Survey Methods for Monitoring Bat Populations
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A Perspective on Thermal Imagery for Bat Emergence Counts: Best Practices, Challenges, and Recommendations for the Future

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Abstract - Accurate information on population sizes is crucial for animal conservation and management. For bats, especially those that roost in large caves, this information can be challenging to obtain with visual or photographic methods, as bats often hide in cave crevices, emerge in low light conditions, and cease to emerge in artificial illumination. Recent advances in thermal imagery have made recording devices more affordable and easier to use, and thermal imagery has quickly become a viable option to record bat emergence for population counting. Researchers have developed automated bat counting software to process videos with favorable but variable results, and we believe camera quality and subjective user methodology are some of the biggest factors affecting automated counting software accuracy. Recognizing the importance of video quality, we compiled a perspective on using thermal imagery to record bats, including addressing its challenges and offering best practices for obtaining accurate census data.

Introduction

The movement of bats as they emerge from cave refugia provides researchers with unique opportunities to census populations (Mitchell-Jones and McLeish 2004). Whether caves function as hibernacula or maternity sites, these underground retreats can house thousands of bats and provide predictable locations for monitoring. These colonies provide an opportunity to census volant animals with minimally invasive techniques. By gathering data in a way that minimizes disturbance, biologists can obtain information on population sizes and shifts in phenology (Voigt and Kingston 2016) with great potential to inform conservation.

Traditional techniques to count bats, such as photographic counts, disturbance surveys, and estimation of roost surface area have inherent challenges. In addition to being time and resource intensive, these approaches are also subject to human bias and often require a trained observer. Many caves and evening emergences are impractical for visual, photographic, and video counts due to low light, challenging terrain, interference from vegetation, multiple entrances, and the sheer number of individuals (Allison 1937, Humphrey 1971, Kloepper et al. 2016, Krutzsch 1955). These conventional methods to census bats within caves are often inaccurate due to inaccessibility and the difficulty of finding bats in complex subterranean environments. Furthermore, human presence may cause significant disturbance to sensitive populations (Kunz et al. 2009, O'Shea and Bogan 2003). Researchers have historically calculated density estimates from sample counts and roost surface area, but these estimates have high error (Ammerman et al. 2009, Bourne 2015). Disturbance surveys, during which researchers use light and noise to rouse bats into flight for counting,

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may injure individuals, alter behavior, and cause other adverse effects (O'Shea and Bogan 2003). Mark-recapture studies are also invasive and can be challenging to conduct for many species (Bourne 2015, Mellado et al. 2022). Acoustic monitoring holds much promise, but requires additional model development before researchers and managers can widely use it for population estimation (Eddington et al. 2023, in press; Hoggatt et al. 2024; Kloepper et al. 2016; Revilla-Martín et al. 2021). Researchers have used image-enhancement technologies to monitor game species and small mammals for many years (Boonstra et al. 1994). For example, night-vision scopes are used to collect and amplify light, but this technique can be used only at night and may cause eye strain (Allison and Destefano 2006, King and King 1994, Kirkwood and Cartwright 1991, Sabol and Hudson 1995). Individuals also have used radar, which uses radio waves, as well as lidar, which uses lasers of varying wavelengths, for imaging bats, but the cost and skill required to deploy these technologies are often prohibitive (Azmy et al. 2012, Horton et al. 2015).

Over the past 2 decades, infrared imaging has emerged as a common technique to record bats as they leave their roost (Betke et al. 2008; Frank et al. 2003; Hristov et al. 2008, 2010; Kloepper et al. 2016). Infrared imaging can be categorized into near-infrared (reflectance) or far-infrared (thermal) imaging. Reflectance is produced by shining an external long-wave light on the object of interest, resulting in light reflected to a camera sensor (Allison and Destefano 2006, Kunz et al. 2009). Although the resulting image can be quite detailed, logistical challenges in the field can arise due to limited illumination range and power requirements needed to run the external lights (Elliott et al. 2005), and shadows cast by bats can make it difficult to discern them against the background (N. Sharp, Alabama Wildlife and Freshwater Fisheries, Tanner, AL, 2024 pers. comm.). Far-infrared imagery uses specialized optics and sensors to capture radiation leaving an animal's body in the form of heat and converts it into a visual image (Hristov et al. 2008, Rogalski 2012). Because far-infrared overcomes many of the limitations of near-infrared imaging in challenging field conditions, far-infrared imagery has become the preferred method for bat monitoring and has been widely adopted by environmental consultants, researchers, and wildlife managers (Collins 2023, Havens and Sharp 2015, Mitchell-Jones and McLeish 2004).

