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A COMPARISON OF THE EFFICIENCY OF MOBILE AND STATIONARY ACOUSTIC BAT SURVEYS

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ABSTRACT. Acoustic surveys with echolocation detectors have become a common method for monitoring bats worldwide. In the eastern United States, the spread of white-nose syndrome and the threat it poses for many bat species, particularly endangered species such as the Indiana bat (*Myotis sodalis*), has increased the need to monitor bat populations. Two popular methods, stationary and mobile surveys, are currently used by agencies in the United States to inform management and conservation efforts and by researchers to monitor and study bat populations. Despite the widespread use of these methods, no study has compared the efficiency in echolocation 'capture' success relative to human-hour of effort of these two methods. To compare these techniques we collected acoustic data with Anabat detectors in state forests of southern Indiana using stationary and mobile surveys in the way they are typically implemented. We compared the efficiency of each method at recording identifiable call files and *Myotis* bat call files per survey hour and hour of human effort, the proportion of call files recorded that were identified as *Myotis* bats, and the total number of bat species detected. Stationary surveys detected higher species richness, a higher proportion of *Myotis* bats, and were more efficient at recording *Myotis* bat call files per hour of effort than mobile surveys. Because of limitations in resources faced by many agencies, it is important to understand the efficiency of these methods relative to the effort expended implementing them. Whenever possible, we recommend the preferential use of stationary survey over mobile surveys.

Keywords: acoustic surveys, bats, mobile surveys, *Myotis*, stationary surveys

INTRODUCTION

Bat species worldwide are currently facing many threats, including the loss and fragmentation of habitat (Thomas 1988; Brosset et al. 1996; Fenton et al. 1998; Law & Chidel 2002; Borkin & Parsons 2010), disease (Ingersoll et al. 2013; USFWS 2014), climate change (Humphries et al. 2002), and the development of wind energy facilities (Kunz et al. 2007; Arnett et al. 2008; Jain et al. 2011). In the eastern United States, the threat of white-nose syndrome (WNS) has increased concern for the conservation of many bat species. This infection, caused by the fungus *Pseudogymnoascus destructans* (formerly *Geomyces destructans*; Lorch et al. 2011; Minnis & Linder 2013), originally discovered in New York in 2006, has now been confirmed in 25 states and five Canadian provinces and has killed more than 5.5 million bats (Turner et al. 2011; USFWS 2012; WNS 2015). White-nose syndrome affects seven bat species in the United States, the majority of which belong to the genus *Myotis*. This genus includes the federally endangered Indiana (*M. sodalis*) and gray (*M. grisescens)* bats, the northern long-eared bat (*M. septentrionalis*), which has been proposed for listing as endangered (USFWS 2013), and the little brown bat (*M. lucifugus*) whose population declines have made it a potential candidate for future listing (Frick et al. 2010; Dzal et al. 2011; Thogmartin et al. 2012, 2013; Ingersoll et al. 2013).

The existence of these threats necessitates techniques that will efficiently inventory and monitor bat species for proper management. Methods that effectively estimate population trends are necessary to support listing decisions, to set recovery goals, and to monitor the success of conservation efforts. Methods traditionally employed to survey bat populations include visual counts of roosting bats, evening

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emergence counts, mark-recapture methods, mist netting, harp trapping, and hibernacula surveys (Kunz 2003). More recently, with the development of ultrasonic detectors and automated call identification software, acoustic surveys have become a popular tool for monitoring bats (Walters et al. 2013), particularly in areas of eastern North America where bat populations have been reduced by WNS and managers have sought alternative cost-efficient techniques.

Acoustic surveys provide a non-invasive and relatively simple method for monitoring bat activity and community composition, often providing a more accurate estimate of species richness than the more invasive mist net capture methods (Murray et al. 1999; O'Farrell & Gannon 1999). These surveys are also a cost-effective method to sample many bat species in large areas (Roche et al. 2011; Coleman et al. 2014). Acoustic surveys are implemented using ultrasonic echolocation call detectors that record the calls of foraging and commuting bats. The characteristics of these calls, such as frequency and duration, can later be used to identify the species recorded (O'Farrell et al. 1999) with automated techniques exceeding 90% accuracy in species identification of call libraries (though field recordings are expected to have lower rates of accuracy due to call degradation; Britzke et al. 2002, 2011).

