Listening for Bats

Exploring the Audiomoth for acoustic monitoring of bats in Nova Scotia

www.merseytobeatic.ca info@merseytobeatic.ca 902-682-2371 9 Mount Merritt Road, Kempt, Nova Scotia

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Prepared by Lori Phinney, Species at Risk Biologist, MTRI

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Partners include the Confederacy of Mainland Mi'Kmaq, Canadian Wildlife Service, Parks Canada, Nova Scotia Department of Lands and Forestry (NS DLF) Wildlife Division, Nova Scotia Environment, Taylor Lab, Acadia University, Nova Scotia Bird Society, Mersey Tobeatic Research Institute, and Nova Scotia Nature Trust.

Background

Listening Together Project

The Listening Together project is a collaborative effort to explore acoustic monitoring technologies to listen for species at risk in Kespukwitk, southwest Nova Scotia. Emerging acoustic technologies are expanding the potential to monitor biodiversity on a large scale. By using cutting edge acoustic technology, we can research and monitor various taxa across the landscape. Lead by John Kearney and Associates, this project is targeting at-risk birds and bats through partnerships with Mi'kmaq communities, conservation and research organizations, and university and government scientists. The goal of the project is to use acoustic monitoring to characterize the importance of various ecosystems to overall biodiversity. Specifically, we want to identify ecosystems significant to at-risk birds and bats to improve conservation and better inform management. Through our partnerships, we want to monitor biodiversity, build relationships, develop tools for analyses, and promote community monitoring. The Mersey Tobeatic Research Institute (MTRI) is leading the bat component of this project. MTRI has been involved in bat conservation since 2013, working with partners to research and monitor at-risk bats and educate the public.

Year One

In year one, as part of the Listening Together project, MTRI focused on supporting and developing relationships for long-term bat monitoring and conservation. MTRI specifically 1) designed a work plan to adapt acoustic monitoring efforts in Kespukwitk to the North American Bat Monitoring program (NABat), and 2) hosted a meeting for Atlantic Canada bat researchers to facilitate knowledge sharing.

Below is a summary of those activities and their contribution to bat conservation efforts in the region.

<u>NABat Program:</u> MTRI created a workplan to review monitoring protocols, inventory, estimate required resources (equipment, funds, effort), and identify priority sites for monitoring (Lori Phinney, 2020). MTRI engaged Parks Canada, Acadia First Nation (AFN), and Bear River First Nation (BRFN) in developing this workplan and prioritizing sites that were of interest to both the NABat program and these groups. As a result of year 1 efforts of the Listening Together project, these partnerships and the NABat workplan accelerated the first NABat trial monitoring during the summer of 2020. As part of long-term monitoring efforts by Parks Canada, the first two grid cells were monitored in Kejimkujik National Park and National Historic Site (KNPNHS) during July 2020. COVID-19 restrictions limited the capacity to conduct field data collection and thus only these two of several priority sites were monitored. Also initiated during 2020, the Canadian Wildlife Health Cooperative (CWHC) began establishing the NABat program across Atlantic Canada in partnership with provincial government biologists. The CWHC hosted a series of online workshops to train interested organizations and individuals on NABat monitoring protocols, where AFN and BRFN were able to participate in a workshop hosted on Feb. 18, 2021. MTRI will continue to engage with these partners and support implementing NABat in the region.

<u>Atlantic Canada Bat Meeting:</u> MTRI initially planned an in-person meeting of bat researchers in partnership with KNPNHS in late March 2020. Due to COVID-19 restrictions, the meeting was rescheduled to April and formatted to be a series of video-recorded online presentations concluding with a Zoom discussion. Moving the meeting online allowed more individuals and organizations to participate, with over 70 participates in total. We renamed the event to the Atlantic Bat Symposium,

presenting a series of ongoing bat research and outreach projects in the region. This began on International Bat Appreciation Day (April 17) including talks on bat research in NB, PEI, NFLD, Cape Breton, acoustic monitoring, WNS and stewardship. We had participants from Trent University, University of Waterloo, Indigenous communities, Parks Canada, eNGO's, federal and provincial government. After the meeting we conducted an exit survey and identify future directions for the bat research community with feedback from 27 individuals. Participants identified a need to provide more opportunities for Atlantic Canadians to come together to discuss bat conservation (85.2% responded yes to this question). As well, participants would like another bat workshop organized in the future (26/26 who responded said yes) with 81.5% suggesting annually or and 14.8% preferring every 2 years. Participants are also interested in learning more about bat boxes and best practices for monitoring Northern myotis.