Monitoring bats with thermal imagery has greatly expanded our capacity to observe and understand bat behavior. For example, thermal imaging has revealed new insights into bat foraging and social interactions in flight (Yang et al. 2013), leader-follower dynamics during emergence (Weesner et al. 2023), and roost re-entry behavior (Fu et al. 2018). Researchers and managers have used thermal imagery to understand flight behavior around wind turbines and develop approaches for decreasing bat mortality (Cryan et al. 2014; Cullinan et al. 2015; Horn et al. 2008; Matzner et al. 2015, 2020; Perrow 2017). Researchers have also accurately estimated the abundance of tree-roosting bats using drone-based thermal imaging (McCarthy et al. 2021). On an individual level, a calibrated camera capable of thermographic measurements can determine the surface temperature of bats, leading to insight into physiological function and energetic costs (Bartonička et al. 2017, Hristov et al. 2008, Lancaster et al. 1997, Reichard et al. 2010), most notably in response to threats, such as white-nose syndrome (Gmutza et al. 2024, Hayman et al. 2017).

Perhaps the greatest use of thermal imagery for bats is in determining bat counts during emergence (Sabol and Hudson 1995). Thermal imagery has vastly improved the efficiency and accuracy of population estimates for large colonies of *Miniopterus australis* Tomes (Little Bent-wing Bats) (Augusteyn et al. 2021), *Leptonycteris nivalis* (Saussure) (Mexican Long-nosed Bats) (Ammerman et al. 2009), *Tadarida brasiliensis* (Geoffroy) (Brazilian Free-tailed Bats) (Betke et al. 2008, Frank et al. 2003, Ganow et al. 2015, Hristov et al.

2010), as well as colonies of *Myotis grisescens* Howell (Gray Bats) that are small to moderate in size (Bentley et al. 2023, Sabol and Hudson 1995). Newer estimates from thermal imaging have revealed that earlier methods, especially manual roost counts, had a high error rate. This has led some biologists to question the accuracy of past non-thermal counts (Ammerman et al. 2009, Betke et al. 2008). Interpreting changes in population estimates over time is challenging, as it is unclear whether these changes reflect a true difference in numbers or result from variations in census accuracy.

When monitoring cave-dwelling bats with thermal imaging, researchers have various technological options to consider. Lightweight, portable, user-friendly, and affordable cameras are best suited for cave environments. A frame rate of 30 Hz or higher helps prevent blurring of images (Bentley et al. 2023), and a thermal sensitivity of 20–50 mK is ideal for detecting bats (Havens and Sharp 2015). A resolution of 640-by-480 pixels or higher is preferred for detailed video analysis, although 320-by-240 pixels may suffice. Using digital zoom on a camera increases the size of the bats in the viewfinder, but the resolution remains the same, leading to a decrease in image quality. The type of camera lens affects the field of view, with fixed lenses common in lower-cost models and interchangeable lenses available in higher-grade cameras. Waterproof housing is essential for durability and disinfection in caves where *Pseudogynmnoascus destructans* is present (White-nose Syndrome Disease Management Working Group 2024). Additional factors to consider include selecting a camera that saves to a file compatible with most video applications (.avi, .mov, and .mp4 are most common) and uses a secure digital (SD) card with sufficient speed to write the thermal-video data. Some camera models may also allow recording directly to a laptop computer via an ethernet cable.