Two common techniques for acoustic survey implementation are stationary and mobile surveys. During stationary surveys, detectors are placed in a sampling location and allowed to passively record calls of bats for a set length of time (Murray et al. 2001; Ford et al. 2011; Stahlschmidt & Brühl 2012). Such an approach is particularly useful for determining species presence/absence, conducting occupancy analysis, assessing species diversity or recording an index of bat activity. During mobile surveys, detectors record bat calls while moving along a route; these surveys can be performed on walking, driving, or boating transects (Roche et al. 2011; Whitby et al. 2014). This technique is well suited for assessing an index of population abundance (since individual bats are rarely resampled), monitoring population trends, and surveying large areas.

Both mobile and stationary surveys are currently being used to monitor and study bat populations by researchers, consulting firms, citizen scientists, and government agencies (e.g., Furlonger et al. 1987; Walsh & Harris 1996; O'Farrell et al. 1999; Baerwald & Barclay 2009; Jain et al. 2011; Beeker et al. 2013; Shier et al. 2013; USFWS 2014; Jack Basiger, Civil and Environmental Consultants, Inc., Pers. Comm.). The USFWS has developed a stationary survey protocol for determining the presence/probable absence of Indiana bats during the summer and other agencies have issued guidelines for conducting mobile driving surveys (Britzke & Herzog 2009; USFWS 2014). Both types of acoustic surveys are currently being used by the Indiana Department of Natural Resources to survey bat communities in Indiana (Shier et al. 2013). In addition, a large-scale monitoring program for North American bats is in development and both mobile and stationary acoustic surveys are included as part of that program (Loeb et al. 2012, L.E. Ellison, Pers. Comm.).

Both stationary and mobile surveys are widely used, though their relative effectiveness in sampling bat populations is unclear. Previous research has identified differences in the effectiveness of acoustic survey techniques relative to the type of surveys used, the type of recording device, the weatherproofing technique, and the height of detectors (Menzel et al. 2005; Collins & Jones 2009; Britzke et al. 2010; Stahlschmidt & Brühl 2012; Whitby et al. 2014; Coleman et al. 2014). Thus, differences in the performance of stationary and acoustic surveys would be expected. Despite their popularity, no study has previously compared the efficiency of driving mobile surveys and stationary surveys at detecting *Myotis* bats relative to time investment.

In this study we examined the relative efficiency of mobile and stationary surveys with particular focus on the human-hours of effort expended implementing each technique. To accurately compare the efficiency of these techniques, we collected data with each in the way in which they are typically implemented when surveying a bat community at a particular property. Thus, we did not pair our mobile and stationary surveys as a means of direct comparison for the same habitat. Rather, as is standard, we deployed multiple stationary acoustic detectors throughout a property of interest and allowed those units to collect ultrasonic data for multiple sequential nights. As is also standard, our mobile acoustic surveys only lasted a single night at a time (though with replicates) and mobile routes were necessarily constrained to roads over which a vehicle could travel. Therefore we did not intend to make a direct comparison between methods based on location, but rather implemented each technique in the way they are typically deployed when surveying large properties. This allowed us to determine the human-hours of effort needed to employ each technique and to compare their efficiency according to time expended. We compared the total number of call files identifiable to species recorded per hour of sampling and per hour of effort for each survey method. Because of the conservation interest of the genus, we also considered the efficiency in capture via the number of *Myotis* call files recorded per hour of sampling and effort and the proportion of call files identified as a *Myotis* species. We also compared the number of bat species detected by each technique. Considering the resource limitations faced by researchers and federal and state agencies, we believe that understanding the effectiveness of sampling techniques at assessing bat communities relative to time investment is crucial (also *see* Whitby et al. 2014).