Purpose

Year Two

In year two, the overall goal for the bat component of this project was to explore potential of using the Audiomoth acoustic device for citizen scientist bat acoustic monitoring. The Audiomoth is a low-cost (~50 USD unit and ~35 USD case), open source environmental acoustic sensor (Hill et al., 2019). The Audiomoth has a range of applications as this device can record in the audible and ultrasonic range in terrestrial environments. The device was originally developed by Alex Roger's group at Oxford University and the University of Southampton for a citizen science project to monitor cicada species (Browning et al., 2017). Since then, these devices have been used for a variety of applications such as bird and amphibian monitoring (LeBien et al., 2020).

For bats, there is a long history of using acoustic sensors to detect, record and identify bats commonly known as 'bat detectors'. This is because bats are relatively difficult to study, as they are active as night, elusive, and many species emit ultrasonic echolocations above the human hearing range (Frick, 2013). The first bat detector was made in 1938 and now today there are an array of acoustic sensors on the market for monitoring (Zamora-Gutierrez et al., 2021). One of the barriers to bat acoustic monitoring is the cost of recorders, with commercial devices like the Song Meter SM4BAT-FS from Wildlife Acoustics (www.wildlifeacoustics.com) costing ~949 USD (see Adams et al., 2012 for more devices). The Song Meter is currently being used as part of standardized acoustic monitoring of bats across Atlantic Canada coordinated by the Canadian Wildlife Health Cooperative (Mcburney & Segers, 2020). This acoustic monitoring is a component of, and contributes to, the continent-wide North American Bat Monitoring Program (Loeb et al., 2015). Given the cost of these devices, equipment is shared among organizations across provinces resulting in a limited number of sites that can be monitored.

Although bat acoustic monitoring presents several challenges (Browning et al., 2017), the Audiomoth may help relieve some of these barriers and limitations. Because of their low cost, more devices can be purchased with limited resources, thus increasing the capacity to involve the public and the ability to purchase more sensors. This provides the potential to conduct large-scale projects, such as targeting rare bat species at a larger number of sites (e.g. Weston, 2020), and conducting a long-term citizen science monitoring programs like the National Bat Monitoring Programme in Great Britain (Barlow et al., 2015). Audiomoths may also be advantageous for their low power consumption, small size and weight (size of a credit card) and ease of use (Hill et al., 2019). Although, the performance of the Audiomoth relative to traditional monitors is unknown.

Goals

With the recent implementation of standardize bat acoustic monitoring in the Atlantic Canada and emergence of an acoustic monitoring tool that addresses some of the barriers to previous tools, our primarily goals in this study were to:

1. **Audiomoth Configuration:** setup and assess the Audiomoth for acoustic monitoring of at-risk bat species in Nova Scotia.
2. **Performance Test:** compare bat activity captured by the Audiomoth to the Song Meter SM4BAT.
3. **Summarize Recommendations:** develop recommendations for bat acoustic monitoring in the region by citizen scientists.

Methods

Study Site

In Nova Scotia prior to the invasion of White nose syndrome (WNS) in 2011 (Nova Scotia Department of Lands and Forestry, 2011), the historically most abundant bats were hibernating species. This includes the Little brown myotis *(M. lucifugus),* Northern myotis *(M. septentrionalis),* and Tri-colored bat (*P. subflavus)* (Broders et al., 2003; Moseley, 2007; Nova Scotia Department of Lands and Forestry, 2011; Taylor, 1997). Small numbers of migratory species including *Lasiurus cinereus, Lasiurus borealis, Lasionycteris noctivagans* and few, if any *Eptesicus fuscus* have also been documented (Lucas & Hebda, 2011; Rankin, 2017; Taylor, 1997). By 2013 in Nova Scotia, 93% of *Myotis* spp. declined at the major hibernation sites (COSEWIC, 2013). Due to WNS, the three hibernating species were provincially and federal listed as Endangered (Environment Canada, 2018). More recent population monitoring shows activity levels and capture rates of these species still remain low (Grottoli & Broders, 2020; L. Phinney, 2020).

Initial plans were to acoustically sample in Queens County during the fall of 2020 near areas of previously identified bat activity e.g. foraging sites and maternity colonies. Given the COVID-19 restrictions and the postponement of numerous projects to the fall, acoustic deployments were delayed from fall to winter. Acoustic sampling was conducted in Annapolis County at a bat overwintering site (Figure 1). Bat activity is typically higher outside of winter, although bats arouse a handful of times during hibernating. For example, Little brown myotis have been found to shift arousal from after sunset in early winter to random arousal during mid/late hibernation (Czenze & Willis, 2015). The presence of bats at this site was discovered after the invasion of WNS and monitoring began in 2015. Up to 50 bats have been identified at the site with regularly ~35 individuals since 2015 (personal communication, Pam Mills, NS DLF). The presence of bats at the site can be visually observed from outside the structure and this was confirmed during December 2020 (Figure 1).

