DOI: 10.30427/ecotrop201907

INTERNATIONAL JOURNAL OF TROPICAL ECOLOGY

SHORT COMMUNICATION

USE OF SMARTPHONES IN SCIENCE: EVALUATION OF LOW COST AND ACCESSIBLE METHODS TO IDENTIFY AND STUDY ROOSTING BATS

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Keywords: Chiroptera, Bat Behavior, Tropical Bats, Thermal ecology, Echometer, *Myotis nigricans*

INTRODUCTION

Activity patterns of bats at colonial roosts vary according to many factors, including seasonal species requirements, temperature, and overall physiological ecology of bats, which utilize a variety of urban and forested roosting habitats (Garcia-Ruiz *et al*. 2017, Kunz 1982). Elucidating these patterns may add greatly to our understanding of bat behavior as current threats to bat populations are numerous, including potential increases in hyperthermia related to climate change as well as a reduction and loss of forested habitats (Estrada *et al*. 1993, Welman *et al*. 2017). Video analysis and infrared thermal imaging are powerful tools for studying mammal behavior and quantifying body surface temperature and may provide important baseline data on environmental preferences of roosting bats (Dezecache *et al*. 2017, McCafferty *et al*. 2015). Moreover, thermal imaging, or infrared thermography (IRT) is useful for detecting and investigating mammals with elevated surface body temperature relative to their abiotic surroundings (Hart *et al*. 2015, McCafferty 2007, Vandecasteele *et al.* 2017). Infrared video technology has previously been utilized as a non-invasive method for quantifying roost exit counts or emergence (Elliott *et al*. 2006, Divoll *et al*. 2015). Presently, little information is available regarding methods for recording activity patterns and behavior using emerging, low-cost handheld technology. Traditional techniques require infrared or thermal imaging cameras costing several thousands of dollars. Increasingly, handheld smartphone-enabled bat detectors are being utilized to monitor and identify bats (Willie *et al*. 2018, Frank *et al*. 2019). The use of many of these methods is likely to become more widespread as technological advancements emerge utilizing applications of smartphones, and as digital recorders and cameras become more affordable. Here, we report on the efficacy of a low-cost infrared camera, a novel smartphone thermal camera, and an ultrasonic smartphone bat detector we used to document diurnal and nocturnal bat behavior at roosts in Panama.

MATERIALS AND METHODS

Study area. The study was conducted over four days between 07-Jan-2018 and 10-Jan-2018 in Chiriquí province, Panama (8° 12′ 20.38″N, -82° 11′ 44.67″W) at 19 meters above sea level. The local landscape is comprised of coastal private property, mixed secondary forests, and agricultural and urban development. The roost consisted of a 2.7 m by 5.5 m open concrete structure below an aluminum roof adjacent to a dwelling (Fig. 1a). To correlate bat activity and emergence (i.e. number of flights observed) with environmental variables, we obtained weather metrics (wind speed, barometric pressure, sunset, and moon phase) from online sources (www.timeanddate.com, last accessed: 03 May 2018), as these are often associated with emergence times in insectivorous bats (Thomas & Jacobs 2013)

Acoustic Identification. We identified bats using the Echo Meter Touch 2 ultrasonic recorder (~$200 US) attached to an iPhone and Echo Meter Touch application firmware version 2.2.7 (Wildlife Acoustics, www.wildlifeacoustics.com). We used the following settings when recording; audio division rate of 1/20, gain set to medium, trigger minimum frequency 8 kHz, medium trigger sensitivity, 3 second trigger window, and sample rate of 256K. During video recordings (see below), we recorded files with calls of individual bats exiting and flying in front of the observed roost periodically and saved them as WAV files. Acoustic files containing calls were initially identified to species in real-time using the Echo Meter application auto ID selection for the Neotropics. Recordings were also identified in Kaleidoscope Pro (version 4.2.0, Wildlife Acoustic, Inc.) using the Neotropical classifier (version 4.2.0). We used the default "Panama" setting to determine the species included in the call identification model. When viewing full-spectrum files, the Kaleidoscope viewer uses a Hanning window, with FFT size of 256 and 50% overlap (default settings). Kaleidoscope automatic identification works on zero-crossing technology in which WAV files are converted to Zero crossing and analyzing zero crossing dots. Moreover, this device and related software uses a patented clean-up full spectrum signal prior to zero crossing and utilizes smart filtering using digital signal processing techniques to improve signal to noise ratio against Gaussian noise (Wildlife Acoustics, personal communication).