Over the years, researchers have used multiple methods to count bats after capturing them on thermal video. Unsurprisingly, manual counting was the first and simplest technique. Multiple observers often played back video in slow motion, counting sample clips to calculate a total estimate (Elliott et al. 2011), or manually counted the bats present in an entire video. Researchers then created a semi-automated system that calculated an estimate based on bat counts, exit rate, velocity, and length of flight path from a sample of frames (Sabol and Hudson 1995). Another early model calculated estimates based on the density of columns of bats emerging at similar velocities and trajectories (Frank et al. 2003). The Thermal Target Tracker, or "T3", was a system developed by the U.S. Army Corps of Engineers and originally used by the military for missile tracking, but was later adapted for use with bats (Bourne 2015, Ganow et al. 2015, Melton et al. 2005). The software estimated roost counts automatically, requiring less time and effort to count bats compared with previous methods (Bourne 2010). Unfortunately, the U.S. government owned this software; it was not updated, and it became incompatible with newer technology (Bentley et al. 2023).

Researchers have continued to design similar algorithms specifically for bats, calculating totals by detecting and tracking individuals as they pass through the video frame (Hristov et al. 2008). Recently, developers released 2 open-source utilities that analyze thermal video for population estimation: Thru-Tracker and BatCount v.1.24, both of which analyze different video formats to count objects moving through user-specified regions of interest (Corcoran et al. 2021, Bentley et al. 2023). Both programs were originally developed in the MATLAB (Mathworks, Natick, MA) environment and process typical videos at a rate of approximately 1 frame per second, depending on computer processing power. The developers of BatCount are currently working on version 2.1 to integrate the software with new machine-learning algorithms and high-performance computing, which can speed processing time nearly 100 fold.

Although both software options perform automated bat counting, users should understand how the counting algorithms detect and track bats to ensure the software outputs reflect accurate roost counts. Since the initial testing and release of BatCount v.1.24 in 2023 (Bentley et al. 2023), its developers have processed dozens of videos from researchers and collaborators, expanding the software's application across a range of conditions, locations, roost population sizes, and users. Through the testing of the software and in conversations with partners in the bat community, the authors of this paper have identified a disconnect between the desire for accurate automated thermal counting and the reality of this tool in practice, as obtaining accurate counts from such software requires skill in both recording high-quality videos and understanding software operation.

This disconnect motivated us to develop guidelines for thermal imaging and software analysis, propose tips for the novice user, and identify obstacles the bat community must address to advance the accuracy of population counting. Thermal imagery continues to become more affordable, but even the most advanced automated counting techniques can only be as good as the quality of the video and the knowledge and proficiency of the user. Based on our experience and data collected from colleagues, we provide our perspective on best practices for capturing thermal imagery, challenges for successful incorporation of this technology into a large-scale monitoring program, such as the North American Bat Monitoring Program (NABat), and recommendations for the future.

Perspectives from colleagues

To supplement our experiences and perspective on challenges and best practices, we interviewed 7 biologists (Table 1) about their experience counting bats with thermal imagery. We initially emailed individuals based on interactions at regional meetings of North American bat working groups and recommendations of colleagues; the individuals in Table 1 represented volunteers willing to be interviewed. One interview occurred over video conferencing; the remaining respondents chose to answer our questions via email. The list of interview questions can be found in Supplemental File (available online at http://www.eaglehill.us/NABRonline/suppl-files/nabr-010j-s1).

Respondents averaged 9.5 years of experience using thermal imagery to monitor bats from caves, cave-like structures, and trees or tree-like artificial roosts, with a range of 2 to 18 years of experience. Only 3 respondents had formalized training in thermal imagery for bats, and this training was specific to a single camera/software system (Melton et al. 2005). The cameras used to image bats included these models: FLIR Photon, FLIR E11, FLIR E60, FLIR

Table 1: Name and affiliation of individuals, who shared their advice and experiences for counting bats with thermal imagery.