No survey effort has been conducted at this site since January 2020, when there were 36 bats identified, due to COVID work restrictions and concerns of exposing bats to the virus (personal communication, Pam Mills, NS DLF). The CWHC advised a precautionary approach to protect bats from potential infection with SARS-CoV-2 until more information is available (Canadian Wildlife Health Cooperative, 2020). The current susceptibility of Canadian Wildlife to SARS-CoV-2 is not known but reports indicate some species of wildlife are susceptible to infection. Research activities involving handling or close contact to bats are advised to be postponed.

Figure 1. Bat overwintering site in Nova Scotia acoustically sampled during December 2020. Acoustic equipment was placed outside the entrance to the site.

Audiomoth Configuration

Three Audiomoths were set up to optimize sampling for bat detection. They were deployed ~11 m away from the site entrance and 3 m high on metal poles with each unit in a waterproof case adjacent to the next unit (Figure 2). Audiomoths were zip tied in a line to a section of wood mounted at the top of the metal poles. The first deployment was from Dec. 3-8, 2020 from 16:30-21:30 with no bat activity detected so a second deployment was conducted from Dec. 16-24, 2020. Audiomoths were programmed to record close to sunset from 17:00 to 21:00 as sunset was reported to be between 16:39-16:43 during the recording period (https://www.timeanddate.com/sun/). We used 64 GB Sandisk Extreme UHS Speed Class 3 (U3) microSDHC cards as high performance memory cards are necessary for high sample rates. The Audiomoth Configuration App estimated with this SD card size the units would record 7 GB/day allowing for a recording period of 9 days in total using 3 lithium batteries.

Figure 2. Bat overwintering site acoustically sampled during December 2020 using 3 Audiomoths and 1 Song Meter SM4BAT-FS with a U2 Ultrasonic Microphone. Acoustic equipment was positioned outside ~11 away from the entrance to the site.

The Audiomoths were programmed to settings recommended by North American Bat Monitoring Program for the Atlantic Canada region (Table 1; Mcburney & Segers, 2020). This included the frequency range and sample rate. For settings not corresponding to NABat, we reviewed recommendations from the Audiomoth Support Forum (https://www.openacousticdevices.info/support). This included the gain and amplitude threshold (Table 1). All three Audiomoths were programmed to the same settings, using the firmware 1.5.0, except for the amplitude threshold setting. This setting is designed to reduce recorded file size, where audio segments that contain a sample value greater or equal to the threshold will be saved and thus avoids saving periods of silent audio segments (Open Acoustic Devices, 2020). The threshold feature is ideal for bat acoustic sampling, as bats often make short passes leaving most of the recordings empty (Open Acoustic Devices, 2020). We tested the amplitude threshold at 128, 256 and 512 (left to right in the center photo; Figure 2).

Table 1. Audiomoth settings programmed during acoustic sampling in Annapolis County, Nova Scotia during Dec. 16-24, 2020.

Setting	Audiomoth 1	Audiomoth 2	Audiomoth 3
Frequency Band (kHz)	15-120	15-120	15-120
Sample Rate (kHz)	250	250	250
Gain	Medium	Medium	Medium
Amplitude Threshold	128	256	512
Recording Period (UTC-4)	17:00-21:00	17:00-21:00	17:00-21:00
Sleep Duration (s)	5	5	5
Recording Duration (s)	295	295	295

Performance Test

To assess the performance of the Audiomoth, the units were deployed alongside a Song Meter SM4BAT-FS with an U2 Ultrasonic Microphone (Wildlife Acoustics). The SM4BAT was programmed to record continuously during the first and second deployment of the Audiomoths. This was to record any bat activity that occurred outside of the recording timeframe of the Audiomoths in case bats were active outside periods not recorded by these devices. No activity was detected by the SM4 during the first deployment. During the second deployment on Dec. 16-24, we found all bat activity was detected during the recording period we set for the Audiomoths, so recordings outside of 17:00-21:00 were not used in this study. The settings used for this device follow the recommendations of NABat (Mcburney & Segers, 2020): firmware 2.3.0, the gain was set to 12 dB, 16k high filter off, 256 kHz sample rate, 1.0-50 ms call duration, 15 s max length of recording, 2 s trigger window, 12 dB trigger level and 15 kHz minimum trigger frequency. The U2 microphone was angled horizontal relative to the ground, in the same direction that the Audiomoth microphones were facing. The sensitivity of the U2 microphone was checked using the methods recommended by the manufacturer (Wildlife Acoustics, 2020).

