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

[illegible][1] [illegible][2] [illegible][3] [illegible][2]

[illegible]
conditions, and cease to emerge in artificial illumination. Recent advances in thermal imagery have [illegible]
viable option to record bat emergence for population counting. Researchers have developed automated [illegible]
software accuracy. Recognizing the importance of video quality, we compiled a perspective on using [illegible]

Introduction

[illegible]
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). Research- [illegible]
surveys, during which researchers use light and noise to rouse bats into flight for counting,

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al. 2016; Revilla-Martín et al. 2021). Researchers have used image-enhancement technolo- [illegible]
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 [illegible]
gistical challenges in the field can arise due to limited illumination range and power require- [illegible]
make it difficult to discern them against the background (N. Sharp, Alabama Wildlife and [illegible]
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, [illegible]

[illegible]
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 [illegible]
Cullinan et al. 2015; Horn et al. 2008; Matzner et al. 2015, 2020; Perrow 2017). Research- [illegible]
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 [illegible]

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 [illegible] *Miniopterus australis* [illegible]
[illegible] *Leptonycteris nivalis* [illegible]
[illegible] *Tadarida brasiliensis* [illegible]

[illegible] *Myotis grisescens* [illegible] over time is challenging, as it is unclear whether these changes reflect a true difference in [illegible]

[illegible] 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 [illegible] *Pseudogymnoascus destructans* [illegible] era 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- [illegible]

[illegible] them on thermal video. Unsurprisingly, manual counting was the first and simplest tech- [illegible] 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 [illegible]

Researchers have continued to design similar algorithms specifically for bats, calculat- [illegible] tov et al. 2008). Recently, developers released 2 open-source utilities that analyze thermal [illegible] different video formats to count objects moving through user-specified regions of interest [illegible]

[illegible] how the counting algorithms detect and track bats to ensure the software outputs reflect ac- [illegible] the bat community, the authors of this paper have identified a disconnect between the desire [illegible]

[illegible] good as the quality of the video and the knowledge and proficiency of the user. Based on our [illegible] into a large-scale monitoring program, such as the North American Bat Monitoring Program [illegible]

Perspectives from colleagues

[illegible] - [illegible] 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 [illegible] 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 [illegible]

[illegible]	Affiliation
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	Georgia Department of Natural Resources
Pete Pattavina	[illegible]
Piper Roby and Will Seiter	[illegible]
[illegible]	[illegible]

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).

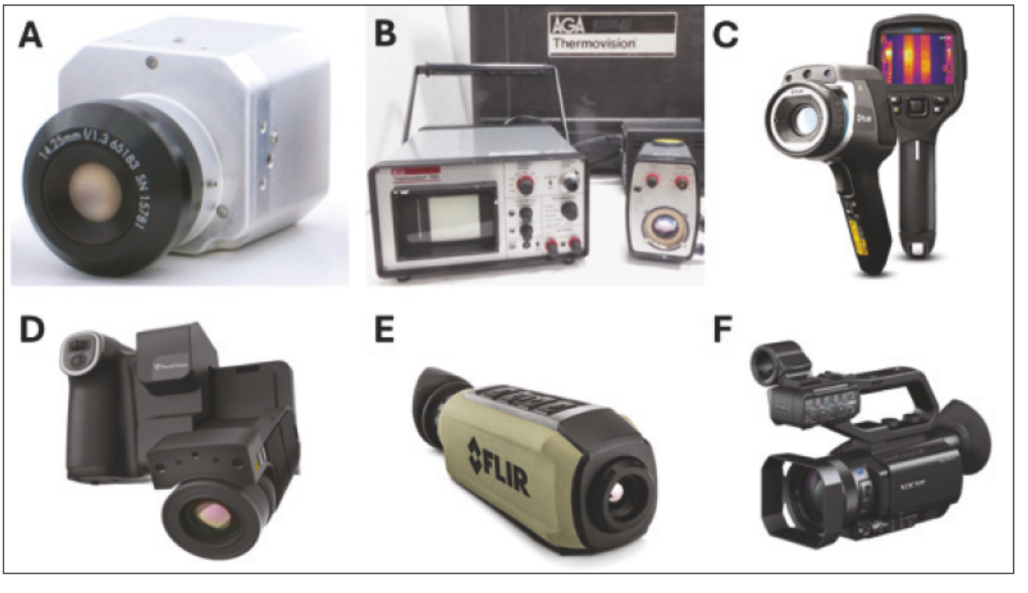

Figure 1. Examples of thermal imaging equipment used to record bat emergences. A) FLIR Photon, B) AGA Thermovision 782, C) FLIR E60, D) Planck THH-960, E) FLIR Scion OTM, and F) Sony PXW-X70.

Participants emphasized that the most important factor for a successful recording was [illegible] 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 [illegible]

[illegible] B Count, and/or ThruTracker, and had recommendations to improve software performance. Re- [illegible] who rely on volunteers for data collection. For some of the newer FLIR Scion models, filming [illegible]

A [illegible] software analysis is critical to improving accuracy. You must understand how targets (bats) [illegible] when the count confidence is so low that software count output should be discarded. This [illegible] needed (Pattavina, personal interview, 4 April 2024).