Name	Affiliation
Shelly Colatskie	Missouri Department of Conservation
Cory Holliday	The Nature Conservancy
Katrina Morris	Georgia Department of Natural Resources
Pete Pattavina	U.S. Fish and Wildlife Service
Piper Roby and Will Seiter	Copperhead Environmental Consulting, Inc.
Nicholas Sharp	Alabama Wildlife and Freshwater Fisheries

Scout, FLIR Scion OTM 236 (Teledyne FLIR, Wilsonville, OR), AGA Thermovision 782 (Teledyne FLIR, formerly AGA), ATN OTS-HD 640 (ATN, Doral, FL), InfiRay Zoom ZH38 (InfiRay Technologies, Yantai, China), Pulsar Helion2 XP50 Pro 2.5-20 (Yukon Advanced Optics Worldwide, Vilnius, Lithuania), and Planck THH-960 (Planck Vision Systems, Santa Barbara, CA). Although not a thermal camera, some respondents used an infrared-sensitive Sony PXW-X70 (Sony Corporation of America, New York, NY) and an infrared-sensitive Sony Handycam, both with external infrared illumination (Fig. 1). In general, users expressed dissatisfaction with their cameras, including high price, poor customer service, short battery life, narrow field of view, inability to change lenses or settings, displays that could not be dimmed or shut off, and shadows that complicated counting (relevant only to infrared cameras). One user highlighted the need for consistency of hardware specifications for standardized counting, commenting "we should all be meeting a certain resolution and speed (frame rate) standard for our recordings, to the best of our ability" (Pattavina, personal interview, 4 April 2024).

All respondents commented on the challenge to identify the ideal camera placement to image emergences, including statements such as, "often, I will record at a site multiple times before discovering the best recording positions of placement. If I have multiple cameras, it can be helpful to record with slightly different angles the same night and compare results for [the] best option for analysis" (Holliday, personal interview, 27 March 2024). Others mentioned that it can be helpful to scout a location prior to imaging, but recognized that doing so is not always feasible. Another user commented, "I feel like we bumble through every single filming event, and I have low confidence that we are maintaining a high standard of recording at our sites. It's labor intensive to reach our sites and set up. We try to schedule 1 site each night, but probably need to allocate 2–3 nights of filming at each location to account for improper recording or at least multiple vantage points for recording . . . Many of our sites require more planning than we allocate, so I feel like we are wasting our time because of our lack of expertise" (Pattavina, personal interview, 4 April 2024).

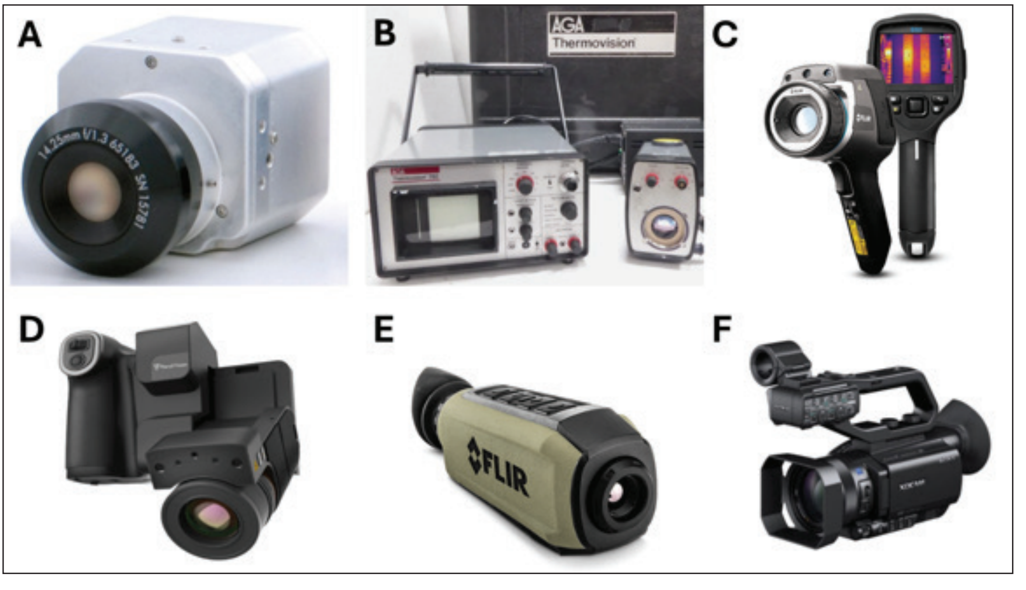

Figure 1. Examples of thermal imaging equipment used to record bat emergences. A) FLIR Photon, B) AGA Thermovision 782, C) FLIR E60, D) Planck THH-960, E) FLIR Scion OTM, and F) Sony PXW-X70.

