Introduction: Survey Methods for Monitoring Bat Populations

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Introduction

Bats contribute significantly to natural pest control, pollination, and seed dispersal, supporting agriculture and biodiversity worldwide (Kunz et al. 2011). Yet, bat populations in North America continue to decline at an alarming rate, impacted by white-nose syndrome (Hoyt et al. 2021), wind-energy developments (Frick et al. 2017), and habitat degradation (Russo and Ancilloto 2015). Given these pressures, effective bat monitoring has become more critical than ever.

Traditional monitoring approaches—such as mist-netting and visual counts—have yielded valuable insights (Kunz and Parsons 2011) but are labor-intensive, can overlook elusive species, and sometimes disturb the bats themselves. In response, researchers have applied technological advances—including thermal imaging, acoustic monitoring, and tagging techniques—that promise to complement and enhance traditional approaches. This special issue, *Survey Methods for Monitoring Bat Populations*, focuses on advancing the science of bat population monitoring. The 8 studies that are presented take a variety of formats, including research articles, opinions/perspectives, and initial evaluations of emerging technologies. Here, we synthesize the principal findings by survey method and highlight promising directions for future research.

Survey Methods

Visual emergence counts

In the first paper of the special issue, Barclay et al. (2024) used visual observations conducted multiple times per week to count *Myotis lucifugus* (Le Conte) (Little Brown Bat) emerging from 2 roosts in Alberta, Canada. They observed considerable fluctuations in counts across the season, and even on consecutive nights, underscoring the need for repeated surveys to obtain accurate population estimates. Visual observations were particularly effective at their sites because all bats emerged before complete darkness, a finding confirmed by inspecting the roost by flashlight after each survey. While visual observation proved reliable in this study, such intensive multi-night efforts are uncommon, and emerging technologies, such as imaging and acoustic surveys, may offer more time-efficient alternatives.

Jaffe et al. (2024) expanded on this approach by combining visual counts with drone-based thermal imaging and acoustic monitoring at roosts of *Myotis grisescens* Howell (Gray Bat) in Tennessee and *Eptesicus fuscus* (Palisot de Beauvois) (Big Brown Bat) in North Carolina. At the larger Gray Bat colony, which hosted up to 2987 individuals, 2 newly trained observers independently counted emergences. The authors found close agreement between observers for most survey periods, except a 5-minute interval, during which counts

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deviated by ~200%. This discrepancy occurred when emergence peaked at 200–300 bats per minute, suggesting a threshold above which human accuracy may diminish. Drone-based thermal imagery differed from visual counts by a median of 17.5% and 32% at their 2 study sites. Jaffe et al. (2024) highlighted the value of integrating visual observations with other methods to improve reliability and validate results. Future studies should examine how observer accuracy is affected by high emergence rates and varying environmental conditions. The authors identified several drawbacks to using drones, including limited battery life, potential flight instability, high equipment costs, and the need for specialized training and permits for nighttime operation. Still, drone videography may be a useful method for counting bats under specific conditions.

Imaging techniques

Imaging technologies, such as thermal and near-infrared cameras, offer an alternative to human observation for counts of bat emergences. Researchers have explored these approaches for decades, but recent advances have made them more accessible. Notably, freely available software, like *BatCount* (Bentley et al. 2023) and *ThruTracker* (Corcoran et al. 2021), have facilitated broader adoption of imaging techniques in bat population studies.

In this special issue, Ammerman et al. (2024) demonstrated the utility of thermal imaging for long-term monitoring of populations. Their study analyzed 16 years of thermal-imaging videos from a cave inhabited by the endangered *Leptonycteris nivalis* (Saussure) (Mexican Long-nosed Bat). The authors compared counts from humans watching videos to those produced with *ThruTracker*, an automated program. On average, counts made by *ThruTracker* were 91% consistent with those made by humans. Importantly, manual counting required 48–60 times more human labor than the automated approach, excluding computer-processing time. Despite the high accuracy of *ThruTracker*, the authors noted its inability to differentiate species, underscoring a current limitation of this technology.

Ahlberg et al. (2025) expanded on this work by summarizing insights from users of their software program *BatCount*. They interviewed 7 individuals, each with 2–18 years of experience with thermal-imaging cameras. While the potential of imaging technologies is clear, the authors presented a sobering account of the challenges still facing researchers. Commonly encountered problems included difficulty finding affordable and suitable cameras, uncertainty about how to deploy cameras at field locations, and the steep learning curve associated with using available software. The authors provided suggestions for improving this work in the future, including implementation of field-training workshops, equipment loan programs, and online video repositories.

In a third demonstration, Amichai et al. (2025) described a novel application of imaging technologies that combined thermal and visual-light cameras with echolocation recorders to monitor activity at an offshore wind turbine in the Atlantic Ocean. Surprisingly, 31% of bat detections occurred during the day. Additionally, both video and acoustic detections peaked in August and September. These findings emphasized the power of long-term continuous monitoring for documenting activity and behaviors of bats, something increasingly possible due to technological advances.

