among species and regions (Bradbury 1979) and are further influenced by proximate climate factors (Frick and others 2010, Racey and Swift 1981), surveyors should attempt to confirm the reproductive timing at each roost to determine the most appropriate survey dates.

7.6 Safety and Environmental Considerations 7.6

7.6.1 Minimizing Environmental Impacts 7.6.1

Human activity can disrupt regular ecological conditions and processes in caves and mines, and thus care should be taken to minimize these effects (van Beynen and others 2012). Surveyors are also subject to restrictions on activity and schedules by property owners and State, Provincial, Federal, and tribal agency regulations. Alterations at sites (e.g., marking roost surfaces, attaching scientific equipment, clearing areas to improve access) should be avoided to leave minimal trace of human activity. All personnel should adhere to national decontamination protocols for WNS (www.whitenosesyndrome.org) to minimize potential spread of *Pseudogymnoascus destructans* and other microbes.

7.6.2

7.6.2 Human Safety

A complete list of potential hazards that might be encountered by survey crews in caves and mines and how to avoid these hazards is beyond the scope of this document. In addition to expertise in caving, some sites (e.g., abandoned mines and aqueducts) may require specialized certification to gain access. Some common hazards that may be encountered in caves and mines include unstable floors and ceilings, dropoffs, narrow passages, falling objects, hypothermia, loss of orientation, anoxic conditions, flammable materials and gases, and high levels of radon. Risks from these hazards can be greatly minimized through training and the use of proper gear. All surveyors entering a site should be properly trained according to the site's health and safety regulations and those of the surveyors' sponsors. Sites should be inspected and deemed safe prior to any survey activity, and emergency response plans should be in place. The National Speleological Society (www.caves.org) provides many resources on safety, training, and appropriate gear to be used in caves, and Altenbach and others (2001) provide additional information about conducting mine surveys. Training in vertical climbing is critical before entry into many caves and is available through local chapters (or "grottoes") of the National Speleological Society. Surveying bridges, dams, and tree roosts can also be hazardous. Other hazards include vehicular traffic, wildlife, debris, and even other humans. At a minimum, surveyors should keep a first aid kit on their person or in their vehicle and ensure that all members of the survey party know how to appropriately respond in case a medical emergency arises (e.g., they know directions to the nearest hospital).

7.7

7.7 Locating New Colonies and Documenting Absence of Colonies in Winter and Summer

Colony counts are limited to known roosts, and identification of new roosts is often limited to opportunistic reports or inconsistent search efforts. However, bats may respond to disturbance of the roost by moving to new locations (Elder and Gunier 1978) and occupy new habitat (e.g., mines) as it becomes available (Fath 2002). Monitoring species only where they habitually occur will not fully capture this dynamic variation because changes in distribution will not be detected. Capturing changes in distribution and abundance is especially important given ongoing and expected changes to the environment caused by disease, alteration of landscapes, and climate change.

The colony count aspect of NABat can capture these changes to distribution through a discovery process. The GRTS sampling design of NABat (see ch. 3) provides a strategic approach to locating previously unknown roosts and documenting absence of bats in potential roosts. Results of the stationary and mobile acoustic monitoring program can be used to identify range shifts, and hotspots of acoustic counts may be helpful in directing maternity roost survey searches. This additional roost survey effort should be guided by the master sample (see ch. 3) or predicted probability surfaces derived from the acoustic surveys (see ch. 9). However, acoustic surveys alone will provide little (if any) insight into the potential location of winter roost locations. For example, even though there are at least 45,000 caves in the contiguous United States, with the vast majority of them occurring in the karst regions of the Eastern United States (Culver and others 1999), Indiana myotis are known to occur in only 0.5 percent of them (Thogmartin and others 2012). Furthermore, the number of buildings, trees, culverts, bridges, and other structures potentially inhabited by bats


A tri-colored bat from a hibernaculum in SC. (© Ben Neece)

is likely much greater than the number of caves. Thus, to discover new winter roosts will require devoting resources to inspection of caves, mines, scree fields, and other potentially suitable winter habitat, and elicitation and curation of volunteer-contributed information such as reports from cave enthusiasts, surveys conducted in the course of project clearance (e.g., wind turbine construction, National Environmental Policy Act or Endangered Species Act compliance), local biologists, and the general public. Additionally, newly closed mines, newly constructed bridges, and other modified or newly created roost-capable locations could be brought into the "formal sample list" to prioritize their sampling.

Whether the discovery of additional colonies is necessary for trend analyses is dependent in part on whether a sufficient fraction of the species' population is represented in the sample that can be monitored with limited resources (described more fully in the paragraph below) and whether the accuracy of trend estimates from those data are sufficient for robust inference (see ch. 9). As stressors such as changes in climate and land use modify the distribution of species, discovery of new roosting locations for establishing the range of species may be necessary, especially for species not well monitored by acoustic methods (see ch. 2). Coupling radiotelemetry studies with mist netting or spring emergence monitoring can facilitate discovery of summer colonies, and fall tracking studies may lead to discovery of unidentified hibernacula (Neubaum and others 2006).

In addition to locating new colonies, NABat may help document areas of absence. Given limited resources, however, we do not expect considerable effort to be devoted to determining a species' absence, even from areas seemingly suitable to the species. Nevertheless, where such data exist, it will be important to understand the loss of species from areas where they once occurred and perhaps to identify why they no longer occur in those areas, as well as areas occupied only infrequently (for instance, when abundance increases because of periodic pulses in resources).

7.8 Covariates and Ancillary Data

7.8

A number of covariates are important for providing appropriate context to counts collected at a site. These covariates include the date and time of data collection, descriptions of the roost structure, information on number and experience of the surveyors, the methods used, environmental conditions during the count, and the habitat surrounding the structure. Lists of covariates that should be recorded (if relevant and possible) during internal and external surveys are given in tables 8.1, 8.2, and 8.3, and sample data sheets for recording these data are provided in appendixes F, G, and H.

7.9 Incorporation of New Technologies

7.9

Advances in technology, accessibility of equipment, and intellectual innovations drive continuing evolution of survey methods. As new methods are developed and validated, it is important that strategic transitions to these new methods are planned so that new data can be connected with historic data. Increased effort during the transition to the new method will greatly increase the value of monitoring efforts.

8. Data Management

8.1 8.1 Importance of Data Management

Data and information are the primary products of any well-designed ecological monitoring program. The ability to provide organized and well-documented data and analyses to key audiences and ensure their long-term preservation will determine the monitoring program's efficacy and image among critics, peers, and advocates (Fancy and Bennetts 2012). Therefore, a critical component of any monitoring program is to ensure that data and information are managed so that they can be easily found and compiled, are subjected to full quality control before release, and are accompanied by complete metadata. Many funding sources are now requiring data management or data sharing plans in the proposal process to ensure that data are properly collected, stored, and archived (e.g., National Science Foundation, National Institutes of Health). A centrally located and easily accessible database or portal that carefully tracks all sources of information is also important for projects such as NABat that have multiple organizations involved and cover large geographic areas.

8.2 8.2 History of the Bat Population Database

In 1994, U.S. Geological Survey (USGS) scientists recognized that despite increasing concern for many species of bats known or believed to be declining, data necessary to determine population status and trends were fragmented among agencies and organizations. The Bat Population Database (BPD) was developed to compile existing population information for bats in the United States and territories. The initial goals were to (1) synthesize the existing bat population data and publications into a single Web-accessible database, (2) test the utility of these data for estimating trends in bat populations, and (3) evaluate the applicability of these data for future monitoring programs. The relational database was designed using Microsoft Access® software and compiled various components of bat population data gathered between 1855 and 2001. The original database included counts of bats at colony locations, location attributes, and a bibliography of publications relevant to counts of bats (published literature, theses, agency reports, and State agency records of bat observations). These data were used to investigate colony trends at 179 summer and 294 winter roosts of 22 species of bats (Ellison and others 2003), yet the effort revealed many shortcomings of the existing data such as inconsistencies in survey effort and timing. The database was available to the public on the Internet for several years; however, the search capabilities were limited. Interest in the database languished for years until the combined threats to bats from habitat loss and fragmentation, white-nose syndrome, wind energy development, and climate change generated renewed interest for data suitable for bat population estimation and trend analyses.

8.3 8.3 The Bat Population Data Project

The newly named Bat Population Data Project is an effort by the USGS Fort Collins Science Center (FORT) to upgrade, update, and extend the capabilities of the original BPD to allow for better data management, accessibility, and utility by USGS and its data partners. In addition, the Bat Population Data Project provides data stewardship and coordination to data partners, in particular the NABat Program Team.

BPD (version 2) is the primary tool of the Bat Population Data Project and in 2012 was reconstructed as a Web-based data management application (http://my.usgs.gov/bpd). It contains the original 24,000 field observations, most of which are historical colony counts. BPD v. 2 allows users to search the database by date range, author, species, and State for public information on historical colony counts of bats from the literature and data partners (see sec. 8.6). The BPD now has role-based access control, which is a method of regulating access to network resources based on the roles of individual users within an enterprise or program. Role-based access specifies the ability of an individual user to perform specific tasks such as to view, create, or modify data. The roles are defined according to the user's authority or responsibility within the program. Because the BPD is role based, data partners can obtain their own confidential data in searches. Additionally, BPD v. 2 now includes fields for capture-based data obtained from mist netting and other trapping efforts. Data structures to manage acoustic data fields are currently being developed. The data management plan for the BPD is provided in appendix I.

A tri-colored bat from a hibernaculum in SC. (© Ben Neece)

In the summer of 2013, scientists at FORT began updating the BPD with colony count data collected from 2001 to the present by various agencies' monitoring and endangered species programs and State heritage programs. Further, acoustic data collected from mobile transect surveys that were conducted in the Eastern United States from 2008 through 2013 will be consolidated into the BPD. The colony count and 2008–13 acoustic transect data will be considered "legacy" data. These legacy datasets will provide a baseline of information on bat populations for future monitoring of population trends under the NABat framework.