Participants emphasized that the most important factor for a successful recording was good thermal contrast between the bats and the surrounding background. Some respondents pointed the camera directly at the roost entrance, whereas others pointed the camera perpendicular to or at a 45° angle relative to the emerging stream; some also placed their camera below the emerging bats pointing up towards the sky. Camera placement was primarily dependent on vegetative cover and surrounding landscape. One respondent imaged inside caves, where a natural constriction facilitated better imaging, but this approach included the additional challenges of potential disturbance to the bats and decontamination of gear against white-nose syndrome. Based on comments from respondents, the biggest consideration for camera placement was to ensure that the camera captured the entire stream of bats with sufficient thermal contrast and resolution. For dense emergences in which some bats may be occluded by others, users noted it might be beneficial to image farther away from a roost opening, where the bats begin to spread out from each other. Universally, respondents agreed that no ideal camera distance or placement exists, because each roost is unique. One respondent commented that once they identify the best location for the camera, taking detailed notes of the camera placement and screen recording position is helpful, along with bringing printed screenshots to subsequent deployments. These steps can help ensure consistency for ongoing population monitoring.

Most respondents used automated counting software for their videos, including T3, BatCount, and/or ThruTracker, and had recommendations to improve software performance. Respondents noted that automated software seems more useful with large emergences than with small ones. Some suggested maintaining not only a record of screenshots of camera position, but also the "selection box" (i.e., counting area) for automated software, to aid in replication from year to year. Documenting camera position and selection box can especially help users who rely on volunteers for data collection. For some of the newer FLIR Scion models, filming cave emergences with the "black hot" color scheme (Fig. 2) improved software performance, compared to the default camera setting. An additional recommendation was to wait to start recording until the emergence began, because the background temperature can vary close to sunset, which might affect thermal contrast. Several users commented on placing the camera farther back from the cave opening than anticipated, to give the software a better chance at "picking up" bats moving through the counting zone (Fig. 2).

A common theme for all respondents was the need to develop an understanding of how automated counting software detects bats. The user with the greatest years of experience commented that "understanding thermal contrast and being familiar with your equipment's abilities will save time and repeat recordings. Having a thorough understanding of the software analysis is critical to improving accuracy. You must understand how targets (bats) are tracked, counted, lost, what happens with overlaps, where they are counted, how many frames to detection/loss, etc." (Holliday, personal interview, 27 March 2024). This knowledge comes from manually counting recorded video segments, adjusting different software settings, comparing the software count output to the manual count output, and recognizing when the count confidence is so low that software count output should be discarded. This process is not necessarily easy, as 1 user commented "the available programs seem so nuanced that I feel they need expert practitioners to process the emergence" and emphasized that workshops and/or trained individuals running a quasi-processing lab are urgently needed (Pattavina, personal interview, 4 April 2024).

In addition to comments on camera placement and analysis, other helpful tips from users included investing in a sturdy and reliable tripod, carrying backup equipment, including batteries and SD cards, using a heat pack in the frame of view to help focus and adjust the