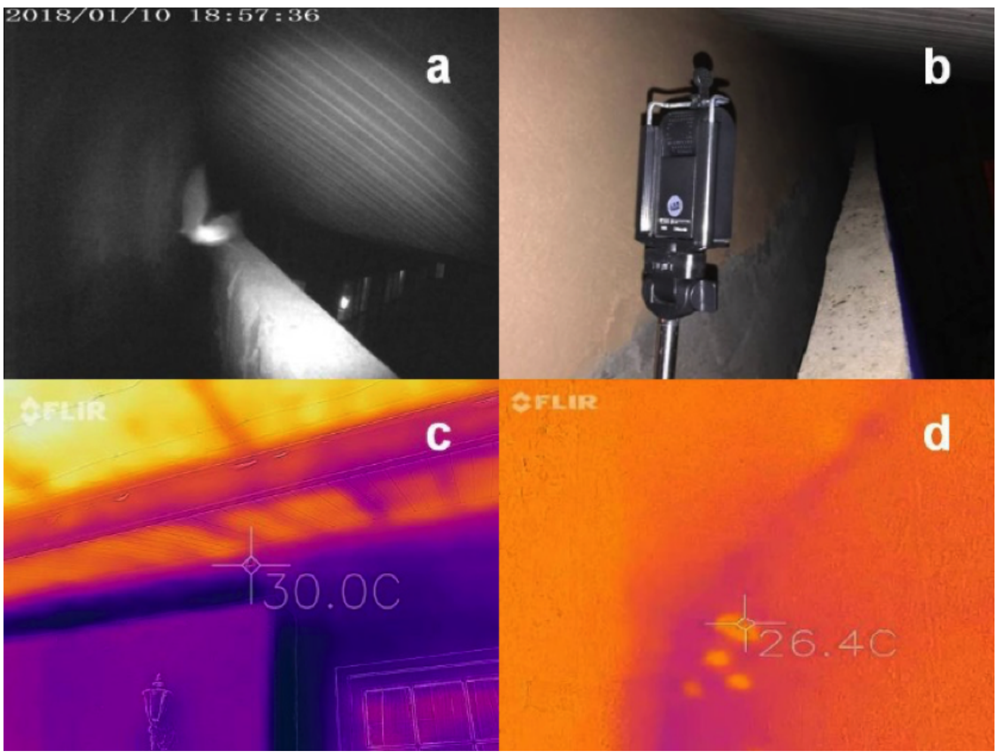

Figure 1. (a) *Myotis nigricans* observed in flight outside roost in Panama and (b) infrared camera deployment. Example of thermal images captured using FLIRONE smartphone camera of diurnal roost temperature of (c) single bat outside of roost and (d) several bats inside the roost. Photographs by Shem D. Unger.

Roost Behavior. We deployed a 720 P HD Conbrov "spy camera" T11 model (~$50 US), with built in 1000 mAh battery, PIT sensor detection angle 60 degrees with detection distance 5-10 meters, 30 frames per second recording rate, maximum continuous recording time of 1.5 hours, to document roost behavior. This camera was equipped with night vision (infrared illumination) capabilities ~up to approximately 1 meter and was positioned directly in front of an open top concrete roost of Black Myotis bats (identified as *Myotis nigricans* using acoustic recording on an Echo Meter Touch 2, and confirmed in Kaleidoscope software, Wildlife Acoustics). This camera was deployed on telescoping poles for 1 hour intervals per day over 4 consecutive nights just before sunset, with start times between 18:55h to 19:12h, to coincide with acoustic monitoring (Fig. 1a & b). Video was recorded on 32 GB microSD cards. Video was reviewed by the authors on a VLC media player at ¼ and ½ speeds for presence of bats. All flight activities of bats entering and exiting the roost, and flying inside and outside of the roost were quantified. Distinct behaviors observed included the number of emergence flights (bats exiting the roost), return flights (bats entering the roost), trailing flights (when one bat was observed immediately after another bat in less than 1 second), internal flights (shorter movements of bats within the roost visible on camera), and external flights (bat flights directly in front of or above roost).

Thermal Imaging. To document the body temperature of bats visible during diurnal roosting we used the FLIRONE thermal camera (~$200 US, Flir Systems, www.flir.com) connected to an iPhone to obtain digital thermograms. This camera is capable of recording temperatures in the range of -20 to 120 °C at a thermal resolution of 80 X 60 IR pixels (www.flir.com). We used the spot feature to document external surface temperature of bats and confirmed this using FlirTools image analysis software. We also quantified mean body temperatures of roosting bats and the ability of FLIRONE thermal software to detect heat signatures of individual bats in flight upon emergence during daylight and, periodically, of bats within the visible roost entrance area (Fig. 1c & d).