Data Processing, Species Identification and Activity Summary

Recordings were processed and manually reviewed for species identification using Kaleidoscope Pro version 5.1.9 (Wildlife Acoustics). Recordings collected from both the three Audiomoths and SM4BAT were in WAV format. Suspected recordings with bat activity were identified from noise using the automated identification tool Bats of North American 5.1.0 Classifier (Wildlife Acoustics). The Auto ID sensitivity was set to Conservative and species region as Nova Scotia with the addition of *E. fuscus* that met the following conditions: 1.5-40 ms, max inter-syllable gap of 500 ms and minimum of three pulses with the advanced signal processing feature turned off. Recordings were split to a max duration of 15 s and sorted by night. After processing, bat and noise recordings were manually reviewed and identified to species following guidelines recommended by NABat (Mcburney & Segers, 2020). Generally, files were identified to species when there were at least three clear search phase calls (single echolocation) that could be differentiated from other species. Calls or sequences (multiple echolocations) that did not meet these requirements were identified as a species grouping, frequency category or noise. Recordings identified as noise that were either periods of silence or true noise (another taxa or environmental noise) were not differentiated from one another. Bat activity was summarized by the number of recordings identified per label category by device.

Results

Audiomoth Configuration

Overall, bat activity was recorded on 7 of 9 nights with only *Myotis* spp. detected, either Little brown myotis or Northern myotis (40kMyo; Table 2; Appendix A). Activity levels were relatively low, where the range of detections was 0-10 with the most activity detected on December 20 and 21. During these two days the mean temperature was highest of the monitoring period, 3.2˚C and 2.8 ˚C, respectively (Canada Department of National Defense, 2020). During the recording periods, the temperature ranged from 8.0 to 6.4˚C. The bat detectors experienced a temperature range of -10.1 to 16.3 from Dec. 16 until retrieval on Dec. 31, 2020 with snow and rain reported by the local weather station (Canada Department of National Defense, 2020).

Between the Audiomoths, all three units detected the same number of *Myotis* species detections per night for 8 of 9 nights except for December 17. For this night, all units recorded one detection within a similar timeframe at ~17:35 where the first pulse was detected between ~17:36-17:40. The recording started for Unit 3 at 17:33:59 and Unit 1 & 2 at 17:34:29. When these timeframes were manually reviewed, Unit 1 detected more pulses (8) while Unit 2 and 3 detected the same (5 each; Figure 3). Unit 1 recorded two more detections at 17:30:00 and 17:35:00, where <3 pulses was detected for the former recording so they were not included in the activity summary as identification would be uncertain and no pulses detected for the latter recording by the other units (Figure 4). As for activity detected on other nights, the time frame was similar among the three units. Although bat activity captured by the three Audiomoth units was similar, the number of noise files was not. Units 1 & 2 detected ~3x as many noise files as Unit 3 (Table 2).

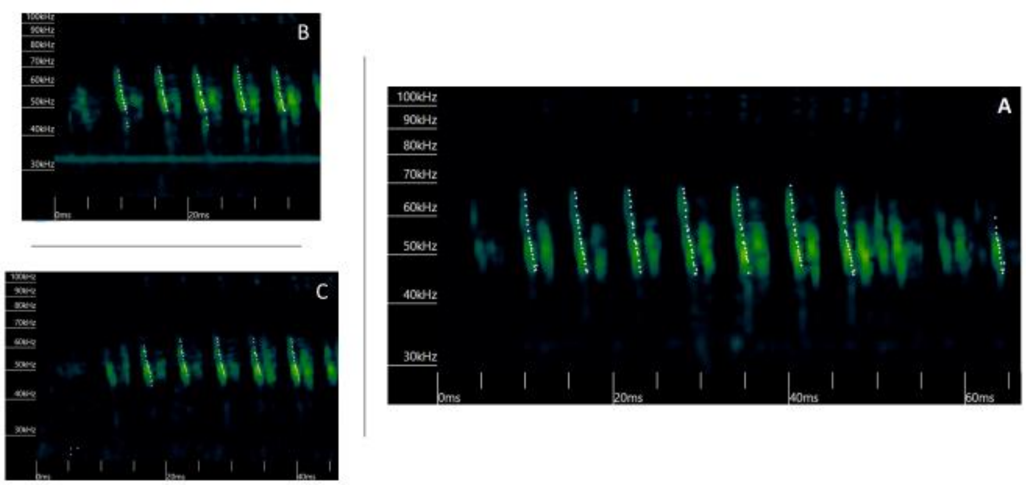


Figure 3. Audiomoth recordings of Myotis species bat activity by three units at the same time interval ~17:35 Dec. 17, 2020 outside a hibernation site. Image A is from Unit 1 with 8 pulses and amplitude threshold of 128. Image B is from Unit 2 with 5 pulses and an amplitude threshold of 256. Image C from Unit 3 with 5 pulses and amplitude threshold of 512. Recordings were processed and viewed in Kaleidoscope in wav format and compressed view to remove periods of silence and time between pulses.