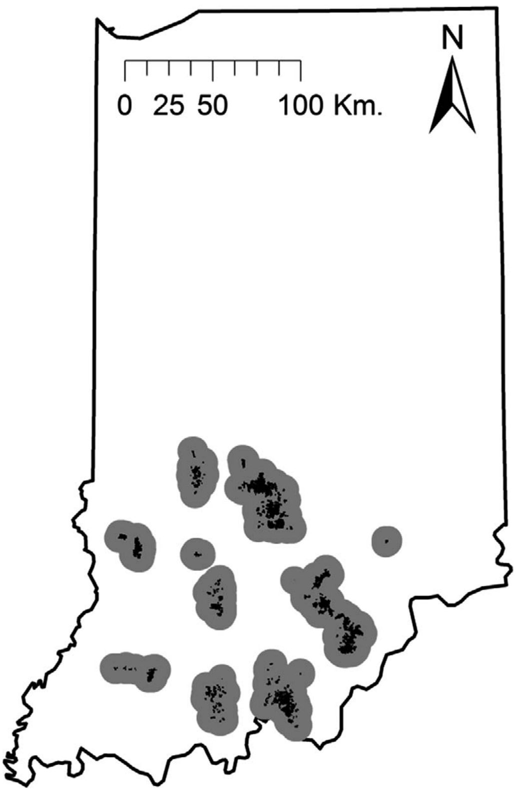

Figure 1.—Study areas sampled using mobile and stationary acoustic surveys May–August, 2012. Black areas represent the 12 Indiana State Forest properties sampled while gray areas denote the 8 km buffer area surrounding those properties. Note: two pairs of forest properties border one another but were sampled independently.

STUDY SITES

Our study area consisted of 12 state forest properties in southern Indiana and the surrounding areas within 8 km of the forest property boundary (center of all areas 38°47′32.15″N and 86°29′47.59″W; Fig. 1). These forests are located within the Southwestern Lowlands, Eastern Bottomlands, Shawnee Hills, Highland Rim, and Bluegrass natural regions (Homoya et al. 1985). Southern Indiana is dominated by hardwood forests that have regenerated in the absence of agriculture since the early 1900s (Jenkins 2013). The two most dominant forest types in Indiana's state forests are oak-hickory and mixed hardwoods representing 57% and 26% of the total land cover, respectively (Shao et al. 2014). Our study area encompasses the range of at least six bat species affected by white-nose syndrome and contains habitat types favored by many of them (Whitaker et al. 2007).

METHODS

A total of 48 stationary and mobile acoustic surveys was conducted from 30 May to 7 August, 2012. A passive stationary survey consisted of four detectors deployed at randomly selected sites within one forest property for five consecutive nights. Each of 12 distinct forest properties was sampled once or twice for a total of 22 stationary surveys (440 detector-nights at 88 sites). A stratified random sampling design (as part of a separate experiment; Pauli 2014) based upon distance to the nearest road was used to select four stationary sampling sites per sampling session per property. Locations were established within forested areas in the immediate vicinity. The average distance between a site and its closest neighbor was 1443 m (range 62–9748 m). Sites that were inaccessible or were in areas where detectors would be conspicuous and at risk of being tampered with were rejected and a new location within the same stratum was chosen. At sampling sites the recording equipment was placed in a flat area within 3 m of the selected point, positioned in the direction of lowest understory clutter, and set to record for five consecutive nights. Each survey night, detectors recorded for 12 h and began recording at least 30 min before sunset and stopped at least 30 min after sunrise. Bat calls were recorded using Anabat II detectors, powered by 9 V and AA batteries, with a division ratio of 16 and stored digitally using compact flash cards in zero-crossing interface modules (ZCAIMs; Titley Electronics, Ballina, NSW, Australia). The recording equipment was placed 1 m off the ground and was enclosed in a plastic container for weatherproofing fitted with a PVC tube angled at 45° and facing the microphone (O'Farrell 1998; *see* Duchamp et al. 2006 for exact weatherproofing specifications).