RESULTS

Weather Metrics. Sunset was at 19:02h with a third quarter moon for the full length of the observation period. Average daily temperature, percent humidity and barometric pressure were 27.5°C, 27.2%, and 29.76 hg respectively. Wind speed for 07-Jan-2018, 08-Jan-2018, 09-Jan-2018, and 10-Jan-2018, was 9.7, 19.3, 14.5, and 9.7 km/hr respectively.

Acoustic Identification. To identify species correctly, we periodically recorded calls ('pulses') during video recording with the Echo Meter Touch 2 from a distance of approximately 5 meters directly in front of the roost entrance with bats, in most cases, visibly in flight directly in front of roost, following Frank *et al*. (2019). We excluded files containing low quality calls, and analyzed a total of nineteen files of *M. nigricans* for identification (five from day one, eight from day two, one from day three when rain was occurring during monitoring, and five from day four) representing a total of 555 pulses. Further analysis of acoustic files using Kaleidoscope Neotropical Classifier (Fig. 2a & b) for species identification were performed using a combination of automatic identification Echo Meter Touch 2 application automatic ID, and Kaleidoscope Pro (Wildlife Acoustics), followed by manual inspection for all file identifications with the following parameters: characteristic frequency (Fc) ~51.2kHz, total duration of echolocation calls (Dur) 2.4 milliseconds, maximum call frequency (Fmax) 66.4kHz, minimum call frequency (Fmin) 50.6 kHz, frequency at the knee 54.1 (Fk) kHz, quality of the knee 2.8 (Qk), and slope at the start of the call (Sl) 532 kHz/milliseconds, identified as *M. nigricans* following similar parameters for the same species observed in Siemers *et al*. (2001). Output and visual inspection of Kaleidoscope Pro resulted in all files being confirmed as *M. nigricans* which matched initial identification using the Echo Meter Touch 2 application.

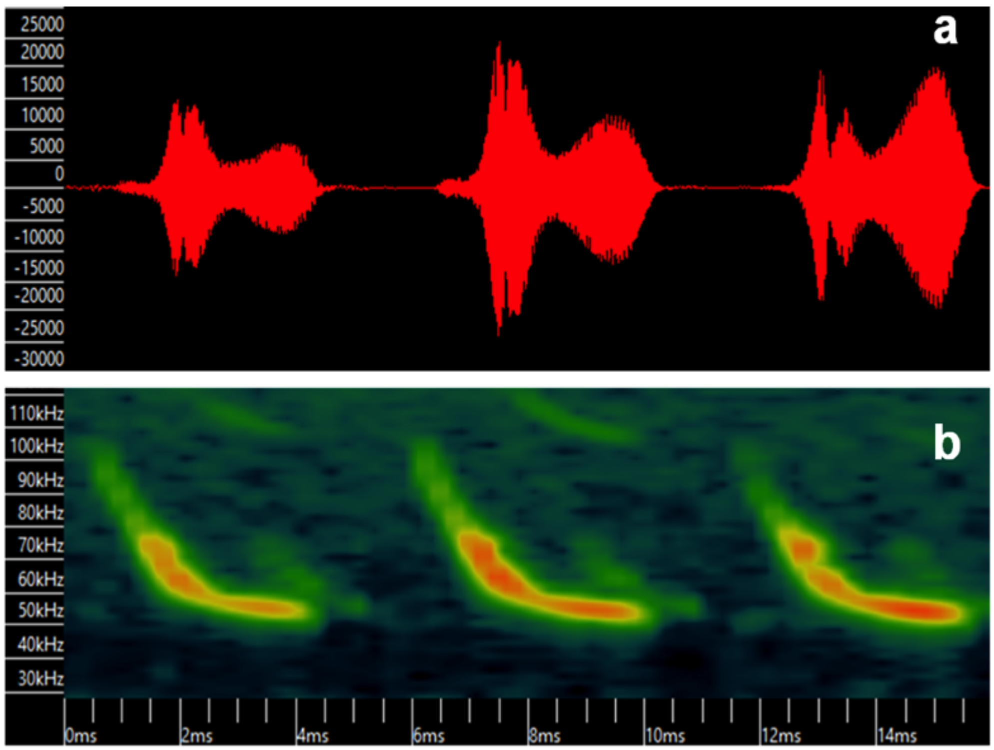

Figure 2. Examples of echolocation call identified as *Myotis nigricans* using the Echo Meter Touch 2 application and identified in Kaleidoscope (Wildlife Acoustics). Oscillogram shows (a) time versus amplitude (dB) and (b) echolocation call sequence close-up of three calls..