[illegible]

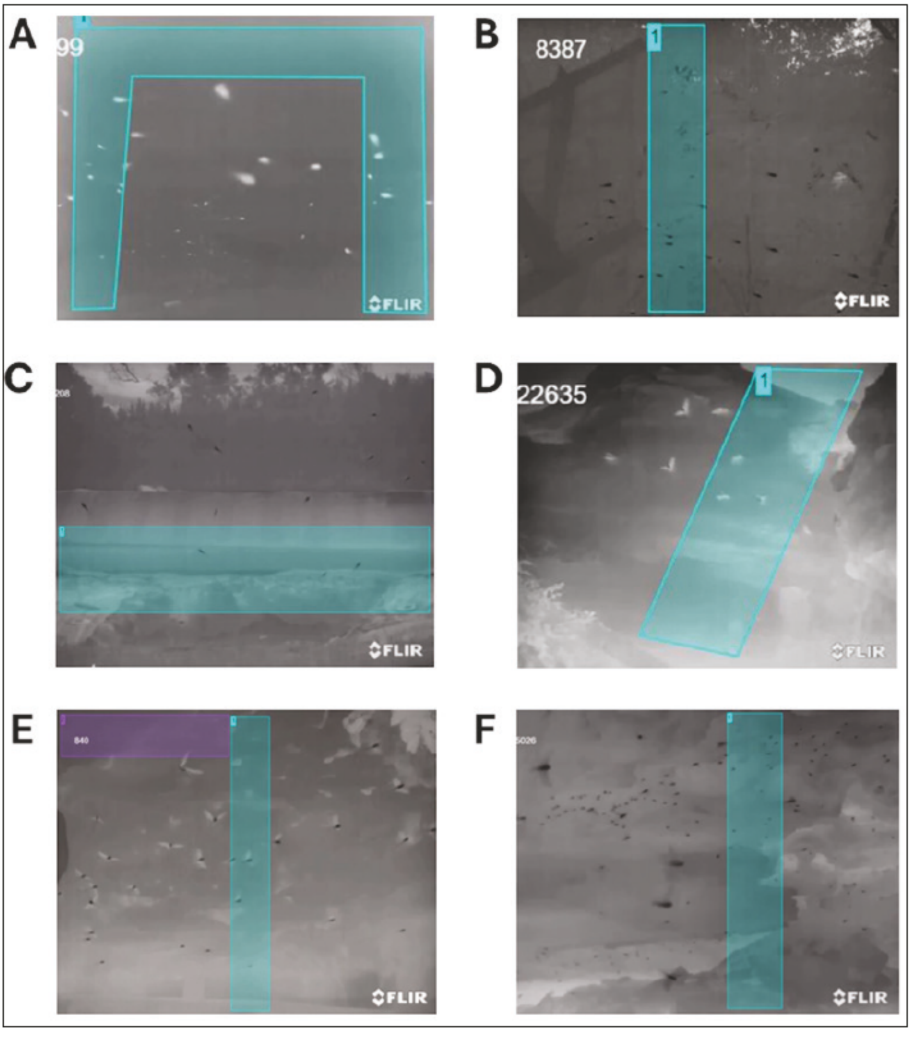

Figure 2. Example screenshots of thermal videos taken at different caves during emergence and processed through BatCount automated software. The teal boxes represent the "region of interest", which is designated by the user and identifies the area where the program counts bats as they fly through. A) 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).

[illegible]
Users also expressed that combining thermal counts with traditional methods at a site (flash- [illegible]

Recommendations for the future

[illegible] trial and error. Regardless of training history, all users expressed difficulties with building [illegible]

[illegible] obtain reliable counts. This level of understanding, however, requires significant time and [illegible]

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

[illegible] camera to obtain sufficient thermal contrast, resolution, and bat movement for accurate [illegible] 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 [illegible]

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 [illegible] menting 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 [illegible]

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

[illegible] could help create consistency in the camera position, which may influence thermal contrast [illegible] sites for which specific location details must remain confidential to prevent unauthorized entry and/or disturbance. Potential solutions are to create agency-specific internal reposi- [illegible] thermal video to provide species identification. The synchronization can be accomplished [illegible] corder and seen in the camera's field of view. To prevent recording social calls or undesir- [illegible]

Provide tested recommendations for imaging systems

Even experienced users often find it challenging to select the best camera for imaging [illegible] facturers to create custom housing and external features for field-specific applications.

W[illegible] ficult for some manufacturers to recommend cameras for bat imaging. Furthermore, without [illegible]

T[illegible] field tested by experienced surveyors could be compiled and updated every few years. Cre- [illegible] staffing, but could become a viable option through inter-agency partnerships or collabora-

[illegible]

Dedicate staff to maintain automated counting software and provide user support

The rise of several automated counting software has significantly reduced the effort [illegible] site-specific parameters, users can push a button and return several hours later with a bat [illegible] influence error rates in population estimates is important for counting accuracy.

[illegible] commercialize the software to provide dedicated customer support through a for-profit mod- [illegible]

Create a centralized database to archive emergence videos

[illegible] feasible with the rapid advancement of machine learning. Due to large file size, many his- [illegible] and ecological significance and preserving them should be a priority. In addition, having [illegible] storage capacity, internet bandwidth and speed, and file-sharing repositories now make this [illegible]

Conclusion

[illegible] 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

[redacted]

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A [redacted]
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