Acoustics

Acoustic surveys are now standard for documenting bat presence and species diversity in summer habitats. However, acoustic surveys have their limitations, including potentially inaccurate species identification and difficulty relating the number of acoustic detections to the number of bats that are present. Nevertheless, efforts such as the North American Bat

Monitoring Program (Loeb et al. 2015) generate estimates of population trends for individual species by aggregating acoustic data over multiple years and geographic regions.

Multiple studies in this special issue reported novel ways to use acoustics to census bats. Specifically, Jaffe et al. (2024) and Eddington et al. (2025) deployed acoustic recorders near the exits of bat roosts and correlated the recorded sound levels with the exit rates of bats, as measured with either thermal imaging or human-made counts. Instead of counting echolocation calls, these authors used a simple formula to calculate sound levels of aggregate acoustic emissions of emerging bats. After an initial calibration period, researchers could use acoustic recordings to track changes in roost population size over time. Previous studies had found that the sound-level approach only works for large colonies that contain tens of thousands of individuals. However, by using median sound levels instead of root-mean-square (rms) sound levels, Jaffe et al. (2024) generated counts at roosts that contained a few hundred bats. On average, these counts differed by 15% from human observation counts, though the human-made counts likely had error of their own. In the second study, Eddington et al. (2025) used a similar approach, but they highlighted issues that can arise with this newer technique. Specifically, they demonstrated that low-cost AudioMoth detectors varied considerably in recorded sound levels among units. Furthermore, these authors showed that the relationship between recorded sound levels and number of bats present at some caves differed between nights. These issues must be overcome if this method is to yield accurate results.

Lastly, Metcalfe et al. (2025) evaluated tradeoffs between use of an echolocation recorder designed to conduct rigorous science and another that provided natural history enrichment for community scientists. Perhaps unsurprisingly, the detector designed for scientific study recorded nearly 3 times more bat passes and produced recordings of better quality, which led to detection of a greater number of species. However, data from both types of detectors resulted in similar models of overall bat activity. Therefore, the increased user engagement of the lower-cost detectors could outweigh the reduced data quality for some projects.

Tagging bats

Mark-recapture is the benchmark for monitoring changes in populations. It provides a way of estimating abundance and probability of survival, as well as information on roost use and inter-roost movements. Passive integrated transponders (PIT tags), which are implanted subcutaneously, are an increasingly common method of marking bats.

Waag et al. (2025) reviewed 5 ongoing studies that marked bats using PIT tags, to illustrate various objectives that might be addressed using this technology. These authors emphasized how the use of RFID (radio frequency identification) readers and antennas have expanded the power of this technique by allowing bats to be "re-sighted" with a system that operates continuously. In a study of Little Brown Bats in Colorado, only 15.7% of tagged individuals were recaptured using nets or traps, but >64% of tagged individuals were later detected using RFID antennas. Similarly, RFID detections resulted in population estimates that were nearly 4 times higher than those from standard emergence counts. Hence, consistent with the theme of other papers in this Special Issue, technological advances in the form of continuously operating RFID antennas resulted in greatly improved quantity and quality of monitoring data. Nevertheless, the authors emphasized that loss of PIT tags could be a problem and suggested that future studies measure loss rates, not only to improve results of data analyses, but to improve our understanding of species- or sex-specific rates of tag loss.

Sensor integration

A common theme from this Special Issue is that there is no single optimal method to survey bats, as highlighted by the papers of Amichai et al. (2025) and Jaffe et al. (2024). Each study used multi-sensor approaches to improve the ability to detect and count bats beyond what was possible with a single sensor. While it obviously required more effort to conduct such detailed investigations, the payoff was a higher degree of reliability in the resulting data, and an ability to cross-validate detections using multiple methods. As technology-based survey methods become more streamlined, multi-sensor surveys likely will become more feasible.

Conclusions and Future Directions

This Special Issue highlights emerging techniques for surveying bats. The approaches presented here are not meant to replace traditional survey methods, such as capture or visual observation. Instead, these newer techniques provide researchers and managers with an improved toolbox to answer the questions most important to them and their study systems. Monitoring changes in bat populations is a challenging endeavor, and it is important that any new procedures generate data that can be reliably obtained from species of interest. Additional methods, such as estimating population sizes using genetics (Dool 2020) and advanced analytical approaches that maximize inference from standard field methods (Rodhouse et al. 2019, Udell et al. 2024), could not be covered in this special issue; however, these other techniques play vital roles in monitoring bat populations. As with many new methods, advanced technologies have a learning curve, which can be an impediment to their adoption. Much additional work is needed to streamline workflows and dampen the learning curve for widespread adoption of these emerging tools. We hope the studies presented in this special issue provide a foundation upon which such improvements can be made.

Literature Cited

Ahlberg, S.E., V. Kuczynska, and L.N. Kloepper. 2025. A perspective on thermal imagery for bat emergence counts: Best practices, challenges, and recommendations for the future. Journal of North American Bat Research, Special Issue 1:46–58.