8.4 Database Architecture 8.4

BPD users will be able to archive and access observation data, site location information, acoustic metadata from species identification processing, and colony count data that are collected as part of NABat or outside of it. Protocols developed in this document determined the fields to be collected and stored in the BPD (see tables 8.1, 8.2, and 8.3). Observation information includes dates, times, and the specific conditions during the periods surveyed. Other data fields include observers, environmental variables (e.g., moon phase, cloud cover, temperature), observation methodology (e.g., colony count, acoustic survey), and general habitat descriptions (table 8.1). Site location information includes the following fields: site name and generalized random-tessellation stratified (GRTS) grid cell identifier, country, State or Province, county (if applicable), geographic coordinates, land ownership, and elevation (table 8.2). Additional fields related to acoustic data collection are provided in table 8.1, and include information on how the files were collected (e.g., type and model of acoustic detector, microphone type, recording mode, trigger window length, and microphone height). Fields related to species identification of acoustic files will be in a separate table within the BPD architecture and will allow the automatic upload of spreadsheets from software packages that automatically identify bats to species based on their echolocation call characteristics (see ch. 6). Spreadsheets created in Anabat™ AnalookW software using the "Count Labels" tool will also be uploadable to the BPD. Colony count data fields include the roost structure (e.g., cave, mine, bridge, or bat box), colony type (e.g., maternity, hibernaculum, bachelor, transient, or mixed), species, estimation method, population estimate for each species, and lower and upper limits of population estimates (table 8.3). Because the BPD is a relational database, multiple tables are linked by unique identification numbers. For example, multiple Observation IDs are linked to a particular Location ID, multiple Colony Count IDs are linked to an Observation ID. A detailed data dictionary will be developed and provided to NABat participants and data partners.

Table 8.1—Fields to be collected for NABat related to observations

Fields	Description	Applicable survey method
Site	Location Name (e.g., cave name, transect identifier/ name)	All surveys
Grid Cell ID	Generalized random-tessellation stratified (GRTS) 10- by 10-km grid cell number provided by NABat	All surveys
Surveyors	Names of all surveyors	All surveys
Years of experience	Number of years of experience observing (colony counts) or identifying species (acoustic surveys)	All surveys
Moon	Moon phase	All surveys
Observation methodology	Colony count, stationary point, or mobile transects	All surveys
Observed habitat description	Habitat type (urban, agricultural, rangeland, forest land, water, wetland, barren land)	All surveys
Survey start/end	Beginning and end time of survey	All surveys
Other research?	Identify other activities conducted simultaneously with count surveys	All surveys
Photographic equipment	Identify cameras used during the survey	All surveys
Photos?	Y/N – submit photos that illustrate the detector set-up, surrounding area, habitat	All surveys
Observation comments	Other comments	All surveys
Roost structure	Cave, mine, bunker, barn, tree, bridge, etc.	Colony counts
Estimate method	Survey methods (e.g., internal-photographic, external thermal infrared camera, emergence count, etc.)	Colony counts
Colony type	Maternity, bachelor, hibernaculum, transient, mixed	Colony counts
Roost size	Dimensions of roost including width, length, and height; diameter at breast height and estimated height for trees	Colony counts
Proportion of roost surveyed	Map or sketch of surveyed area and estimated percent of roost surveyed	Colony counts
Vertical distance (m)	Height of bats in structure	Colony counts
Horizontal distance (m)	Distance between observers and bats	Colony counts
Roost temp (°C)	Air temperature within the roost	Colony counts
Roost RH (%)	Relative humidity within the roost	Colony counts
Presence of water	Indicate if there is standing or flowing water in the roost	Colony counts
Roost protected?	Locks, gates, restricted access	Colony counts
Roost accessibility	Specific equipment, training, needed to access the roost	Colony counts
Signs of disturbance	Evidence such as predation, graffiti, flooding, or collapsed walls or ceilings	Colony counts
Other roosts?	Number and distances of known roosts in the vicinity (<10km)	Colony counts
Observed WNS?	Y/N (number observed will be entered into the colony table)	Colony counts
Specimens collected?	Y/N (number collected will be entered into the colony table)	Colony counts
RH (%) start/end	Relative humidity at beginning and end of survey	Colony counts, mobile transects
Date	Month, Day, Year	Colony counts, mobile transects
Sky start/end	Estimate of cloud cover at beginning and end of survey	Colony counts, mobile transects
Temp. start/end (°C)	Temperature reading at beginning and end of survey	Colony counts, mobile transects

Continued

Table 8.1 (Continued)—Fields to be collected for NABat related to observations

Fields	Description	Applicable survey method
Wind start/end (km/h)	Calm, light, moderate, high at beginning and end of survey	Colony counts, mobile transects
Moonrise/moonset	Time of moonrise and moonset	Colony counts, mobile transects, and stationary points
Sunset/sunrise	Time of sunset and sunrise	Colony counts, stationary points
Date deployed	First night of survey	Stationary points
Date ended	Date acoustic monitoring ended	Stationary points
Time recording started	If detector shut down mid-operation, record the date and time	Stationary points, mobile transects
Time recording stopped	If detector shut down mid-operation, record the date and time	Stationary points, mobile transects
Nightly temp (°C)	High/low/mean temperatures obtained from local weather recording stations or on-site recorders (for each detector)	Stationary points
Nightly RH (%)	High/low/mean relative humidity obtained from local weather recording stations or on-site recorders (for each detector)	Stationary points
Nightly wind (km/h)	High/low/mean wind obtained from local weather recording stations or on-site recorders (for each detector)	Stationary points
Significant weather	e.g., thunderstorm on a particular night, sudden cold snap, windstorm, continuous rain	Stationary points
Distance to clutter	Distance between detector and nearest source of clutter	Stationary points
Bat detector model	Type and model number of bat detector	Stationary points, mobile transects
Microphone Type	e.g., SMX-US™, Anabat™ standard, Hi, or stainless steel microphone	Stationary points, mobile transects
Recording mode	Zero-cross or real-time full spectrum	Stationary points, mobile transects
Gain settings	Switch settings for SM2BAT+™, digital gain setting for SM3BAT™, input gain for Petterson D500x	Stationary points, mobile transects
Signal-to-noise ratio	Trigger level	Stationary points, mobile transects
Frequency filters	High pass frequency (HPF) for SM2BAT+™; FrqMax and HPF for SM3BAT™; recording setting for Petterson D500x	Stationary points, mobile transects
Trigger window	e.g., idle setting or Max TBC (time between calls, see ch. 4)	Stationary points, mobile transects
Maximum file length	e.g., duration (see ch. 4)	Stationary points, mobile transects
Microphone height	Height of microphone above ground	Stationary points
Waterproofing	e.g., Bat-hat, PVC pipe, none	Stationary points
Microphone orientation	Vertical, horizontal, 45°, facing down	Stationary points, mobile transects
Calibration method	e.g., Anabat™ Equalizer	Stationary points, mobile transects
Method of species identification	e.g., Kaleidoscope® Pro, Sonobat™, BCID, EchoClass, other models, filters, visual examination	Stationary points, mobile transects
Version of software	Include versions of libraries used if applicable (e.g., Kaleidoscope® Pro 1.1.20 with North American Classifiers 1.04)	Stationary points, mobile transects
Format of files	Format of files used in species identification (e.g., input of .wav, output of zero-cross)	Stationary points, mobile transects
Postprocessing	Postprocessing of auto-identified files using manual verification	Stationary points, mobile transects

WNS = white-nose syndrome

Table 8.2—Fields in the location table of the Bat Population Database to be collected for NABat

Fields	Description
Site Name	Location name (e.g., cave name, transect identifier, stationary point)
Grid cell ID	Generalized random-tessellation stratified (GRTS) cell designated number for 10- by 10-km grid cell
Country	Country
State or Province	State name or Province name
County	County, if applicable
Federal agency	Federal land owner, if applicable
Land unit	Name of land unit (e.g., Acadia National Park, Ouray National Wildlife Refuge)
State owned?	Y/N
State land name	Name of State-owned land unit
Georeference	Map datum (WGS84 is recommended)
Latitude/longitude	Latitude and longitude of survey in decimal degrees (for mobile transects, this will be entered for both start and end points)
Elevation (m)	Elevation of site

Table 8.3—Fields in the colony count table of the Bat Population Database to be collected for NABat

Fields	Description
Present?	Y/N
Species	Species associated with this particular count (if multiple species of bats are observed, a new colony count record will be created for each species)
Population estimate	Number of bats counted
Lower limit	Lower range of count
Upper limit	Upper range of count
Number of clusters	Tally of the number of clusters counted
Size of clusters	Estimated or measured size of each cluster counted
Dead bats	Count or estimate of number of dead bats
Number captured	Number of bats captured during colony count survey
Number marked	Number of bats banded or marked during colony count survey
Number collected	Number of bats collected (e.g., museum, white-nose syndrome diagnostics)
Colony comments	Any other notable observations

8.5 Additional Support for NABat Provided by the Bat Population Database 8.5

A lesser long-nosed bat pollinates an agave flower.

8.5.1 Geographic Information System Support 8.5.1

NABat will provide States, Provinces, and other partners the GRTS-based master sample in the form of an ArcGIS® shapefile and attribute table with an ordered list of grid cells to survey for their particular area. Each State, Province, and other partner organization will be required to track the status of each grid cell sample unit and provide that information to NABat for tracking and archiving in the BPD. This will enable the sampling design inclusion probabilities to be tracked and used for weighting in subsequent analyses. Grid cells that are dropped and replaced with grid cells further down on the list must be recorded as such. The criteria used to justify replacing units must be recorded as well. Figure 3.2 provides an example of how such a list should be managed. BPD developers will be creating an application for tracking the GRTS-based master sample so data partners will be able to sign in and easily see which cells are already "adopted" for their jurisdiction, which cells have been dropped, and which cells are next in line to be surveyed. 8.5.2

8.5.2 Datasheets and Applications

Standardized datasheets for collecting colony count and acoustic data for the NABat program will be provided in a Microsoft Excel® spreadsheet format. Applications for hand-held field tablets or smartphones that will allow data to be automatically uploaded to the BPD will be developed in the future. Automatic species-identification software programs produce varying output formats. Spreadsheet uploaders for the following automatic species-identification programs will also be developed: EchoClass, BCID, Kaleidoscope®, and Sonobat™. Additional uploaders may be developed for new software programs if they become widely adopted.

8.5.3 Archiving Acoustic Files 8.5.3

Acoustic files collected during the NABat program will be stored and archived by investing in dedicated file storage hardware and eventually through cloud-based resources. The acoustic files themselves will be linked to the BPD acoustic table by unique file names so that proper quality assurance and control (QA/QC) can be periodically conducted. NABat will not be identifying the acoustic files to species; however, NABat plans to provide periodic QA/QC on a randomly selected 10 to 20 percent of the calls submitted by data partners. Automatic species-identification programs will continue to improve as more acoustic data are collected, and NABat will incorporate these into its QA/QC policies.

8.6

8.6 Data Partnerships

Data partnerships will be developed with organizations collecting data for NABat. Data partners are considered owners of the data they contribute and can dictate how those data are displayed on the BPD Web site. Data projects are created and maintained by the data partners to logically consolidate and organize their field data. For example, the NABat program will be a data project within the larger BPD architecture and can be managed by the identified NABat team members (fig. 8.1). Partners of NABat will agree that the data they are collecting for the program will be used as part of annual and multiannual assessments and analyses. The NABat data will not be accessible to the public or other partners/users until these annual and multiannual assessments and analyses are peer reviewed and published unless partners request that they may be made public. Users of the BPD are individuals who have chosen to manage their own data, but NABat also has identified the need for dedicated database manager(s) to help facilitate data entry and uploading for the success of the program (see ch. 10 and fig. 10.1).