Roost Behavior. The camera provided consistent clear video capable of identifying bats in flight visibly leaving and entering the roost when reviewed at ¼ and ½ speeds and when video still images were reviewed using the VLC player. We documented a total of eighty-four total observations of activity of individual bats in the course of four days representing several behaviors including thirty-two emergence flights, thirty-four return flights, two trailing flights (two individuals observed following within one second), four internal flights (short movements within the roost), and twenty-six external flights (bats flying directly in front of or above the roost; Table 1).

Thermal Imaging. We observed single bats exiting the roost periodically (~ four to five times daily between 8:00 h to 14:00 h). Mean surface temperature of bats recorded by the FLIRONE during diurnal activity was 29.49 + 0.78°C (N = 18), whereas mean surface of bats inside the roost was 25.69 + 0.58°C (N = 14). Internal and external temperature of the roost structure was 25.69 + 0.58 °C and 27.925 + 1.33°C, respectively.

DISCUSSION

We illustrate the efficacy of a handheld iPhone-enabled acoustic identifier, the Echo Meter Touch 2 detector and FLIRONE thermal imaging camera, in addition to an affordable night vision video camera, to identify and characterize nocturnal and diurnal bat roosting activity. Although more advanced thermal imaging cameras exist to collect more detailed thermal information for roosting bats, the FLIRONE is a promising affordable tool (~$200 US) to determine relative temperature differences between bats and their environment. We successfully noted individual *M. nigricans* bats exiting and returning to roost, in addition to documenting flights inside and outside of the roost.

In this study, we show that activity patterns of bats can be readily documented using both a low-cost night-vision camera and smartphone-attached thermal imaging camera and bat detector. These devices are ideal for roost counts as they last at least 60 minutes. We expect non-invasive camcorders with infrared capabilities or infrared lights, which are ideal for observations of bats (Knörnschild *et al*. 2014, McFarlane *et al*. 2015, Young 2006), to increase in use as advances in digital technology increase and become increasingly affordable. However, we caution observers monitoring larger colonies in which bats may emerge in larger numbers or in greater frequencies to position themselves at ideal distances from roosts to maximize acoustic recording and video monitoring. Moreover, we successfully recorded echolocation calls using the detector and identified roosting bats as *M. nigricans* in Kaleidoscope Pro, indicating the potential for hand-held bat recorders to identify individual bat species in low clutter environments (in proximity to the roost area). The call parameters we observed are consistent with observed *M. nigricans* recorded calls (Siemers *et al*. 2001). We caution researchers, however, and recommend utilizing both hand capture and possible use of other bat detectors to confirm and validate species identification of bats initially identified with the Echo Meter Touch 2 application, particularly in the tropics where diversity is high. Researchers could further assess the reliability of hand-held detectors for species identification with visual inspection, possibly recording calls when releasing mist-netted bats, and also validate using other non-invasive sampling such as DNA barcoding of guano or genetic sampling of small tissue samples from individuals.

Our methods require minimal financial investment (i.e., when used with smartphones) and can be modified to meet specific needs of researchers to characterize roost selection and individual behavior of bats. We recommend this affordable night-vision video be used if species identification is confirmed via other methods, as we found video analysis to work primarily for enumerating single bats and small colonies (< 25 individuals per roost). We also recommend increasing the video capture quality (frames per second) for night-vision cameras, as bat were readily visible in video played at ½ and ¼ speeds in flight, but occasionally appeared blurry when single-stop motion frames of recorded video were analyzed. Application of thermal imaging to quantify roost individuals needs further study, as we were only able to use thermal imaging to quantify a small number of individuals. Because the entrance to the roost was a small opening in concrete, it is likely several bats may have accessed the lower portion of the concrete structure. Use of this affordable thermal imaging camera may provide further thermal resolution in areas with more contrasts in temperature (eg. winter roosting bats in North America and Europe) and thus generate thermal pictograms for roosting bats in temperate climates. We recommend concomitant deployment of multiple cameras with marking techniques, such as fluorescent tagging of bats for individual identification, further characterization of emergence and external flights as foraging flights, and future demographic studies in urban Neotropical environments.

ACKNOWLEDGEMENTS

We thank the Smithsonian Tropical Research Institution for permitting access to our research sites, and La Fundación Kucikas for funding. Travel funds for this project were provided by a 2018 Wingate University's WINGS travel grant and Wingate University Biology Department.

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