Ammerman, L.K., A.E. Loehn, F.A. Calderon, R.D. Pourshoushtari, E.R. Adams, and M.T. Dixon. 2024. Long-term monitoring of endangered Mexican Long-nosed Bats (*Leptonycteris nivalis*) and a test of an automated census approach. Journal of North American Bat Research, Special Issue 1:11–29.

Amichai, E., G.M. Forcey, M. Vukovich, and J.R. Willmott. 2025. Multi-sensor arrays provide complementary information on bat presence and activity in the offshore environment. Journal of North American Bat Research, Special Issue 1:75–88.

Barclay, R.M.R., T. A. Monteiro, E.N. Miller, L.E. Hiles. 2024. Fluctuations in bat-house colony size may hamper estimation of population changes. Journal of North American Bat Research, Special Issue 1:1–10.

Bentley, I., V. Kuczynska, V.M. Eddington, M. Armstrong, and L.N. Kloepper. 2023. BatCount: A software program to count moving animals. PLoS One 18:e0278012.

Corcoran, A.J., M.R. Schirmacher, E. Black, and T.L. Hedrick. 2021. ThruTracker: Open-source software for 2-D and 3-D animal video tracking. bioRxiv 2021.05.12.443854.

Dool, D.E. 2020. Conservation genetic studies in bats. Pp. 29–62, *In* J. Ortega and J.E. Maldonado (Eds.). Conservation Genetics in Mammals. Springer, Cham, Switzerland. 378 pp.

Eddington, V.M., S. Ahlberg, V. Kuczynska, E.R. White, and L.N. Kloepper. 2025. Evaluating an acoustic method for estimating trends in bat summer colony counts with AudioMoth recorders. Journal of North American Bat Research, Special Issue 1:59–74.

Frick, W.F., E.F. Baerwald, J.F. Pollock, R.M.R. Barclay, J.A. Szymanski, T.J. Weller, A.L. Russell, S.C. Loeb, R.A. Medellin, and L.P. McGuire. 2017. Fatalities at wind turbines may threaten population viability of a migratory bat. Biological Conservation 209:172–177.

Hoyt, J.R., A.M. Kilpatrick, and K.E. Langwig. 2021. Ecology and impacts of white-nose syndrome on bats. Nature Reviews Microbiology 19:196–210.

Jaffe, K., R. Carter, and A.J. Corcoran. 2024. Evaluating methods for emergence counts at bat roosts: A pilot study comparing drone-acquired thermal imagery, acoustic estimates, and visual observations. Journal of North American Bat Research, Special Issue 1:30–45.

Kunz, T.H., and S. Parsons. 2011. Ecological and Behavioral Methods for the Study of Bats. Second Edition. Johns Hopkins University Press, Baltimore, MD. 901 pp.

Kunz, T.H., E. Braun de Torrez, D. Bauer, T. Lobova, and T.H. Fleming. 2011. Ecosystem services provided by bats. Annals of the New York Academy of Sciences 1223:1–38.

Loeb, S.C., T.J. Rodhouse, L.E. Ellison, C.L. Lausen, J.D. Reichard, K.M. Irvine, T.E. Ingersoll, J.T.H. Coleman, W.E. Thogmartin, J.R. Sauer, C.M. Francis, M.L. Bayless, T.R. Stanley, and D.H. Johnson. 2015. A plan for the North American Bat Monitoring Program (NABat). General Technical Report GTR-SRS-208, USFS Southern Research Station, Asheville, SC. 100 pp.

Metcalfe, A.N., T.J. Weller, C.A. Fritzinger, B.P. Holton, and T.A. Kennedy. 2025. Trade-offs in designing a participatory acoustic study of bats: Comparison of user engagement and data quality between two ultrasonic detectors. Journal of North American Bat Research, Special Issue 1:89–99.

Rodhouse, T.J., R.M. Rodriguez, K.M. Banner, P.C. Ormsbee, J. Barnett, and K.M. Irvine. 2019. Evidence of region-wide bat population decline from long-term monitoring and Bayesian occupancy models with empirically informed priors. Ecology and Evolution 9:11078–11088.

Russo, D., and L. Ancilloto. 2015. Sensitivity of bats to urbanization: A review. Mammalian Biology 80:205–212.

Udell, B.J., B.R. Straw, S.C. Loeb, K.M. Irvine, W.E. Thogmartin, C.L. Lausen, J.D. Reichard, J.T.H. Coleman, P.M. Cryan, W.F. Frick, and B.E. Reichert. 2024. Using mobile acoustic monitoring and false-positive N-mixture models to estimate bat abundance and population trends. Ecological Monographs 94:e1617.

Waag, A.G., J.S. Johnson, R.A. Schorr, W.F. Frick, T.M. Laverty, D.J. Neubaum, J.L. Siemers, J.J. Treanor, G.A. Reyes, and B.J. Halstead. 2025. Using passive integrated transponder (PIT) tags to monitor and research bats: Applications, benefits, and limitations. Journal of North American Bat Research, Special Issue 1:100–118.