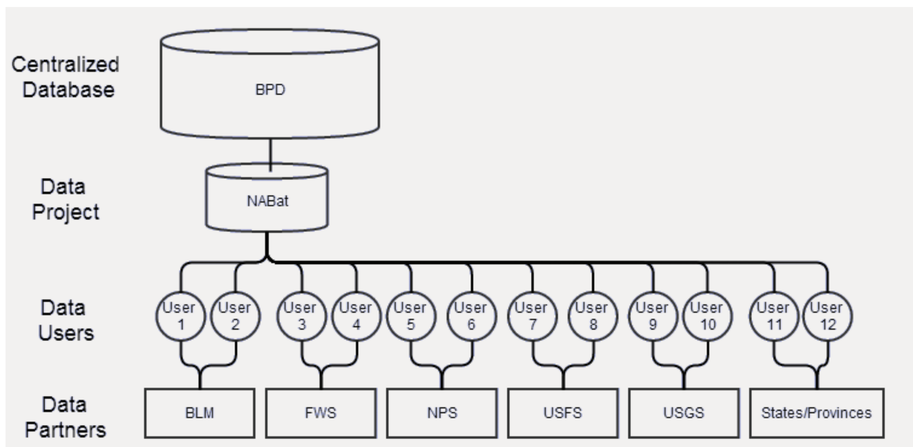


Figure 8.1—A schematic of the U.S. Geological Survey Bat Population Database (BPD) showing the relationships among the central database, the NABat data project, data users, and data partners (not a complete list). BLM = U.S. Bureau of Land Management; FWS = U.S. Fish and Wildlife Service; NPS = U.S. National Park Service; USFS = U.S. Forest Service; USGS = U.S. Geological Survey.

9. Analysis

Portrait of a spotted bat.

The main analytical goal of NABat is to provide robust inferences regarding the distributions and abundance of North American bats and how these state variables are changing over time. Occupancy models can be used to estimate regional species distribution and change over time using data collected following the protocols recommended in NABat for acoustic monitoring (see chs. 4 and 5). These approaches do not allow for estimation of absolute abundance or density because it is not possible to relate the number of calls to the number of bats at stationary point surveys. However, counts of species on mobile transect data can be treated as indices of relative abundance to estimate changes in populations over space or time if detectability can be modeled sufficiently. Colony count data contribute to distribution models and, in addition, can be used to estimate population size if the counting method allows for accurate within-colony counts and if the sampling frame for selection of colonies is well defined.

This chapter describes various analytical methods that can be used with the proposed data collection protocols (see chs. 4, 5, and 7). These suggested methods are based on the best currently available analytic approaches; however, as the field of statistics and environmental monitoring progresses, more suitable approaches may be developed and should be applied if the situation warrants. The methods discussed here are appropriate and recommended state-of-the-art approaches for analyses of data generated from these protocols.

In addition, as highlighted below, the suggested statistical models have assumptions that need to be met for valid inferences to be drawn. Initial analyses of the data from NABat will include evaluation of data for possible violations of model assumptions. Simulation-based studies can be used to assess the repercussions of violated assumptions on inferences as data become available. Misidentification is a significant concern for acoustical surveys of bats (e.g., Clement and others 2014). Evaluation of these errors and incorporation of appropriate ways of estimating or accommodating false positives and negatives via analytical or field-based methods will be an ongoing analysis component for acoustical bat survey data.

All monitoring programs should be subject to ongoing review, and information from the beginning years of data collection from the bat surveys will be used to inform and possibly modify the protocols provided here regarding replication and effort needed for estimating detectability and occupancy. Also, as monitoring questions evolve and scientific understanding progresses, interim assessments on the efficacy of the protocols to inform and support the core needs of NABat (see ch. 1) will be undertaken. These interim assessments will be useful for maintaining management and conservation relevancy of NABat over time.

9.1 Acoustic Data Analyses 9.1

9.1.1 Raw Data 9.1.1

Acoustically recorded data are gathered from bat detectors at fixed locations (hereafter, stationary points; see ch. 4 for details) and acoustic detectors mounted on vehicles traveling prescribed routes (hereafter, mobile transects; see ch. 5 for details). Both of these methods record bat ultrasonic calls emitted as bats pass near a detector. Detectors at stationary points can record multiple passes from individual bats over the course of any given night, while it is assumed that a detector mounted on a car driving a mobile transect records only one pass per individual (Roche and others 2011).

Estimation of occupancy requires replicate sampling at selected sites (grid cells). As bat surveys are omnibus (i.e., encounter multiple species for which sampling requirements will likely vary), initial design recommendations are based on generic recommendations from occupancy sampling (e.g., Mackenzie and Royle 2005) and the occupancy analyses conducted by Rodhouse and others (2012).

For stationary points, the temporal observation unit is a night, and each recorder is deployed for four nights. The recommended sampling intensity is four detectors per 100-km^2 grid cell placed far enough apart to serve as spatial replicates. Selection of sampling locations for the within-grid-cell replicates may vary regionally, and may be chosen from habitats that best represent the regional diversity of bats to maximize detection probabilities. See chapter 4 for details of the stationary point location suggestions and considerations. Date, time, location, and species identification for each bat pass, along with relevant covariates, will be available in the Bat Population Database (BPD) (see ch. 8).

For mobile transects, the temporal observation unit is also one night, although surveying takes place only for 1 to 2 hours each night. Each transect should be surveyed on two nights, the minimal replication to permit estimation of detection probabilities. Transects may vary in length but should be approximately 25 to 48 km and may span one or more 100-km^2 grid cells. Date, time, location, and species identification of each bat pass detected, along with relevant covariates, will be available in the BPD.

9.1.2

9.1.2 Response Variables for Occupancy Analysis

For each grid cell, data from both mobile transects and stationary points will be summarized as detection (1) or nondetection (0) for each species by detector by night, thus creating detection histories for each grid cell (sampling unit). Note that a detection corresponds to at least one recorded and identified call for a species. For mobile transects, only data from the portion of the transect included within that particular grid cell will be included. A grid cell with complete recommended coverage for a season would have a detection history composed of 18 zeros and ones for detections of species X (2 for the mobile transect run twice and 4 stationary points run for 4 nights each). However, the methods described here can accommodate more or fewer observations within a season.

9.1.3

9.1.3 Response Variables for Abundance Indices

Data from mobile transects will generally be aggregated to the number of passes per species per night on the portion of the transect within each selected grid cell. For some analysis purposes, it may be possible to aggregate data from the whole transect, including portions outside of the starting grid cell.

9.1.4

9.1.4 Modeling Occupancy

Occupancy models require repeated sampling in time or space within each sampling unit for estimating detectability. The recommended sampling protocol for NABat will provide both spatial and temporal replication of stationary detectors and temporal replication of mobile transects. As mentioned earlier, pilot data will be used to explore temporal and spatial variability in detection probabilities to inform allocation of effort within a sampling unit as the program evolves. The analysis method proposed below makes use of both stationary and mobile data, accommodating differences in detectability between sampling methods. For more detailed information on occupancy modeling, see Mackenzie and others (2006) who provide a detailed introduction.

The proposed model for analysis is as follows: let Z_i = the partially latent occupancy state in grid cell i during the summer prior to the appearance of volant young, with distribution:

$$Z_i \sim Bernoulli\ (\varphi_i)$$

where

φ_i = the latent occupancy probability

We model φ_i as a function of covariates $\boldsymbol{Q_i}$ at the level of the grid cell (bold denotes vector valued quantities), i.e.,

$$logit(\varphi_i) = \boldsymbol{\alpha Q_i}$$

where

$\boldsymbol{\alpha}$ = occupancy-level coefficients for grid cell (sample unit) level covariates.

The observation on night k at detector j within grid cell i is

$$Y_{ijk} = \begin{cases} 0 \ no\ detection \\ 1 \ detection \end{cases}$$

with distribution:

$$Y_{ijk} \sim Bernoulli\ (Z_i p_{ijk})$$

where

p_{ijk} = the detection probability

Probability of detection can be modeled as a linear function of covariates, including length of road for mobile transects, using a logit link as follows:

$$logit\ (p_{ijk}) = \beta X_{ij} + \delta W_{ik} + \theta I(MethodType)_{ijk} * \mathrm{LengthOfRoad}_{ijk}$$

where

β = detection-level coefficients for detector-level covariates
δ = detection-level coefficients for temporal covariates
θ = proposed parameter to adjust for species detections contributed from using mobile transects of varying lengths within a grid cell or sample unit
X_{ij} = detector-level covariates (e.g., habitat type) that vary across detector j within grid cell i
W_{ik} = temporal covariates that vary by night k within grid cell i (e.g., hours of recording for stationary detectors)
$I(MethodType)_{ijk}$ = the indicator for the type of method used, either mobile (1) or stationary detector (0), so the interaction term allows for adjusting by length of road within a grid cell

This model assumes that after accounting for appropriate detection-level covariates, replicate surveys within a grid cell are independent within a season. A multiscale parameterization proposed by Nichols and others (2008) that incorporates multiple detection methods could also be explored for this type of combined data.


A tri-colored bat from a hibernaculum in SC. (© Ben Neece)

The model above can be fit using Bayesian methods (Kéry and Schaub 2011, Lunn and others 2000) or via maximum likelihood methods. The actual covariates used to explain occupancy and detection may differ among species and regions. Habitat covariates for occupancy analysis must be available for all grid cells and will be assembled in a Geographic Information System; covariates for estimation of detection probabilities are required for all detectors. See tables 8.1 and 8.2 for a list of covariates for stationary points and mobile transects, respectively. This list may change over time as more data are collected and the relative importance of different covariates can be assessed.

The above model is designed to produce predictive occupancy probabilities for each grid cell over each species range, which can be displayed in the form of species distribution maps (e.g., Rodhouse and others 2012). It can also be used to quantify associations between species occupancy and biologically meaningful covariates. The model can also be used to predict the consequences of changes in covariates on species occupancy.