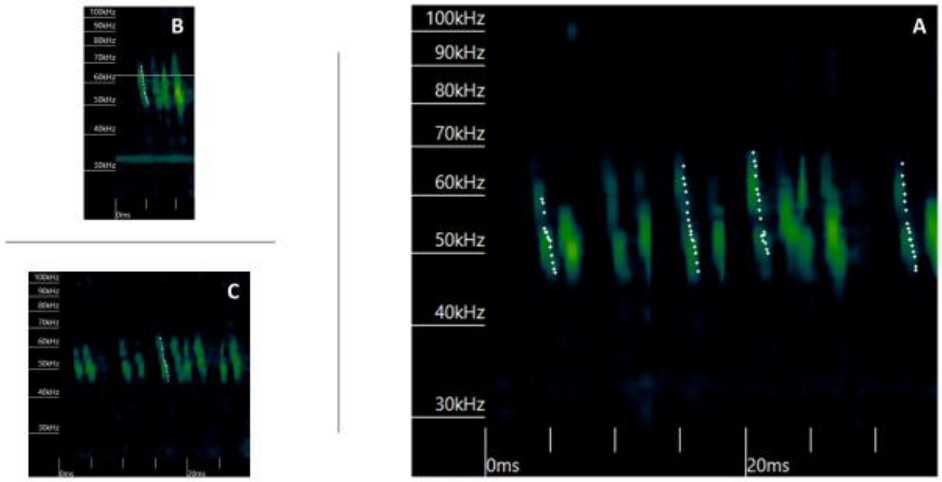


Figure 4. Audiomoth recordings of Myotis bat activity by three units at the same time interval ~17:30 on Dec. 17, 2020 at a hibernation site. Image A is from Unit 1 with 4 pulses while image B is from Unit 2 and image C from Unit 3, both with 1 pulses. Recordings were processed and viewed in Kaleidoscope in wav format and compressed view to remove periods of silence and time between pulses.

In comparison, the Audiomoth devices detected relatively less bat activity (9-11 recordings per unit) than the SM4BAT (26 recordings; Appendix A). However, there was only one of 8 nights of activity (December 19, 2020) where the Audiomoth units detected no activity compared to the SM4BAT. The SM4BAT also detected relatively less noise, where Unit 1 & 2 detected 5x more and Unit 3 almost 2x more noise recordings. Bat activity compared to noise was less than 2% of all recordings for any device. Of the recordings manually identified as bat collected from all four devices, 35/60 were identified by Kaleidoscope as noise. The remaining 25/60 were suspected bat recordings of the selected signal parameters and species.

Table 2. Comparison of Myotis spp. bat activity detected by various acoustic monitors and manually identified outside an overwintering site from Dec. 16-24, 2020 from 17:00-21:00. The Song Meter SM4BAT-FS with a U2 microphone was compared to the Audiomoth programmed with different amplitude threshold settings: Unit 1 128, Unit 2 256, Unit 3 512. The count of noise files is indicated in brackets and recordings with 2 individuals are marked by an asterisk and counted as one recording.

Date	Audiomoth 1	Audiomoth 2	Audiomoth 3	SM4BAT
16-12-2020	1 (959)	1 (959)	1 (187)	3 (346)
17-12-2020	3 (957)	1 (959)	1 (806)	4 (96)
18-12-2020	1 (959)	1 (959)	1 (367)	3 (47)
19-12-2020	0 (960)	0 (960)	0 (48)	1 (14)
20-12-2020	2* (958)	2* (958)	2* (289)	10* (158)
21-12-2020	4 (956)	4 (956)	4 (956)	5* (967)
22-12-2020	0 (960)	0 (960)	0 (49)	0 (5)
23-12-2020	0 (960)	0 (960)	0 (48)	0 (4)
24-12-2020	1 (959)	1 (959)	1 (47)	1 (7)
Total	**11 (8628)**	**9 (8630)**	**9 (2797)**	**26 (1644)**

For the SM4BAT, the night with the most activity was December 20, 2020. On this night, there was also a relatively large difference in the number of Audiomoth detections. The SM4 detected the same number of recordings as the Audiomoths on Dec. 22-24 (example of Dec. 24 in Appendix C) whereas from Dec. 16-21 the SM4 detected 1-8 more recordings. On December 20, there were 10 recordings whereas each Audiomoth unit only each detected 2 (Appendix A). However, all devices detected one recording with two individual bats (example from Audiomoth Unit 3 in Appendix B). Periods of activity captured by the SM4 on this date occurred from 18:02-18:12 (5 recordings), 19:20 (1 recording) and 20:31-20:58 (4 recordings). In comparison, Unit 1 detected activity at 17:31 and 17:42, Unit 2 20:31, 20:43 and Unit 3 20:30, 20:41.