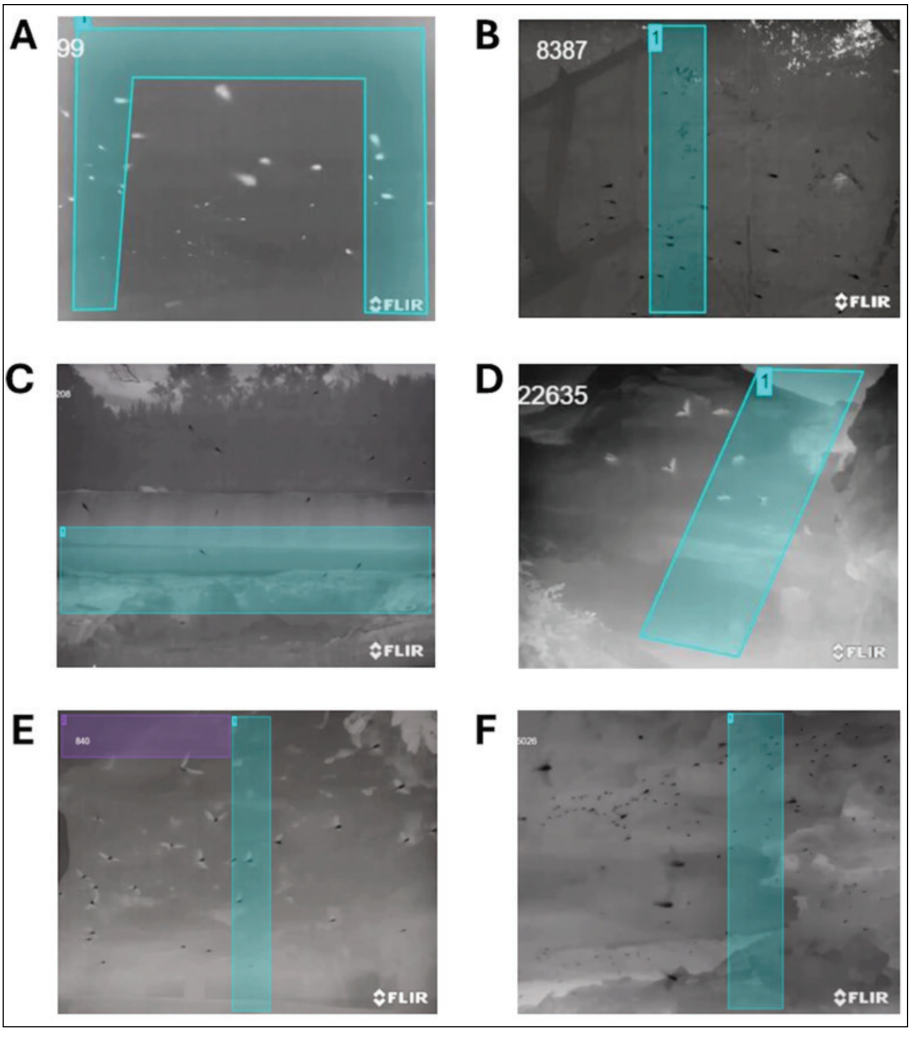

Figure 2. Example screenshots of thermal videos taken at different caves during emergence and processed through BatCount automated software. The teal boxes represent the "region of interest", which is designated by the user and identifies the area where the program counts bats as they fly through. A) Screenshot from video taken inside a cave. Bats are emerging from the center of the background; therefore, bats appear small at first, then larger as they approach the camera. B) Screenshot from video taken outside a cave. Bats are emerging from the gate chute on left. Bats are at a consistent distance from camera, but foliage is in the background. C) Screenshot from video taken outside a cave. Bats are emerging from a cave entrance located below ground level, and there is a fabric drape going across center of frame to facilitate counting. The background foliage is visible above the fabric. D) Screenshot from video taken outside a cave, close to the entrance. Bats are emerging in a consistent stream from cave entrance on right. E) Screenshot from video taken from outside a cave, with camera pointing toward the entrance. Bats are emerging from the left and flying over the gate, which is barely visible. The purple box represents a secondary region of interest to count any bats that fly across the top of the video screen. F) Screenshot from video taken inside a large space of a cave. Bats are emerging from the left at variable distances from the camera. Videos A and D were recorded with the "white hot" setting (a default setting for most thermal imaging cameras), whereas B, C, E and F were recorded with the "black hot" setting (an optional setting available on some thermal camera models).

camera, and using protective covers over the tripod legs to streamline decontamination. Users also expressed that combining thermal counts with traditional methods at a site (flashlight counting, photography, etc.) helps when comparing estimates from thermal imaging to historical counts.