The model, as formulated above, describes patterns of occupancy for a single year. Multiyear information from repeated monitoring permits the extension of this model to estimation of parameters associated with change in occupancy, including local extinction (defined as the probability of a site being unoccupied in one year given it was occupied the year before) (MacKenzie and others 2006) and colonization (MacKenzie and others 2003, McKann and others 2013). Specifically, the occupancy parameter can be allowed to vary over time as follows (MacKenzie and others 2003):

$$\psi_t = \psi_{t-1}(1- \varepsilon_{t-1}) + (1- \psi_{t-1})\gamma_{t-1}$$

where

ψ_t = the time-specific occupancy probability, dependent on the occupancy probability at the previous time step (ψ_{t-1})
ε_{t-1}= the probability of local extinction
γ_{t-1} = the probability of colonization

This is referred to as the multiseason occupancy model (Fiske and Chandler 2011, MacKenzie and others 2006). Additional extensions of the model can be used to estimate occupancy simultaneously for multiple species and to estimate species richness (Royle and Dorazio 2008).

As noted above, occupancy methods assume that individuals are identified correctly to species, but one of the challenges with acoustic data is that a percentage of calls are unidentified or incompletely identified (i.e., some species are difficult to distinguish). Some calls may also be confidently but incorrectly classified. A growing literature suggests that misidentifications can bias estimation in occupancy models (e.g., Clement and others 2014). Clearly, further work is required to develop methods to incorporate and address these additional data and misidentifications (Catelan and others 2010, Kéry and Schaub 2011, Miller 2012). Quantifying misidentification rates, developing procedures such as collecting ancillary data to correct for misclassification during estimation, and implementing composite estimation for groups of species that cannot be easily distinguished in acoustical surveys should be a priority for future research.

An additional methodological consideration is incorporation of unequal sampling probabilities for grid cells (i.e., design weights) within an occupancy model (Gelman 2007).

9.1.5 Estimating Indices of Abundance

9.1.5

Methods have not yet been developed for estimation of absolute abundance or density of bats from acoustic data, but the number of calls per species along the mobile transects can be used as an index of abundance. For some analyses (e.g., relating indices of abundance to grid-level covariates), only data collected within the grid cell can be used, but other analyses may use data from the complete route as the analysis unit, even if part of the route extends outside the grid cell.

Single surveys of routes can be analyzed using log-linear models in a similar fashion as the North American Breeding Bird Survey (BBS) (Sauer and Link 2011). Log-linear models can control for factors that influence detection of bats in the context of the analysis. For the BBS, analyses control for observer differences and experience; in acoustical surveys, similar covariates could be employed to accommodate changes in hardware and software that may be developed over time and among sites that improve our ability to record and distinguish bat calls. Road length and time spent driving can also be used as an offset or covariate in the analysis to adjust for variable coverage. Additional covariates that may influence detection may be identified during initial analyses.

Replication of routes within seasons, as recommended by NABat protocols, provides additional information that can potentially be used in N-mixture models (Royle 2004) (see sec. 9.2.2) to estimate an index of abundance that incorporates covariates of detectability. The model proposed by Kéry and others (2005) can be applied to time series data to estimate population change.

As in occupancy analyses, abundance estimates are conditioned on confirmed identifications (Kéry and Schmidt 2008; MacKenzie and others 2003, 2009; Royle and Link 2006). If a significant number of calls are incompletely identified (e.g., *Myotis* sp.), analysis can be conducted by modeling the species group rather than individual species. New approaches would need to accommodate misclassification as well as incorporate both incompletely identified and fully identified records into a single model.

Number of calls detected per night at stationary points provides a measure of activity at individual locations. Inferences from these data about abundance would require strong assumptions about the relationship between the number of calls per night at a site and the number of individuals. Auxiliary data on behavioral and calling patterns of individual bats would be required to test those assumptions.

9.2 Colony Counts

9.2

Counts of bats collected at or in colonies present a number of challenges (Kunz and others 2009). If a site can be entered, visual censuses can be conducted; this is especially true for species forming small, easily observed clusters of roosting individuals (see ch. 7). With increasing species abundance, irregularities in roost structure and substrate, and variability in cluster density and dispersion, other methods for counting bats are necessary. As a result, most surveys of bats do not result in the count of the entire roost population (Kunz and others 2009). Thus, model-based estimation is necessary for converting raw counts to estimates of population abundance.

9.2.1

9.2.1 Raw Data

Colony counts, whether internal or external, represent the number of bats observed at a roost. Implicit in many of these counts is the assumption that bats are counted without bias and all individuals in a roost are available to be counted. In the presence of violations of these two assumptions, counts are necessarily less than the total number of individuals. However, it is also assumed that an individual bat is only counted once; double counting could inflate the total number of individuals. Methods proposed for counting individuals at roosts (see ch. 7) seek to minimize bias and accommodate differential availability, but users of these data should remain aware of these issues.

9.2.2

9.2.2 Modeling Count Data

As with acoustic mobile transect surveys, surveys of roosts can be analyzed using log-linear models (Thogmartin and others 2012); these approaches currently do not explicitly differentiate a detection process from an abundance process. Approaches for doing so exist, however. State-space approaches, for instance, parse the count process into an observational model and an environmentally determined process model (Buckland and others 2004, de Valpine and Hastings 2002, Hinrichsen and Holmes 2009). For multiple-measure data (i.e., multiple observers or multiple visits within an index period), an explicit-process hierarchical model of the following form could be considered:

$$N_i \sim Pois(\lambda_i)$$

where

N_i = the true abundance at location i
λ_i = the expected value for abundance

The expected value can be modeled using a log-linear model as follows:

$$log(\lambda_i) = \beta_0 + \sum_{k=1}^{m} \beta_k x_{ki}$$

where

β_0 = the abundance intercept
$\beta_{1:m}$ = the coefficients for abundance covariates $x_{1:m}$ (e.g., presence of WNS, proximity to or density of wind energy generation)

The count of bats at location i and visit j, Y_{ij}, (or if double-observer the j subscript distinguishes the observer observations) can be modeled using the binomial distribution with:

$$Y_{ij} \sim Bin(N_i, p_i)$$

where

p_i = the per-bat detection probability

The detection probability can then be modeled using a logistic model as follows:

$$logit(p_i) = \alpha_0 + \sum_{k=1}^{m} \alpha_k z_{ki}$$

where

α_0 = the detection intercept
$\alpha_{1:m}$ = the coefficients of detection covariates $z_{1:m}$ (see table 8.1)

This is the N-mixture model of Royle (2004), which assumes each individual is counted only once. For example, for exit counts, we assume that an individual bat makes only one exit flight that may or may not be detected by an observer (no multiple passes). The N-mixture model may be extended to accommodate estimating spatial and temporal dynamics such as changes in population size (Royle and Dorazio 2008) and conditions in which individuals are double counted (Ingersoll 2010).

For data such as exit counts, where bats flying into the roost can be distinguished and counted separately from bats flying out of the roost, the maximum number of bats that leave the roost may be estimated for an observation period. This sum is called the *maximum emergence*. Maximum emergence can be used to correct the count for multiple passes into roosts. Assuming the data fit an appropriate distribution, the N-mixture model can potentially be used to estimate actual colony size (Ingersoll 2010).

N-mixture models may be difficult to fit to bat roost data due to the need to appropriately define underlying distributions and a lack of independence of observations. Johnson and others (2014) suggest some approaches for evaluating lack of independence among individuals; these approaches can be explored for bat data.

9.2.3 Dynamic Count Models 9.2.3

Statistical models for estimating changes in abundance over time have been proposed (e.g., Dail and Madsen 2011, Kéry and others 2009, Royle and Dorazio 2008). For example, the models proposed by Kéry and others (2009) could be used as an extension to N-mixture models for the case of multiple years of data at the same sites including within-year replication for estimating detection.

In the case of count data recorded at the same sites over many years that lack within-year replication (most legacy or historic data using single-observer and single-visit data), the approach in Royle and Dorazio (2008) may be used. For these data, the following implicit-process hierarchical model is possible, which can only be used for relative abundance estimates (Royle and Dorazio 2008):

$$E(y_{it}) = e^{\Sigma_{j=1}^{n} f_j(x(t)_{it}) + \Sigma_{k=1}^{n} \beta_k(x_{it}) + B_i}$$

where

$E(y_{it})$ = the expected value for the count of bats at location i and year t
$f_j(x(t)_{it})$ = nonlinear functions of year such as cubic regression splines
$\beta_k(x_{it})$ = linear functions of covariates
B_i = a set of random effects for sites to accommodate the yearly observations (similar to a classic repeated measures design with random subject effects)

$E(y_{it})$ can be scaled to an index of relative abundance by dividing by its maximum, giving the fraction of the largest estimated abundance:

$$\frac{E(y_{it})}{\max\left[E(y_{it})\right]}$$

The nonlinear functions allow inference regarding the shape of the population trajectory, particularly local extrema such as maxima or minima. Terms can be eliminated using information-theoretic criteria (e.g., Deviance Information Criterion, Akaike's Information Criterion). If no nonlinear terms are retained by model selection, then no extrema may be inferred; if linear terms are reduced to intercept only, no annual trend may be inferred (Ingersoll and others 2013). These models can be fit using Bayesian methods with WinBUGS, R, or similar software.

Portrait of a hoary bat.

The Dail and Madsen (2011) model may also be appropriate for survey data without multiple visits within a year. This approach models changes in total abundance over time as follows:

$$N_1 = R\,\lambda$$
$$N_t = \omega N_{t-1} + R\,\gamma$$

where

N_t = the time-specific abundance, dependent on the abundance at the previous time step N_{t-1}
ω = the survival probability
γ = the recruitment rate
R = the number of sample units
λ = the expected value for the initial abundance

This model is an N-mixture model generalized for open populations (Dail and Madsen 2011) and is implemented in the R library *unmarked* as the function pcountOpen. As with the N-mixture model of Royle (2004), this model can account for heterogeneous detection probabilities. The generalized model can accommodate covariate-dependent heterogeneity in N, ω, and γ as well, though some inferences are strongly dependent on assumptions about the underlying distributions in this approach.

One advantage of these dynamic models is that known stressors, such as proximity to wind turbines, climate values, or presence of WNS, can be included as covariates for the dynamic or yearly varying effects. Likewise, measurable results of management policies, such as installation of gates on caves and mines, can be included. In this way, effects of stressors and management practices on local extinction, colonization, survival, and recruitment may be estimated.

9.3

9.3 Determining Sampling Sufficiency for Occupancy and Hibernacula Counts

9.3.1

9.3.1 Occupancy Estimation

The initial implementation of NABat will include an investigation into survey design elements for acoustic methods. Specifically, we will address the following questions:

(1) What are sufficient sample sizes (i.e., number of grid cells) for distribution modeling and yearly trend detection?

(2) How many within-season replicates are needed to adequately estimate detection?

(3) Is the planned revisit design (always revisit every site every year) reasonable or will it need to be adjusted periodically, resulting in the need for a panel design?

These questions form the central issues for review of the program in the initial 2 to 3 years of implementation.