Discussion

All of the recorded call sequences were attributable to the two common *Myotis* species found Nova Scotia. Although *Myotis* bat calls are difficult to distinguish, the majority of activity likely represents the Little brown myotis. Little brown myotis was historically the most abundant species and recent summer monitoring during 2018/2019 revealed most acoustic activity (>80%) was that of this species. In comparison, Northern myotis is both more challenging to detect acoustically and is experiencing relatively greater declines as a result of WNS. No call sequences of the Tri-colored bat or migratory species were recorded. Regardless of which *Myotis* species, this site is likely significant to bat populations recovering from WNS. Monitoring efforts should remain a priority at this site and when it is safe to do so, continuation of colony counts.

Variation in acoustic equipment is one of the challenges in using this technique for monitoring (Browning et al., 2017) and has been noted as a confounding issue when monitoring a variety of terrestrial species including birds, amphibians and bats (Adams et al., 2012; Larson & Hayes, 2000; MacLaren et al., 2018; Rempel et al., 2013; Venier et al., 2012). The quality and quantity of acoustic recordings may vary by units (microphone and/or recorder) of the same brand and between brands of recorders. Other variables like positioning, weatherproofing, environment and species may also contribute to which species are detected and the number of detections per species.

The difference in quality and quality of acoustic recordings between the Audiomoth and SM4 may be due to numerous factors. As more studies examine the Audiomoth, specific differences may be identified. For example, the signal to noise ratio (SNR) was found to be slightly lower than the Song Meter SM2 (https://www.openacousticdevices.info/audio). Also, many features of the device like the case and Amplitude Threshold have only been introduced within the past year (e.g. 2020, https://www.openacousticdevices.info/application-notes).

In this project, the Audiomoth performed similarly to the Song Meter SM4Bat-FS with the U2 microphone. It detected activity on all nights except for one identified by the SM4. This shows that the two brands may perform similarly for identifying species composition. However, we would need to compare the Audiomoth to the SM4 in more scenarios (e.g. various seasons, environments) and with >1 species to be confident. For activity levels, the Audiomoth detected relatively less activity in contrast to the SM4. Most often passive acoustic monitoring is used to assess activity patterns of communities but can be used to answer of variety of questions (Sugai et al., 2019). The number of bat detections between monitoring periods are often used as a proxy for population trends as individual bats cannot be identified in recordings and therefore abundance cannot be estimated. In the case of assessing long-term activity trends, it would be important to compare activity collected by the same device rather than between brand as shown here. Otherwise, an equipment correction factor would be necessary to account for equipment variation.

For the detection of bats, recorders that eliminate detecting and saving both noise and periods of silence are essential. This avoids having to manually review a large number of files with no activity. In this, the Audiomoth did not perform as well as the SM4Bat-FS with the U2 microphone. For example, Audiomoth 1 and 2 each recorded >8,000 noises files that were manually reviewed. Over half of the bat recordings were identified as noise by the processing software and were only identified from manual review. Ideally, the processing program would have identified all files with bat activity not as noise for efficiency in reviewing recordings. As programs advance and increase in their accuracy of bat species identification, a large number of noise files would not be as problematic. However, the data management associated with storing a large number of noise files does creates challenges. Each Audiomoth recorded ~60 GB of raw data from 9 evenings of 4 hour periods of monitoring with 64 GB cards. After processing, this resulted in a total of ~120 GB of data from both the raw and process data for only 11 or less recordings of bat activity per unit. In order avoid recording files of no interest and possibly extend the deployment, the amplitude threshold setting should be used. In contrast, the SM4 recorded a total of ~49 GB of data across those nine days while recording continuously with only 7.36 GB recorded from 17:00-21:00.

Depending on the research question, focal taxa, species and study design, the Audiomoth may be appropriate for a variety of projects. We identified that using an Amplitude Threshold of 512 balances detecting bat activity while eliminating recording noise files relative to the SM4. Using a higher amplitude threshold lowers the number of files recording periods of silence and may allow for longer deployments before memory cards reach maximum storage. As Audiomoth features continue to be refined and developed, we suspect the performance of this device for the monitoring of bats will only improve.

Table 3. Recommended Audiomoth settings for bat acoustic monitoring in Nova Scotia, Canada. Settings may need to vary depending on the research question, study site and focal species. Settings based on findings of this study and guidelines from the NABat program (Mcburney & Segers, 2020).