Recommendations for the future

Based on our experience and feedback from colleagues, we see a clear need for better training and guidelines for both imaging bats and using counting software. Users with over 10 years of experience in imaging bats still struggle with camera placement and analysis, so expecting a new user to obtain reliable and accurate counts with minimal training is unrealistic. Despite advances in technology, simply buying a camera, recording videos, and running the video through automated software does not ensure success. Achieving high-quality videos and reliable counts from analysis software requires experience, knowledge, patience, and skill. Some respondents began thermal imaging with formalized training, while those without training either gathered knowledge from colleagues or honed their skills through trial and error. Regardless of training history, all users expressed difficulties with building skills to image and count bats using software.

Advances in computing offer the potential for automatic counting from any video platform (Bentley et al. 2023, Corcoran et al. 2021), but users of such software must understand how the algorithms work and should not treat it like a black box in which they input a video, blindly run a process, and accept the output as accurate. Because most software applications have tunable parameters to accommodate different roost environments and counting needs, no default settings apply across all recording conditions. Therefore, users must develop a comprehensive understanding of how their counting software works, how each adjustable parameter affects auto-detection and counting of bats, and how to modify parameters to obtain reliable counts. This level of understanding, however, requires significant time and resources that may be challenging for agencies that are already stretched thin. Moving forward, to obtain reliable counts of bats emerging from roosts for long-term monitoring, we make 5 recommendations.

Implement field-based workshops for thermal imaging specific to roost emergence

The key challenge our users identify is learning the optimal positioning of a thermal camera to obtain sufficient thermal contrast, resolution, and bat movement for accurate counting, regardless of whether they count the imaged bats manually or with automated software. Because many cave roosts present logistical challenges for access, each recording attempt is high stakes, and a failed recording attempt wastes precious resources. Providing hands-on, field-based training in thermal imagery could abate some of these risks. Such instruction could cover understanding camera settings, determining appropriate camera positioning, and gaining feedback on video position and quality from experts in thermal imagery. Ideally, training should take place across multiple nights and in regions with different types of caves and roosts, to expose trainees to the range of scenarios they may encounter in their work.

These sessions could potentially expand into an official certificate program, allowing individuals who complete the in-person training to qualify as leaders for more site-specific training in their home regions, in partnership with agency staff or community volunteers. Including training status in the metadata of any video or counts uploaded to repositories or monitoring programs (such as NABat) could serve as a metric of quality assurance. Implementing this certificate, however, may introduce logistical challenges, such as identifying a group or agency to oversee the certification and ensuring that training keeps pace with changing technology.

Document and archive site-specific standardized camera placement and recording settings and verify species ID with acoustic recordings

Once trained users determine the best camera location and recording settings for a given cave, documenting and archiving the information would be useful. Details including camera screenshots, tripod placement in relationship to nearby landmarks, and camera height could help create consistency in the camera position, which may influence thermal contrast and count accuracy. This documentation will not only aid in standardization for long-term monitoring, but also serve as a useful guide for other individuals monitoring the site or additional sites with similar characteristics. A centralized repository for collecting and sharing this information is necessary for knowledge transfer, but it may be prohibitive for sensitive sites for which specific location details must remain confidential to prevent unauthorized entry and/or disturbance. Potential solutions are to create agency-specific internal repositories that are not open to the broader public, to obscure the precise locations of caves and roosts, or to refer to prominent sites by their common or historical names.

One downside of thermal imagery is that it cannot be used to identify species, but in many situations, a worker can deploy an acoustic recorder that is manually synchronized to the thermal video to provide species identification. The synchronization can be accomplished with a hand clap or any other visual-acoustic marker that can be heard on the acoustic recorder and seen in the camera's field of view. To prevent recording social calls or undesirable echoes of bat signals resulting from a cluttered environment, these acoustic recorders should be placed outside, yet near, the opening to the roost in as open an area as possible. These recordings should also be collected in continuous (i.e., not triggered) mode to align with the thermal video recording.