McKann and others (2013) analyzed the survey effort necessary to reduce bias in estimates derived from multiseason occupancy models. For instance, their work indicates that bias in occupancy probability is most dependent upon p, the probability of detection. Their work also indicates that for larger values of p, the number of sites necessary for unbiased parameter estimation is lower. When $p = 0.5$, for instance, the probability of detecting the species of interest at least once during multiple visits to a site (p_{site}) is 0.97 after 5 visits. However, if $p = 0.1$, p_{site} drops to 0.41; to compensate for the lower probability of detection, the sample design must increase the number of visits from 5 to 40. McKann and others (2013) conclude that if p is low, bias in occupancy will be acceptable when p_{site} is ~0.9 and the number of sites exceeds 60; to estimate the probability of colonization and extinction with acceptable bias would require >120 sites sampled. These results emphasize the need for a sampling design that ensures adequate detection of species. Fortunately, detection probability can be increased through appropriate study design. McKann and others (2013: 178) wrote:

> If efforts can be made to improve detection by, for example, surveying for a greater period of time (e.g., 10 min instead of 5 min per visit), surveying during ideal weather, choosing an optimal time of day (Williams and Berkson 2004), or using experienced observers (Jeffress and others 2011), relative bias of parameter estimators will decrease.

Erecting a gate at the entrance of Hubbards Cave, TN, to protect bats from disturbance and vandalism.

Chapters 4 and 5 provide many suggestions on detector deployment that will increase species detection and identification for acoustic sampling.

9.3.2 Hibernacula Counts 9.3.2

Other than a few endangered species [e.g., Indiana (*Myotis sodalis*) and gray (*M. grisescens*) myotis], few roosting species are regularly assessed for population status and trends. As such, as more data are contributed to the BPD on a regular basis, it will be necessary to determine when enough data have been collected for reliable species-wide inferences.

Leveraging power law relations is one means of determining whether wintering populations of hibernating species have been sufficiently surveyed. We expect that all hibernating species exhibit a power law relation between the frequency and size of colonies for the purposes of thermoregulatory control (Thogmartin and McKann 2014). Typically, the majority of hibernating bat populations are small, with larger populations being relatively rare. Thus, the frequency N and size n of bat populations can be characterized by a power law relation. Power laws are often described by a cumulative distribution function for N as:

$$f(n) = bn^{-\alpha}$$

where

$f(n)$ = in this case, the frequency of hibernacula with n individual bats
b = an unknown constant indicating the intensity of the pattern
α = the rate at which larger populations are progressively less abundant

When logarithms are taken of both sides of the equation, log(n) can be plotted against log$[f(n)]$, resulting in a straight line with slope α (fig. 9.1).

Power laws to understand the organization of Indiana myotis populations were developed by Thogmartin and McKann (2014). Indiana myotis are currently the best surveyed of the eastern North American hibernating species, with populations in hibernacula ranging between <400 and ~40,000 bats (more than two orders magnitude difference in group size). These populations demonstrate a linear relationship between log frequency and log size (fig. 9.1). From this distribution of annual population sizes, we see a noticeable dip in the frequency of small populations numbering between 2 and 32 bats. It is not clear if this is a function of the biology of the species (e.g., thermoregulatory benefits of larger groups) or a gap in the survey design (i.e., smaller

Figure 9.1—The relationship between the log frequency of group size and its log size for Indiana myotis (*Myotis sodalis*) in 1996. The slope (alpha) of the relationship varies from year to year, but is roughly equal to ¾-power when back transformed. This ¾-power has important thermoregulatory implications. Numbers in red are the difference between the predicted and observed number of populations. (from Thogmartin and McKann 2014)

hibernacula go unnoticed and are therefore not surveyed). In this example, if the dip is attributed to a gap in survey design, it would amount to no more than ~2 percent of the total Indiana myotis population being missed by current survey efforts. Whether such a small proportion of bats missed from the sampling design warrants increased effort needs to be determined. For instance, as WNS passes through populations of this and other eastern hibernating species, there is some expectation that bats will demonstrate reduced sociality during hibernation (Langwig and others 2012). Thus, there may be a need for added effort towards surveying the smaller populations that are currently poorly sampled. Decisions of this sort will need to be addressed periodically and subsequent sampling adjusted accordingly (see sec. 1.5).

If a power law relation for a species of interest cannot be calculated, it may mean that the sample is inadequate to draw robust inferences regarding the species. Unfortunately, knowing there are gaps in a survey does not indicate how to alleviate those gaps. Formalized exploratory processes would be necessary to amend the current set of surveyed populations.

9.4

9.4 Incorporation of Legacy and Found Data

NABat will endeavor to include acoustic and count data with appropriate sampling methods that were collected outside of the NABat sampling framework (see ch. 3). This assumes that field methods compliant with NABat protocols have been used. Approaches exist for weighting legacy and found data to incorporate them into the master sample structure. For example, existing mobile transects could be clipped to the grid to determine sample unit membership and adjust sample weights accordingly. However, these weights would then need to be incorporated into the model-based analysis, particularly if there are highly variable weights across sample units and these weights are related to the latent occupancy state of the associated grid cell. Similarly, historical roost counts will be compiled and incorporated where possible into the estimation of species status and trends.

10. Implementation

10.1 Program Structure 10.1

As conceived, NABat is a multinational program requiring broad multiagency support. The central coordination and staffing of NABat will be based in the United States, with Canadian and Mexican coordinators working with the United States coordinator (fig. 10.1). The coordinators will not be responsible for data collection, but instead will encourage participation in NABat by States, Provinces, and other agencies; supply the States, Provinces, and other agencies with the list of grid cells to be sampled; maintain a record of all monitoring programs being conducted as part of NABat; encourage and facilitate submission of data to the Bat Population Database (BPD) through interactions with participants in NABat; provide guidance to States, Provinces, and other agencies on organizing monitoring at various spatial scales; provide guidance to adapt ongoing monitoring efforts to conform to NABat protocols and procedures; and provide feedback to the U.S. coordinator on the monitoring program.

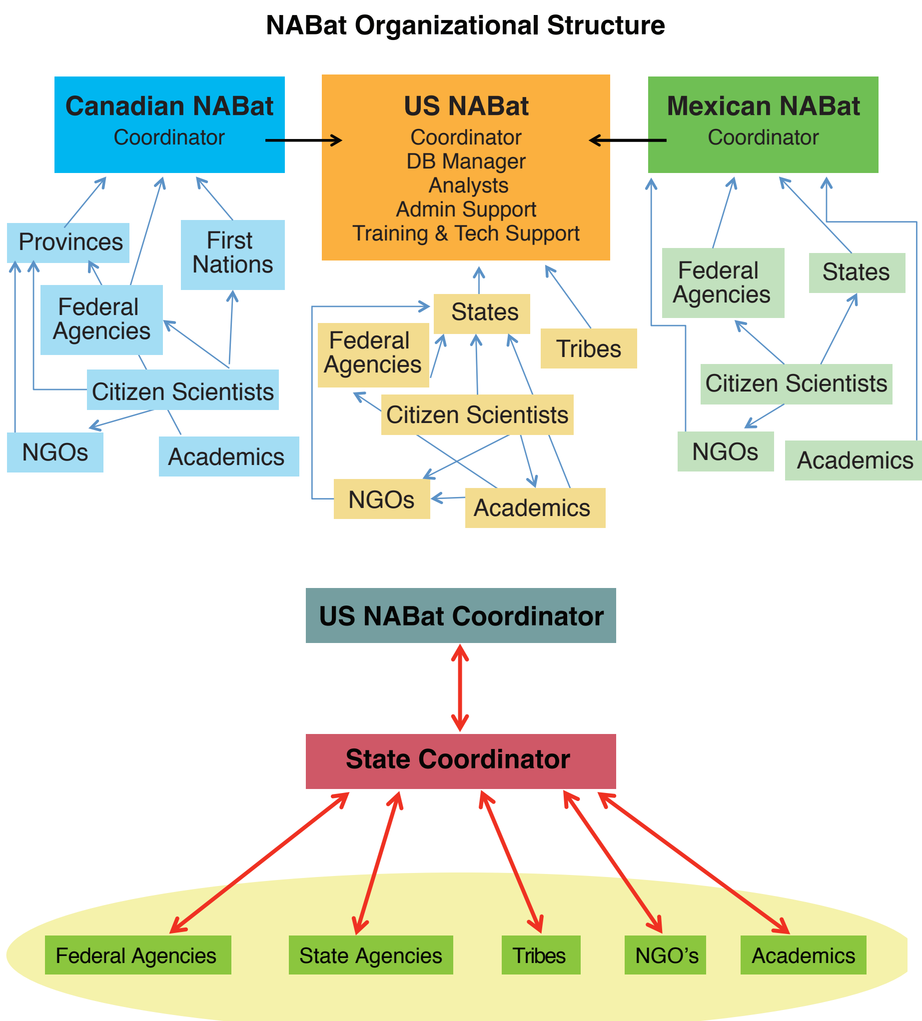
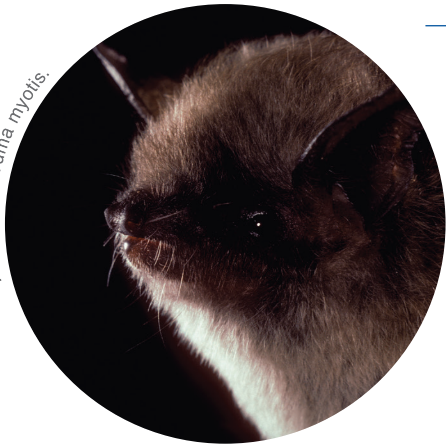


Figure 10.1—Proposed organizational structure of NABat.

10.2



Portrait of a *Yuma myotis*.

10.2 NABat Staffing and Responsibilities

To ensure the success of NABat, several permanent full- and part-time personnel are proposed. These include the U.S. coordinator, an administrative assistant, a Geographic Information System (GIS) specialist, two statistical analysts, a database manager, and a technical and outreach coordinator. The general roles and responsibilities of each are described below.

- The U.S. coordinator will be responsible for coordinating NABat across national boundaries as well as across State, Federal, tribal, and private boundaries. The U.S. coordinator will also be responsible for determining the types of training needed by participants and for working with the technical and outreach coordinator to either develop that training or find professionals with the required expertise to provide the necessary training. The United States coordinator will also be responsible for publicizing NABat and encouraging participation in the program by working with State and Federal agencies, tribes, nongovernmental organizations (NGOs), and the regional bat working groups and assisting the Canadian and Mexican coordinators to encourage participation in their respective countries. Interim United States and Canadian coordinators were appointed in 2014.

- The database manager will manage the BPD, assist users with data entry and retrieval, work with programmers to upgrade the BPD as necessary, work with the statistical analyst(s) and GIS specialist to produce reports and other products, and create and manage data partnerships.