Setting	**Recommendation**
Optimal recording time	Period after sunset
SD card size	≥ 64 GB
Gain	Medium
Amplitude threshold	512
Frequency range	15-120 kHz
Waterproofing	Audiomoth case
Height	≥ 1.4 m
Distance to clutter	≥3-5 m

Future Directions

We suggest testing the Audio in more environments and conditions to assess its performance and capabilities as our study was limited in scope. We recommend the following should potentially be explored to further our understanding of this device:

1. **Test the Audiomoth in a variety of conditions:** the Audiomoth should be tested in a variety of conditions to assess the performance of the settings we identified as appropriate in this study. For example, such as a foraging site in an open area away from clutter and in an area with Tri-colored bat activity as these were not studied.
2. **Test the Audiomoth at various gain settings:** the gain setting should be tested at 'high' as other monitoring efforts have found other settings to be too weak for the detection of birds (personal communication, John Kearney). The testing of the high gain setting may increase the detection of bats at a further distant and increase the performance of the Audiomoth relative to the Song Meter SM4BAT-FS.
3. **Assess the Audiomoth performance to various acoustic devices:** compare performance to other acoustic devices used for the detection of wildlife in the region and an assessment of which devices are appropriate for various research questions. For example, the Song Meter Mini Bat which is a compact version of the SM4BAT-FS (https://www.wildlifeacoustics.com/products/song-meter-mini-bat).
4. **Continue to test new Audiomoth features:** as new applications are released, such as using an external microphone, assess if these can increase the detection of wildlife like bats (https://github.com/OpenAcousticDevices/Application-Notes/blob/master/Using_AudioMoth_with_External_Electret_Condenser_Microphones.pdf).

Appendix A

Bat recordings collected by device, date, and time. Unit 1, 2 and 3 are Audiomoths while Unit 4 are recordings detected by the SM4BAT. Count of pulses and Auto ID were identified by Kaleidoscope whereas all files were manually reviewed for identification by the author. Manual ID of two bats detected in one recording of the same species indicated in brackets.

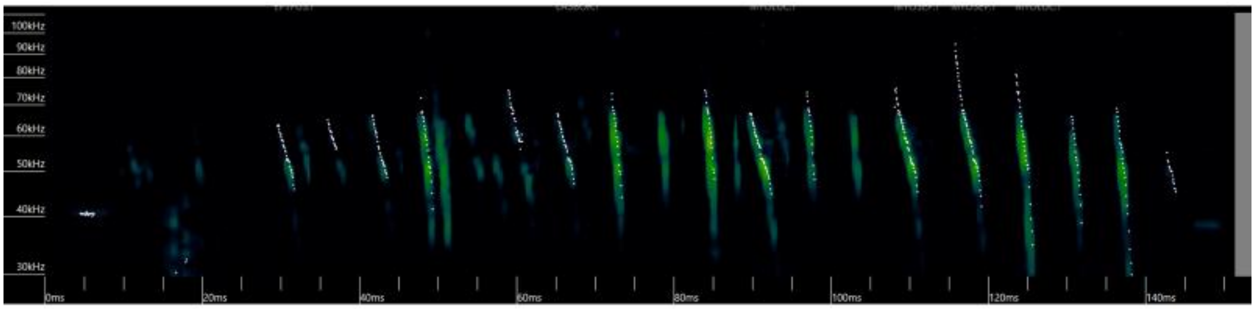
Unit	Date	Time	Duration	Pulses*	Auto ID	Manual ID
1	2020-12-16	17:52:30	14.99955		Noise	40kMyo
1	2020-12-17	17:34:30	14.99955		Noise	40kMyo
1	2020-12-17	17:30:00	14.99955		Noise	40kMyo
1	2020-12-17	17:35:00	14.99955		Noise	40kMyo
1	2020-12-18	17:50:30	14.99955		Noise	40kMyo
1	2020-12-20	20:31:30	14.99955	11	MYOSEP	40kMyo (2)
1	2020-12-20	20:42:45	14.99955	8	NoID	40kMyo
1	2020-12-21	17:26:15	14.99955	10	NoID	40kMyo
1	2020-12-21	20:15:15	14.99955		Noise	40kMyo
1	2020-12-21	20:19:15	14.99955		Noise	40kMyo
1	2020-12-21	20:19:30	14.99955	2	NoID	40kMyo
1	2020-12-24	18:27:45	14.99955		Noise	40kMyo
2	2020-12-16	17:52:29	14.99955		Noise	40kMyo
2	2020-12-17	17:34:29	14.99955		Noise	40kMyo
2	2020-12-18	17:50:44	14.99955		Noise	40kMyo
2	2020-12-20	20:31:44	14.99955	13	MYOSEP	40kMyo (2)
2	2020-12-20	20:43:14	14.99955	7	NoID	40kMyo
2	2020-12-21	17:26:29	14.99955	11	NoID	40kMyo
2	2020-12-21	20:15:44	14.99955		Noise	40kMyo
2	2020-12-21	20:19:44	10.00755		Noise	40kMyo
2	2020-12-21	20:20:00	14.99955		Noise	40kMyo
2	2020-12-24	18:28:29	14.99955		Noise	40kMyo
3	2020-12-16	17:50:00	14.99955	2	NoID	40kMyo
3	2020-12-17	17:33:59	14.99955		Noise	40kMyo
3	2020-12-18	17:50:00	14.99955		Noise	40kMyo
3	2020-12-20	20:30:59	14.99955	6	NoID	40kMyo (2)
3	2020-12-20	20:41:29	14.99955	4	NoID	40kMyo
3	2020-12-21	17:26:14	14.99955	2	NoID	40kMyo
3	2020-12-21	20:15:15	14.99955		Noise	40kMyo
3	2020-12-21	20:19:14	14.99955	2	NoID	40kMyo
3	2020-12-21	20:19:29	14.99955		Noise	40kMyo
3	2020-12-24	18:25:00	3.44064		Noise	40kMyo
4	2020-12-16	17:36:27	5.746		Noise	40kMyo
4	2020-12-16	17:48:33	4.77		Noise	40kMyo
4	2020-12-16	17:51:19	7.056	2	NoID	40kMyo
4	2020-12-17	17:29:33	3.822	3	NoID	40kMyo
4	2020-12-17	17:33:52	7.97	6	NoID	40kMyo