Twelve routes were designed for mobile surveys, one for each forest property. Each route was sampled two to three times over our field season for a total of 26 mobile surveys. Mobile and stationary surveys did not sample the same property concurrently. Each mobile survey route was 40–48 km (25–30 mi) long and included roads in the state forests or within 8 km (5 mi) of property boundaries. We designed routes to avoid overlap in sampling area during each survey and preferentially used low-traffic roads. Routes were driven at a rate of 24–32 km/h (15–20 mph), starting 20 min after sunset on nights with low wind (< 24 km/h), no fog or rain, and temperatures suitable for bat activity (> 12.8°C; Britzke & Herzog 2009). We used an Anabat SD2 ultrasound detector (Titley Electronics, Ballina, NSW, Australia) set at a division ratio of 8 with a vehicle roof-mounted microphone (without weatherproofing) pointing 5–15 degrees off vertical and an Ipaq PDA recording device with Anapocket software to store calls (Britzke & Herzog 2009).

All Anabat detectors (Anabat II and SD2 units) were calibrated before the surveys using an ultrasonic sound emitter to ensure consistent detector sensitivity (Larson & Hayes 2000) and were set with a sensitivity setting near 7 for all units. We used the automated echolocation classification software EchoClass v2.0 (U.S. Army Engineer Research and Development Center, Vicksburg, MS, USA; available at www.fws.gov) to identify the species of bat calls from the recorded call files. Identifiable species were limited to those somewhat common to our study areas (species in "species set 2" in EchoClass; G.S. Haulton, unpublished data) to reduce the potential candidate species and thus, reduce the likelihood of misclassification. Only a portion of the total call files collected could be identified to species due to poor call quality or interference from other sources, such as insect noise.

To determine the efficiency of each method, we calculated the number of hours of effort expended in each survey. For mobile surveys, hours of effort were defined as the time spent driving routes plus an estimated 5 min for setting up and putting away the equipment. The estimated time of effort expended in a single stationary survey (four detectors at a single property) included the time spent traveling to each sampling location within the forest property, set-up time, and pick-up time for each detector once sampling was completed. We did not include the time required to get to the study area for either survey method as this varied for each forest property but was consistent between methods.

We determined the number of call files identifiable to species recorded and the number of *Myotis* bat call files recorded per sampling hour by dividing the number of each by the amount of time the detector was actively sampling. We calculated the number of call files identifiable to species that could be recorded per hour of effort and the number of *Myotis* species bat call files per hour of effort for each method by dividing the total number of call files recorded during each sampling round (four stationary locations for five nights at a particular property) or route (single route for one night at a property) by the total time invested for that survey. We defined species richness for each survey as the number of species identified in at least one call file by EchoClass v2.0 during a sampling occasion. We determined the proportion of identifiable call files classified as *Myotis* bats by dividing the number of *Myotis* bat call files by the total number of call files identified during each survey. For all of these data we conducted two-sample *t*-tests assuming unequal variances to determine if these values differed significantly between the two methods using Bonferroni correction ($\alpha = 0.0083$) to account for multiple comparisons.

RESULTS

During our sampling, a total of 23,215 files were recorded: 2,691 files using mobile surveys and 20,524 files using stationary surveys.

Table 1.—Comparison of the efficiency and effectiveness of stationary and mobile Anabat surveys. Data measured are the number of identifiable files recorded per sampling hour, number of *Myotis* bat call files recorded per sampling hour, number of identifiable files recorded per hour of effort expended, number of *Myotis* bat call files recorded per hour of effort expended, percentage of identifiable calls classified as *Myotis* bats, and species richness recorded. Included for each response variable is the mean (and standard deviation) for stationary and mobile surveys and the test statistic (t), degrees of freedom (df) and p-value (p) from a two-sample t-test assuming unequal variances. Stars denote significantly different results (Bonferroni corrected $\alpha = 0.0083$).