- The administrative assistant will provide administrative support to the entire staff, including maintaining and reconciling budgetary records, arranging travel, maintaining a functional office, and maintaining the NABat Web site.

- The GIS specialist will be responsible for providing and updating all GIS layers necessary to create the master sample of grid cells and will provide the GIS support needed for statistical analysis at various spatial scales. The GIS specialist will also create maps for reports and the Web site.

- The statistical analyst(s) will be responsible for analyzing data at various spatial and temporal scales and working with the database manager, GIS specialist, and coordinator to produce reports and other products. Ideally, there will be two analysts, one to work with the colony count data and one to work with the acoustic data.

- The technical and outreach coordinator will provide training on the implementation of NABat, including assisting with the master sample of grid cells, providing technical guidance and advice on equipment and its use, and conducting training via webinars and presentations at meetings. The technical and outreach coordinator will also develop training materials specifically designed for distribution to citizen scientist participants.

10.3

10.3 Roles and Responsibilities of Participating Organizations

Because the master sample of grid cells will be organized by the States and Provinces (see ch. 1), it is likely that much of the coordination at the regional level will be done by State and Provincial biologists. Thus, the States and Provinces will be responsible for working with Federal agencies, tribes and First Nations, NGOs, and private landowners to conduct monitoring. Individuals and agencies that participate in NABat will be responsible for obtaining the necessary equipment to conduct the monitoring and maintaining the equipment such that it meets performance and data quality standards. We anticipate that equipment will be shared among State and Federal agencies and other organizations, so there is no expectation that all participants will be required to purchase equipment and software. However, participants will be responsible for conducting species identification of acoustic files (see ch. 6 for methods that can be used to identify bat acoustic files). Due to the large-scale nature of NABat and limited resources within agencies, the success of NABat will likely depend on the use of citizen scientist volunteers. Thus, State and Provincial coordinators will also be responsible for recruiting and training citizen scientists with the assistance of the technical and outreach coordinator, providing equipment, ensuring data quality, and overseeing data submission to the BPD. NABat will provide standardized datasheets, and we strongly encourage their use. Use of these standardized forms will ensure that data standards will be met.

Timely and accurate submission of data to the BPD is critical for the success of NABat, as these data will be the basis of the status and trend analyses. Thus, State and Provincial coordinators will be responsible for ensuring that data collected by all participants is submitted to BPD within a timely fashion.

10.4 Potential Role for Nongovernmental Organizations 10.4

Nongovernmental organizations such as Bat Conservation International, Organization for Bat Conservation, National Speological Society, and Nuisance Wildlife Control Operators Association can play an important role in the success of NABat. For example, NABat can partner with these organizations to convene workshops and assist in providing training on methods used in NABat. These organizations may also be a great asset in helping to recruit volunteers from their memberships to participate in surveys. Many members of the National Speleological Society already assist with hibernaculum surveys and provide valuable information on bat populations within caves and mines.

10.5 Timeline 10.5

United States and Canadian coordinators were named in 2014 and are performing many of their duties. Until NABat can be fully staffed, members of the NABat Planning Core Team will continue to act in an advisory role. However, timely creation of the administrative assistant, GIS specialist, analyst, database manager, and technical and outreach coordinator positions will allow NABat to more readily provide necessary support to participating organizations.

Several pilot projects are being initiated in the United States and Canada in 2014 and 2015, and we expect full on-the-ground implementation of NABat by 2016. Acoustic surveys began during summer 2014, and hibernaculum surveys based on NABat protocols began in winter 2014–15. Initial data were submitted to the BPD during fall 2014. The first status reports of North American bats will be produced in 2016 if sufficient staffing is available.

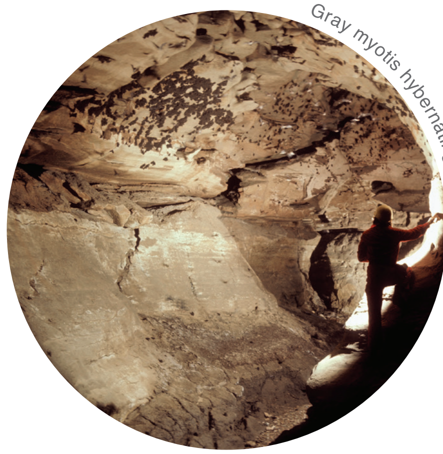
10.6 Available and Needed Resources 10.6

NABat will initially be housed at the USGS Fort Collins Science Center (FORT). This is the location of the current U.S. coordinator and the BPD. Other U.S. government agencies have their monitoring headquarters stationed in Fort Collins (U.S. Fish and Wildlife Service Refuge System Inventory and Monitoring Program and Environmental Conservation Online System, National Park Service Inventory and

Monitoring Program). The close proximity of other agency monitoring programs may encourage collaboration and participation in NABat by these agencies.

The BPD is currently online (https://my.usgs.gov/bpd/) and available for data submission. Thus, the infrastructure for this database is in place, and FORT personnel are available to maintain and upgrade the system. USGS FORT has committed to support these efforts and has agreed to staff the U.S. coordinator position as a derivative of the BPD for the foreseeable future. It will be desirable to archive all acoustic data collected as part of NABat. However, storage of vast quantities of acoustic data (particularly full-spectrum files) will require acquisition of large amounts of disk space (many terabytes) or funding for secure data cloud space.

NABat will not provide acoustic detectors, cameras, or other monitoring equipment and software. The majority of all such materials will be provided by participating agencies and organizations. We recognize that while some organizations may have adequate capacity, many will not. NABat staff will help to coordinate equipment sharing and, when possible, will help to identify funding opportunities to provide States, Provinces, tribes, First Nations, and NGOs with equipment needed to conduct surveys.



Gray myotis hybernating in a cave.

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Appendixes

Appendix A

Number of full and partial 10- by 10-km grid cells contained in each U.S. State

State	Number of full cells	Number of partial cells
Alabama	1233	206
Alaska	13318	3550
Arizona	2824	273
Arkansas	1271	207
California	3839	526
Colorado	2583	228
Connecticut	97	64
Delaware	28	52
District of Columbia	0	8
Florida	1201	535
Georgia	1401	236
Idaho	2002	329
Illinois	1342	231
Indiana	846	180
Iowa	1367	193
Kansas	2044	206
Kentucky	930	237
Louisiana	1050	366
Maine	721	256
Maryland	114	260
Massachusetts	146	146
Michigan	1276	501
Minnesota	2046	298
Mississippi	1125	234
Missouri	1673	251
Montana	3637	343
Nebraska	1888	225
Nevada	2712	291
New Hampshire	189	100
New Jersey	146	107
New Mexico	3021	263
New York	1109	316
North Carolina	1085	382
North Dakota	1735	192
Ohio	978	193
Oklahoma	1681	264
Oregon	2362	297
Pennsylvania	1085	180
Rhode Island	11	39
South Carolina	699	194
South Dakota	1882	218
Tennessee	984	218
Texas	6563	655
Utah	2086	225
Vermont	203	100
Virginia	854	358
Washington	1566	342
West Virginia	525	208
Wisconsin	1336	262
Wyoming	2421	224

Appendix B

Number of full and partial 10- by 10-km grid cells contained in each Canadian Province

Province	Number of full cells	Number of partial cells
Alberta	6422	437
British Columbia	8703	1444
Manitoba	6287	450
New Brunswick	632	194
Newfoundland & Labrador	3379	1463
Northwest Territories	12670	1748
Nova Scotia	431	281
Nunavut	17108	7081
Ontario	9449	1033
Prince Edward Island	28	67
Quebec	14271	1848
Saskatchewan	6324	397
Yukon Territory	4574	537

Appendix C

Sample datasheet for stationary point surveys

Stationary Point Acoustic Monitoring Datasheet

Methods	
	Number of detectors deployed:
	Photos submitted? ☐ Y ☐ N
	Mobile Transect Conducted? ☐ Y ☐ N

Surveyor:	Grid cell ID:
Country:	State/Province:
County (if applicable):	Map datum:
Sunset:	Sunrise:
Start date moon phase:	End date moon phase:

Variable	Detector #1	Detector #2	Detector #3	Detector #4
Location – Latitude				
Location – Longitude				
Date recording started				
Date recording stopped[1]				
Time recording started				
Time recording stopped				
Bat detector manufacturer and model				
Microphone type				
Recording mode				
Trigger window length				
Maximum file length				
Microphone height (m)				
Weatherproofing type				
Calibration method				
Habitat Type[2]				
Feature Sampled[3]				
General Description of deployment[4]				
Gains				
Frequency Band Filters				
High/Low Nightly Temp (°C)[5]				
Night 1				
Night 2				
Night 3				
Night 4				
High/Low Nightly RH (%)[5]				
Night 1				
Night 2				
Night 3				
Night 4				
High/Low Wind (km/h)[5]				
Night 1				
Night 2				
Night 3				
Night 4				
Significant weather events[6]				
Night 1				
Night 2				
Night 3				
Night 4				

[1] Note: recording may stop early due to equipment failure. Please indicate the day/time a detector stopped if this occurred.
[2] Land classes: Urban, agriculture, rangeland, forest, water, wetland, barren
[3] Examples: Cattle water tank, pond, stream, forest road, forest trail, mature forest, wildlife opening.
[4] Examples: Distance to forest edge, distance to hedgerow, parallel or perpendicular to flyway
[5] May be obtained from local weather recording station or on-site recorders.
[6] Examples: Strong thunderstorm on a particular night, sudden cold-snap, windstorm

Appendix D

Sample datasheet for mobile transect surveys

Mobile Transect Acoustic Monitoring Datasheet

Date: Start time: End time:

Location	Surveyor:	Grid cell ID:
	Country:	State/Province:
	County (if applicable):	Map datum:
	Start latitude:	End latitude:
	Start longitude:	End longitude:
Conditions	Sunset:	Cloud cover:
	Moon phase:	Time moon became visible:
	Start temp. (°C):	End temp. (°C):
	Start RH (%):	End RH (%):
	Start wind speed (km/h):	End wind speed (km/h):
Methods	Detector Manufacturer and Model:	
	Microphone type:	
	Microphone placement:	
	Recording mode:	
	Trigger window length:	
	File length:	
	Digipot sensitivity from Anabat™ Equalizer:	
	Gain settings (if applicable):	
Coments	Habitats crossed by transect or general habitat description:	
	Additional comments about transect or conditions:	

Appendix E

Species that can be identified by each of the automatic species-identification software programs (as of March 25, 2015)