Provide tested recommendations for imaging systems

Even experienced users often find it challenging to select the best camera for imaging bats, and many respondents selected models based on recommendations from colleagues, with camera price the primary factor considered. A trade-off exists between camera quality and cost, which currently limits options for many users. As technology continues to improve, the performance of cameras at a given price improves, and custom-designed imaging systems are becoming a more affordable option, allowing users to work directly with manufacturers to create custom housing and external features for field-specific applications.

With ever-changing technologies, selecting an appropriate camera can create confusion, especially for individuals aiming to maximize performance while reducing cost. Many commercially available cameras are intended for industrial applications, which makes it difficult for some manufacturers to recommend cameras for bat imaging. Furthermore, without ground-truthing or standardization, comparing videos recorded by different models can be problematic.

To aid users with camera selection, a list of recommended camera models that have been field tested by experienced surveyors could be compiled and updated every few years. Creating a centralized "lending library" of recommended camera models could also facilitate emergence monitoring with updated equipment while reducing the cost, especially for a single entity that may only need to image a few sites per season. Developing the collection, lending the equipment, and maintaining this library will require additional resources and staffing, but could become a viable option through inter-agency partnerships or collaborations with academic institutions. Another option is to create a list of recommended cameras that can be rented from vendors for infrequent use.

Dedicate staff to maintain automated counting software and provide user support

The rise of several automated counting software has significantly reduced the effort needed to count large numbers of bats in thermal videos. By uploading a video and selecting site-specific parameters, users can push a button and return several hours later with a bat count. These current software options are still free and open source. Unfortunately, despite efforts to create user-friendly interfaces and documentation, our experience in working with users of BatCount indicates that individuals still face a steep learning curve in understanding the intricacies of each program and how to adjust the parameters to obtain the most accurate count possible. Furthermore, understanding how video quality and software parameters influence error rates in population estimates is important for counting accuracy.

Many of the programs for bat counting were developed as offshoots of imaging software by developers with an image-processing background and intimate knowledge of the software. Lacking this background, many novice users of bat-counting software seek training and support from the developers, who struggle with limited resources to provide these services. As a result, software users can become stuck while troubleshooting the software or produce inaccurate results due to poor parameter tuning. One easy solution would be to commercialize the software to provide dedicated customer support through a for-profit model, but this approach would contradict the mission of open-source software. An alternative recommended by the developers of BatCount is to secure funding for a full-time employee who would create training documentation, lead training workshops on software operation and analysis, maintain and update software based on user feedback, and provide technical support to users.

Create a centralized database to archive emergence videos

Analysis of thermal videos currently deemed too poor in quality for use may become feasible with the rapid advancement of machine learning. Due to large file size, many historically recorded videos are stored on external hard drives that are scattered across desks of researchers throughout the world, but these drives are vulnerable to corruption and subsequent data loss. These older videos should be regarded as important artifacts with historical and ecological significance and preserving them should be a priority. In addition, having a centralized database of manually counted videos would allow for easier comparison of different software performance and parameter settings across similar videos. Advances in storage capacity, internet bandwidth and speed, and file-sharing repositories now make this option feasible, but require a single agency or institution to manage and fund. We recommend NABat consider leading this initiative, as they continue to expand their efforts to advance bat conservation across North America.

Conclusion

Thermal imagery provides the potential to obtain accurate roost counts of bats during emergence and is gaining popularity, as the cost of thermal-imaging cameras continues to decrease. Despite its advantages compared to historical approaches, the steep learning curve to capture high-quality images and gain proficiency with automated software remains a significant limitation to wide adoption of roost monitoring via thermal imagery. We outlined several recommendations to overcome these limitations. These include training users, standardizing camera placement, testing and endorsing hardware, lending equipment, funding staff to maintain automated counting software and provide support, and creating a centralized archive of thermal videos. Implementation of these recommendations will undoubtedly require an investment in resources and inter-agency collaboration, but can help advance a standardized framework to ensure high-quality data for both baseline population and long-term monitoring.

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