Measurement	Stationary	Mobile	t	df	p
Ident. files/hour sampled	0.52 (0.86)	11.22 (4.96)	10.81	27	<0.0001*
Myotis files/hour sampled	0.04 (0.06)	0.10 (0.23)	1.15	29	0.260
Ident. files/hour effort	17.99 (29.41)	10.66 (4.69)	1.16	22	0.259
Myotis files/hour effort	1.47 (2.19)	0.09 (0.22)	2.95	21	0.008*
Percentage of *Myotis* files	8.72 (6.40)	0.70 (1.71)	5.71	24	<0.0001*
Species richness	4.59 (2.32)	2.69 (0.93)	3.60	27	0.001*

Of these, stationary surveys recorded 2,771 files that could be identified to species, including 227 *Myotis* call files, whereas mobile surveys recorded 466 identifiable files, only four of which we identified as *Myotis* call files. Sampling time of effort expended on mobile surveys averaged 1.7 hours per route (SD = 0.10) for a total of 44.1 hours. The estimated time of effort expended for stationary surveys totaled 154 hours, or seven hours per survey.

On average, our mobile surveys recorded 21.6 times as many identifiable calls per survey hour compared to stationary surveys and this difference was highly significant (Table 1). Using stationary surveys we recorded 1.7 times as many identifiable files per hour of effort relative to mobile surveys though this difference in efficiency was not significant (Table 1). Stationary and mobile surveys sampled equivalent number of *Myotis* calls per survey hour (Table 1) but stationary surveys recorded significantly more *Myotis* bat call files per unit effort with 16.3 times the efficiency of mobile surveys (Table 1). Stationary surveys also identified a significantly higher proportion of *Myotis* calls and a greater mean species richness as compared to mobile surveys (Table 1). Stationary surveys detected nine species: big brown bat (*Eptesicus fuscus*), silver-haired bat (*Lasionycteris noctivagans*), eastern red bat (*Lasiurus borealis*), hoary bat (*L. cinereus*), eastern small-footed bat (*Myotis leibii*), little brown bat, northern long-eared bat, Indiana bat, and the tri-colored bat (also known as the eastern pipistrelle, Whitaker et al. 2011; *Perimyotis subflavus*). Mobile surveys only detected six of these nine species, not recording any Indiana bat, little brown bat, or eastern small-footed bat call files.

DISCUSSION

By determining the relative efficiency of these two techniques at surveying bat communities in terms of time of effort expended and richness recorded, we demonstrated that stationary surveys are more effective than mobile surveys when considering investment of human effort. Mobile surveys not only detected lower species richness, lower number of *Myotis* call files per hour of effort, and lower proportion of *Myotis* call files, but they failed to detect three species detected by stationary surveys. The length of the sampling periods and the ratio of sampling time to time of effort expended were important factors determining the efficiency of each method. The time of effort (human-hours) spent on stationary surveys is considerably shorter than the length of the sampling period, whereas in mobile surveys the hours of effort expended are equivalent to the sampling period. Thus, stationary surveys sample for longer periods per time of effort. Therefore, even though stationary surveys recorded significantly fewer identifiable files per sampling hour, they were more efficient relative to effort expended. This difference may explain why mobile surveys were less efficient at capturing *Myotis* calls per hour of effort. Stationary survey detectors sample an area for five consecutive nights, whereas, mobile surveys record for very short periods at any given location along the route. Skalak et al. (2012) demonstrated that in order to record higher levels of species richness during acoustic surveys, multiple nights and sampling stations as well as continuous sampling through the night was required. They further found that few nights were necessary to detect common species but longer sampling periods were required to capture rare species. Other studies have also demonstrated nightly bat activity can vary due to a variety of factors, so that in order to capture true nightly activity or species presence it is necessary to survey for multiple nights (Hayes 1997; Fisher et al. 2009; Rodhouse et al. 2012; Romeling et al. 2012). Stationary surveys that are conducted for fewer nights than this research, however, would be expected to have reduced efficiency relative to that measured in this study.