Species	BCID	Echoclass	Kaleidoscope®	Sonobat™
Antrozous pallidus	—	—	X	X
Artibeus jamaicensis	—	—	—	—
Choeronycteris mexicana	—	—	—	—
Corynorhinus rafinesquii	X	—	—	X
Corynorhinus townsendii	X	—	X	X
Eptesicus fuscus	X	X	X	X
Euderma maculatum	—	—	X	X
Eumops floridanus	X	—	X	X
Eumops perotis	—	—	X	X
Eumops underwoodii	—	—	—	—
Idionycteris phyllotis	—	—	—	—
Lasionycteris noctivagans	X	X	X	X
Lasiurus blossevillii	—	—	X	X
Lasiurus borealis	X	X	X	X
Lasiurus cinereus	X	X	X	X
Lasiurus ega	—	—	—	—
Lasiurus intermedius	—	—	—	X
Lasiurus seminolus	—	—	—	X[1]
Lasiurus xanthinus	—	—	—	—
Leptonycteris nivalis	—	—	—	—
Leptonycteris yerbabuenae	—	—	—	—
Macrotus californicus	—	—	—	—
Molossus molossus	—	—	—	—
Mormoops megalphylla	—	—	—	—
Myotis auriculus	—	—	—	—
Myotis austroriparius	X	X	—	—
Myotis californicus	—	—	X	X
Myotis ciliolabrum	—	—	X	X
Myotis evotis	—	—	X	X
Myotis grisescens	X	X	X	X
Myotis keenii	—	—	—	—
Myotis leibii	X	X	X	X
Myotis lucifugus	X	X	X	X
Myotis melanorhinus	—	—	—	X[2]
Myotis occultus	—	—	—	—
Myotis septentrionalis	X	X	X	X
Myotis sodalis	X	X	X	X
Myotis thysanodes	—	—	X	X
Myotis velifer	—	—	—	—
Myotis volans	—	—	X	X
Myotis yumanensis	—	—	X	X
Nycticeius humeralis	X	X	X	X
Nyctinomops femorosaccus	—	—	—	—
Nyctinomops macrotis	—	—	—	—
Parastrellus hesperus	X	—	X	X
Perimyotis subflavus	X	X	X	X
Tadarida brasiliensis	—	—	X	X

X = Can be identified, — = Cannot be identified.

BCID = Bat Call Identification.

[1] SonoBat classifiers that overlap the range for *Lasiurus seminolus* include recordings from these species. However, *L. seminolus* and *L. borealis* produce acoustically indistinguishable calls. Where these species both occur, a file labeled as LASE or LABO should be considered as either species (Personal communication. 2015. J.M. Szewczak, Professor, Humboldt State University, 1 Harpst Street, Arcata, CA 95521).

[2] *Myotis ciliolabrum* and *M. melanorhinus* produce acoustically indistinguishable calls. SonoBat™ documentation advises users, “Consider a classification result for ‘MYCI’ as a classification for MYCI within its defined range and as MYME within its defined range. Where these species both occur, irrefutable species confirmation requires capture, and possibly molecular genetics to disambiguate.” (Personal communication. 2015. J.M. Szewczak, Professor, Humboldt State University, 1 Harpst Street, Arcata, CA 95521).

Appendix F

Sample datasheet for internal winter hibernaculum surveys

Internal Winter Surveys Datasheet

Location	Site name:		Site owner:	
	Land unit:	Grid cell ID:	Portion of site surveyed	
	Site type:[1]			
	Country:	State/Province:	County (if applicable):	
	Latitude:	Longitude:	Map datum:	Elevation:
	Habitat type:			
Roost info	Roost size (dimensions):		Number of other roosts within 10 km:	
	Roost temp. (°C):	Roost RH (%):	Presence of water? ☐ Y ☐ N	
	Outside temp. start (°C):		Outside temp. end (°C):	
	Roost protection:[2]		Signs of disturbance:	
	Special roost survey requirements:			

Date:

Surveyors	**Name**	**Years of experience**
Methods	Survey method(s):	
	Photos submitted? ☐ Y ☐ N	
	Type of photographic equipment:	
	Digital storage location:	
Conditions	Start time:	End time:
	Cloud cover start:	Cloud cover end:
	Moonrise/moonset:	Sunrise/sunset:
	Moon phase:	

BAT SPECIES PRESENT

Species	**Section** (name or describe location of bats within site)	**Estimated number of live/dead bats**	**Upper/ lower range estimates**	**Number of clusters**	**Estimated size of clusters** (number of bats or measured size)	**Colony Type**	**Height of bats in structure**	**Distance between observers and bats**	**Number captured**	**Number banded/ PIT-tagged**	**Number collected**
TOTAL											

Other cave life (identify species and nature of observation and sign):	
Species present but not counted:	
Comments:	
WNS status:	WNS comments:
WNS samples collected: (type/destination/results):	

[1] For example, building, bridge, tree cavity, talus slope, etc.; if tree roost, provide species and status (e.g., live, dead, live-damaged) and bark coverage
[2] For example, gates, locks, fences, etc.

Appendix G

Sample datasheet for internal summer maternity colony surveys

Internal Summer Surveys Datasheet

Location	Site name:		Site owner:	
	Land unit:	Grid cell ID:	Portion of site surveyed	
	Site type:[1]			
	Country:	State/Province:	County (if applicable):	
	Latitude:	Longitude:	Map datum:	Elevation:
	Habitat type:			
Roost info	Roost size (dimensions):		Number of other roosts within 10 km:	
	Roost temp. (°C):	Roost RH (%):	Presence of water? ☐ Y ☐ N	
	Outside temp. start (°C):		Outside temp. end (°C):	
	Roost protection:[2]		Signs of disturbance:	
	Special roost survey requirements:			

Date:

Surveyors	**Name**	**Years of experience**
Methods	Survey method(s):	
	Photos submitted? ☐ Y ☐ N	
	Type of photographic equipment:	
	Digital storage location:	
Conditions	Start time:	End time:
	Cloud cover start:	Cloud cover end:
	Moonrise/moonset:	Sunrise/sunset:
	Moon phase:	

BAT SPECIES PRESENT

Species	**Section** (name or describe location of bats within site)	**Estimated number of adult/ juvenile bats**	**Upper/ lower range estimates**	**Number of clusters**	**Estimated size of clusters** (number of bats or measured size)	**Colony Type**	**Height of bats in structure**	**Distance between observers and bats**	**Number captured**	**Number banded/ PIT-tagged**	**Number collected**
TOTAL											

Other species in roost (identify species and nature of observation and sign):
Species present but not counted:
Comments:

[1] For example, building, bridge, tree cavity, talus slope, etc.; if tree roost, provide species and status (e.g., live, dead, live-damaged) and bark coverage
[2] For example, gates, locks, fences, etc.

Appendix H

Sample datasheet for emergence count data

Emergence Count Datasheet

Date:

Relative abundance of each species:						
Guano: ☐ none ☐ scattered ☐ abundant ☐ large mounds						
Time first bat emerged:			End time:			
	Corynorhinus			**Other**		
TIME	**OUT**	**IN**	**NET**	**OUT**	**IN**	**NET**
2030						
2035						
2040						
2045						
TOTAL						
Other animals seen:						
Comments:						

Surveyors	**Name**	**Years of experience**
Methods	Survey method(s):	
	Photos submitted? ☐ Y ☐ N	
	Type of photographic equipment:	
	Digital storage location:	
Conditions	Start time:	End time:
	Cloud cover start:	Cloud cover end:
	Moonrise/moonset:	Sunrise/sunset:
	Moon phase:	Time moon visible:
	Temp. start (°C):	Temp. end (°C):
	RH start (%):	RH end (%:)
	Precipitation start:	Precipitation end:
	Wind speed start:	Wind speed end:

Location	Site name:		Site owner:	
	Land unit:	Grid cell ID:	Number of entrances monitored/not monitored:	
	Site type:[1]			
	Country:	State/Province:	County (if applicable):	
	Latitude:	Longitude:	Map datum:	Elevation:
	Habitat type:			
Roost info	Roost size (dimensions):		Number of other roosts within 10 km:	
	Roost temp.:	Roost RH (%):	Outside temp. start:	Outside temp. end:
	Presence of water? ☐ Y ☐ N		Number of other roosts within 10 km:	
	Roost protection:[2]		Signs of disturbance:	
	Special roost survey requirements:			
	Species present in roost:			

[1] For example, building, bridge, tree cavity, talus slope, etc.; if tree roost, provide species and status (e.g., live, dead, live-damaged) and bark coverage.

[2] For example, gates, locks, fences, etc.

Appendix I

The NABat Data Management Plan

1. Types of Data Produced and Products

The data gathered during the NABat program will be collected by partners such as States or Provinces, Federal agencies, tribes, academics, nongovernmental organizations, and citizen scientists. The data will be counts of bats at hibernacula and maternity colonies and acoustic data from mobile transects and stationary point surveys. Data collected will be site-specific information such as location, grid cell number, date, times, environmental conditions, variables related to bat detectors and their settings, species identification information, years of experience identifying species or counting bats, and the metadata associated with acoustic surveys (see tables 8.1. 8.2, and 8.3). The Bat Population Data Project and its primary application, the Bat Population Database (BPD), will be the primary repository of these data (http://my.usgs.gov/bpd). A detailed data dictionary will be provided to the data partners and made accessible on the BPD website. Data will be uploaded and entered by data partners, and a dedicated database manager(s) will be responsible for assisting data partners with their data management. The acoustic files collected during mobile transects and stationary point surveys will also be submitted to the NABat database manager(s). The database manager(s) will be responsible for ensuring quality assurance and control (QA/QC) procedures are completed for all data submitted. QA/QC of acoustic species identifications will be conducted on a regular basis by randomly selecting 10 to 20 percent of acoustic identifications and verifying the identifications using a combination of automatic identification software programs and manual qualitative verifications.

2. Data Storage and Preservation

The NABat Program is intended to be a long-term monitoring program. Therefore, the data collected during the program will be archived and preserved for perpetuity using several methods. The U.S. Geological Survey (USGS) is committed to providing an “Integrated Information Environment” for USGS personnel and their external partners to facilitate the production of data that can be shared within the scientific community and the public, and USGS has a commitment to storing data for the long term. An online resource called myUSGS is a suite of content management and collaboration tools for USGS science teams and their partners. The myUSGS platform consists of a growing set of public Web sites that share content within this integrated information environment as well as a wide variety of online Intranet/extranet communities. U.S. Department of the Interior (DOI) users as well as non-DOI users are able to access myUSGS.

Because the BPD uses the myUSGS enterprise hosting services, all data are backed up nightly, and permanent data archives are prepared monthly. The database manager(s) will be responsible for ensuring that the BPD is regularly backed up. Acoustic files collected during mobile transects and stationary point surveys will not be stored within the BPD application, but will be stored on a mini-server at the USGS Fort Collins Science Center (FORT) in the short term. The use of cloud-based services will be investigated in the future to store, archive, and back up the acoustic files. External, secondary data repositories will be used to share specific subsets of NABat data with other data distribution and storage systems, increasing the data backup capability to multiple locations.

3. Data Formats and Metadata

Data will be collected using the count-based and acoustic protocols described in chapters 4, 5, and 7. Standard datasheets will be provided to the NABat participants in Microsoft Excel® spreadsheet format (see appendixes C, D, F, G, and H). FORT plans to develop applications for automatically collecting data using handheld devices such as tablets and smartphones.

When a new data project is created in the BPD, the database manager(s) simultaneously create a complete project-level metadata record using the Federal Geographic Data Committee (FGDC) standards. Data partners will be able to export their FGDC-compliant metadata from the BPD data project interface to an XML file that they can deliver to their agencies' preferred or required metadata repository. Geographic coordinates will be stored and exported in latitude and longitude and will be expressed as decimal fractions of degrees. Metadata for legacy data will also be created and accessible to data partners and participants.

4. Data Dissemination and Policies for Data Sharing and Public Access

Data collected during the NABat Program will always be accessible to NABat team members [coordinators, database manager(s), statisticians, etc.]. These data will not be accessible to the public until the data are summarized and analyzed. Results from analyses will be distributed to managers and policymakers in periodic "The State of North America's Bats" publications. In these reports, the acoustic and colony-count data will be analyzed for trends in occupancy and abundance. After this report is peer-reviewed and released, data sharing with the public will be determined by the original data partnership agreements or data owner.

Glossary

Auto-level—The ability of a bat detector to adjust the basement noise level based on ambient noise. Thus, a bat detector that auto-levels adjusts its sensitivity according to the current noise level.

Availability—Animals are present at the time of the survey and thus available to be counted, if detected.

Bat call/pulse—A sound produced by an echolocating bat.

Bat pass—A sequence of echolocation calls separated from other bat calls by 1 to 2 seconds.

Clutter—Obstacles in the flight environment such as tree branches, leaves, water surface, or other bats.

Colony counts—Counts of bats in roosts including both hibernacula and maternity/bachelor roosts. Counts may be either internal or external.

Data partner—Owners of data that are submitted to the Bat Population Database (BPD). Owners agree to allow NABat to use data submitted to the BPD but have control over how those data are displayed on the BPD Web site and who has access to those data.

Deflector plate—A smooth surface that reflects the signal of a bat into a downward-facing microphone. A deflector plate is one method of weatherproofing and protects the microphone from precipitation. The smooth surface enables a near-perfect reflection of the sound; the deflector plate is typically oriented 45° to the microphone.

Detectability—The probability that animals are observed or recorded during the survey given that they are present.

Design weight—In statistical sampling, the sample design weight is the inverse of the sample inclusion probability. The design weight formally describes the amount of inferential information of each sample unit. For example, when sample sizes are small, weights become larger because each sample unit represents a larger proportion of the sampling frame (i.e., it “carries more weight”).

Found data—Data provided by contributors collected concurrent to NABat but outside of the formal NABat sampling design. Legacy data differs from found data in that it predates the implementation of NABat.

Frequency division—A method of changing ultrasound into audible sound by dividing the frequency of the incoming signal by a set ratio (i.e., the division ratio), thus lowering its frequency.

Full spectrum—A method of recording bat ultrasound that records the full spectral composition of a signal, usually through Fourier analysis. This is displayed as a spectrogram that displays frequency and amplitude of a signal over time. Full-spectrum recordings store large amounts of data because sampling rates need to be twice that of the highest frequency that is to be recorded. Generally, a file generated by a full-spectrum detector will be approximately 1000 times as large as a zero-crossing file of the same bat pass.

Legacy data—Data provided by contributors following sampling designs and protocols developed prior to the development of NABat.

Focal demographic studies—Intensive studies of particular bat colonies to gather detailed demographic data such as survival, reproductive rates, and population growth rates.

Generalized random-tessellation stratified (GRTS) design—A probabilistic sampling design that provides a spatially-balanced ordered list of sample units (10-km by 10-km grid cells) with the unique property that any ordered subset of the list will also be spatially-balanced.

Inclusion probability—In statistical sampling, the inclusion probability defines the likelihood of selecting a specific sample unit (e.g., a 10-km by 10-km grid cell) from a random sampling draw. Inclusion probabilities are very small (~0) when the total sample size is very small relative to the size of the sampling frame. Inclusion probabilities are 1 (100 percent certainty of being included) when a nonprobability sampling scheme (e.g., purposive sampling) is used because only those units chosen for survey are included for consideration. Inclusion probabilities or their inverse, design weights, are used in analyses to properly scale the relative importance or contributions of data from each sample unit.

Maximum emergence—The maximum number of bats that leave a roost during an observation period.

Master sample—The comprehensive list of all sample units within the sampling frame that is randomized and spatially-balanced following a GRTS draw. A single master sample will be produced for each sampling frame (United States, Canada, and Mexico), allowing all contributing partners (e.g., nations, States, and Provinces) to sample from their portion of the master sample list.

Mobile acoustic transect survey—An acoustic survey conducted with a bat detector or microphone mounted on the roof of a car that is driven at 32 km/h along a predetermined route for 25 to 48 km. Routes are driven twice per summer (preferably within one week) and revisited yearly.

Microphone sensitivity—The volume of sound that a microphone can record for a given signal; i.e., the amplitude (loudness) of the sound that the microphone can pick up.

Multiple observer methods—The use of two or more observers, observer occasions, or techniques to estimate the number of bats in a colony.

Noise floor—The sum of all the noise sources and unwanted signals (i.e., anything other than a bat call).

Nonprobability sample—A statistical method of sampling from a definable domain that does not use randomization and does not allow for sample units (e.g., 10-km by 10-km grid cells) to be assigned inclusion probabilities. Nonprobability samples are at much greater risk than probability samples of providing data that are not representative of the target population.

Probability sample—A statistical method of sampling from a defined domain, typically described by a sampling frame, that uses a randomization process to select sample units for survey with each unit having a known selection probability. Simple random sampling is a common equal-probability sampling strategy. The GRTS algorithm provides for a more complex, but flexible, way to draw equal- or unequal-probability samples from a frame of sample units.

Pulse shape—The pattern of frequency change over time of a bat call, as visualized in a frequency-versus-time sonogram. For example, bat calls described as "steep" sweep through a broad range of frequencies in a short time.

Sampling frame—A sampling frame is a statistical tool for defining the population from which a survey sample is drawn. Sampling frames are typically finite (e.g., a list of lakes for water quality study), but can also be infinite (e.g., the infinite number of points within a polygon of interest on a map). The grid-based sampling frame of NABat is finite, allowing for the entire set of all 10- by 10-km grid cell sample units to be organized into a spatially balanced list and assigned inclusion probabilities.

Sample unit—The individual members of a statistically defined population that is being sampled. For NABat, sample units are the 10 km x 10 km grid cells from the grid-based sampling frame.

Stationary point surveys—Acoustic surveys conducted at a spot on the landscape for four nights during a season and revisited every year.

Trigger window—The length of time a bat detector will continue to record after being triggered by a bat call if no additional calls are detected. Also referred to as "Idle Setting" or "Max TBC" in some bat detector systems.

Zero-cross—A method of recording bat ultrasound that provides information about the frequency and timing of bat pulses but does not retain amplitude data of the original waveform. The zero-cross system counts the number of times an incoming signal crosses the "zero line" and measures the time associated with each complete cycle to determine frequencies. Bat recordings stored digitally through this method require approximately $1/1000^{th}$ of the digital memory that a full-spectrum recording of the same sound requires.

Author Information

Susan C. Loeb
Research Ecologist
U.S. Department of Agriculture
Forest Service
Southern Research Station
237 Lehotsky Hall, Clemson University
Clemson, SC 29634

Thomas J. Rodhouse
Ecologist
National Park Service
Upper Columbia Basin Network
63095 Deschutes Market Road
Bend, OR 97701

Laura E. Ellison
Ecologist
U.S. Geological Survey
Fort Collins Science Center
2150 Centre Ave., Bldg. C
Fort Collins, CO 80526

Cori L. Lausen
Research Biologist, Bat Specialist
Wildlife Conservation Society Canada
Kaslo, BC V0G 1M0

Jonathan D. Reichard
Wildlife Biologist
U.S. Fish and Wildlife Service
300 Westgate Center Drive
Hadley, MA 01035

Kathryn M. Irvine
Statistician
U.S. Geological Survey
Northern Rocky Mountain Science Center
2327 University Way, Suite 2
Bozeman, MT 59715

Thomas E. Ingersoll
Computational Biologist
National Institute for Mathematical
and Biological Synthesis
Belcamp, MD 21017

Jeremy T. H. Coleman
Wildlife Biologist
U.S. Fish and Wildlife Service
300 Westgate Center Drive
Hadley, MA 01035

Wayne E. Thogmartin
Quantitative Ecologist
U.S. Geological Survey
Upper Midwest Environmental
Sciences Center
2630 Fanta Reed Road
La Crosse, WI 54603

John R. Sauer
Research Wildlife Biologist
U.S. Geological Survey
Patuxent Wildlife Research Center
12100 Beech Forest Road
Laurel, MD 20708

Charles M. Francis
Manager, Bird Population Monitoring
Canadian Wildlife Service
Environment Canada
1125 Colonel By
Ottawa, ON K1A 0H3

Mylea L. Bayless
Senior Director
United States/Canada Conservation
Bat Conservation International
P.O. Box 162603
Austin, TX 78716

Thomas R. Stanley
Research Wildlife Biologist
U.S. Geological Survey
Fort Collins Science Center
2150 Centre Ave., Bldg. C
Fort Collins, CO 80526

Douglas H. Johnson
Research Statistician and Senior Scientist
U.S. Geological Survey
Northern Prairie Wildlife Research Center
2003 Upper Buford Circle, Suite 135
University of Minnesota
St. Paul, MN 55108

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The purpose of the North American Bat Monitoring Program (NABat) is to create a continent-wide program to monitor bats at local to rangewide scales that will provide reliable data to promote effective conservation decision making and the long-term viability of bat populations across the continent. This is an international, multiagency program. Four approaches will be used to gather monitoring data to assess changes in bat distributions and abundances: winter hibernaculum counts, maternity colony counts, mobile acoustic surveys along road transects, and acoustic surveys at stationary points. These monitoring approaches are described along with methods for identifying species recorded by acoustic detectors. Other chapters describe the sampling design, the database management system (Bat Population Database), and statistical approaches that can be used to analyze data collected through this program.

Keywords: Acoustic surveys, bat detectors, bats, chiroptera, climate change, hibernaculum counts, monitoring, occupancy models, population trends, white-nose syndrome.