Stationary detectors, capable of sampling over multiple nights and with less time effort, have a greater chance of capturing call files of all the species present, especially those of target *Myotis* species. Mobile surveys, in comparison, spend relatively little time recording in a given area and thus have a greater probability of missing species. This is of particular importance when the species being missed are those that are of most interest for conservation efforts, as was the case in this study. If mobile surveys are unable to efficiently detect rare species or provide accurate estimates of richness, this method, despite having some advantages, may be insufficient.

The partial avoidance of roads by bats could be another factor influencing the efficiency of mobile driving surveys. Bats have been shown to avoid crossing roads, particularly when a vehicle is present (Schaub et al. 2008; Zurcher et al. 2012; Bennett & Zurcher 2013; Bennett et al. 2013). These behaviors may be the result of road noise interfering with foraging activities, the perception bats have of cars as predators, or the predation threat bats face in the open areas created by roads (Schaub et al. 2008; Zurcher et al. 2012; Bennett & Zurcher 2013). It is interesting to note that partial road avoidance appeared to be taxonomically skewed in this study. Independent of sampling time, stationary surveys recorded a proportionally higher sample of *Myotis* call files than mobile surveys. Such a phenomenon could be the result of the rapid attenuation of the high frequency calls emitted by *Myotis* species (Lawrence & Simmons 1982). Alternatively, because *Myotis* bats are considered clutter-adapted species (Patriquin & Barclay 2003) they may be less likely to forage over roads. Thus, this genus may be more sensitive to roads as barriers or vehicular disturbance than other species, though more research is needed to further elucidate this relationship.

In this study Anabat II and Anabat SD2 detectors and EchoClass v2.0 software were used for collection and analysis of data. It should be noted that although detectors were calibrated against one another, mobile surveys were conducted with Anabat SD2 detectors, a division ratio of 8, and microphones specially fitted for vehicle mounting while stationary surveys were conducted with Anabat II detector within waterproofing containers and a division ratio of 16. While such an approach is typical for many bat surveys, there is potential that some of our findings were the result of differences in survey equipment rather than the technique itself. Furthermore, we used the classification of a single file to the species level by EchoClass as our primary data. Such an approach is less restrictive than other studies that use maximum likelihood estimates for determining positive species identification (e.g., Coleman et al. 2014). Therefore, our results may contain more species misclassifications than other studies. It will be necessary to test similar results with other types of recording equipment and analysis software, but we suspect where some patterns in the data may be different, the general trends observed in our results will hold.

Monitoring populations is an important aspect of bat management and conservation, but all agencies involved in such activities are constrained by limited resources. Thus sampling efficiency is a priority. Given that stationary surveys seem to be more efficient than mobile surveys in sampling bat community richness and at detecting species of the genus *Myotis* for the effort expended, we recommend that, when possible, stationary surveys should be used preferentially over mobile driving surveys.

There are situations, however, where mobile surveys may be more practical than stationary sampling techniques. Mobile surveys are useful when surveying large areas for common species. In addition, because mobile surveys limit the potential for sampling a single bat multiple times, they may be more adept at providing an index of population size which cannot be done with typical stationary surveys. Mobile surveys can be conducted on public roads so areas with difficult terrain can be sampled easily. There is also no need to request landowner permission to conduct such surveys if they are done on public roads. Stationary surveys also require detectors to be left unattended thus exposing them to potential tampering or damage. In addition, since detectors are obligated for longer periods of time in stationary surveys, mobile surveys are also better suited to sampling large areas if time and detectors are limiting factors. These types of surveys are also useful in citizen science programs or for training purposes since they are easier to implement and do not require the participants to leave their vehicles.

Mobile surveys risk obtaining inaccurate measures of richness and missing rare species, however, and so should not be used for such purposes. It is also important to note that our data were collected within two-years of when white-nose syndrome had been first detected in Indiana, and we suspect in this short period of time that bat populations had not yet declined significantly in our study area. We speculate that the efficiency of surveys at detecting *Myotis* species will only worsen with population reductions which could exacerbate this discrepancy. If a more accurate index of the bat community of an area is needed, stationary surveys are a better option as they provide a more efficient method for monitoring.

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