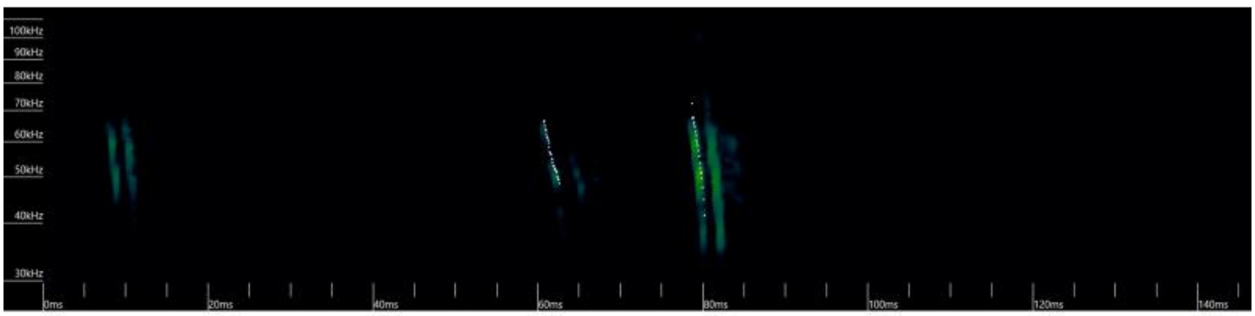
4	2020-12-17	17:56:14	6.138		Noise	40kMyo
4	2020-12-17	17:57:59	9.106		Noise	40kMyo
4	2020-12-18	17:50:05	8.48	11	NoID	40kMyo
4	2020-12-18	17:58:58	3.558		Noise	40kMyo
4	2020-12-18	18:15:46	6.356		Noise	40kMyo
4	2020-12-18	18:19:04	5.042		Noise	40kMyo
4	2020-12-19	17:50:43	4.932		Noise	40kMyo
4	2020-12-20	18:02:43	8.354		Noise	40kMyo
4	2020-12-20	18:05:09	4.944		Noise	40kMyo
4	2020-12-20	18:06:09	4.78		Noise	40kMyo
4	2020-12-20	18:06:39	4.69	3	MYOSEP	40kMyo
4	2020-12-20	18:11:05	9.226		Noise	40kMyo
4	2020-12-20	19:20:39	4.85	3	NoID	40kMyo
4	2020-12-20	20:31:00	7.108	24	NoID	40kMyo (2)
4	2020-12-20	20:42:23	8.344	9	NoID	40kMyo
4	2020-12-20	20:56:51	5.774		Noise	40kMyo
4	2020-12-20	20:58:04	6.06		Noise	40kMyo
4	2020-12-21	17:25:47	15	26	NoID	40kMyo (2)
4	2020-12-21	17:31:50	15	2	NoID	40kMyo
4	2020-12-21	20:14:39	15	6	NoID	40kMyo
4	2020-12-21	20:18:41	15	4	NoID	40kMyo
4	2020-12-21	20:18:58	15	25	NoID	40kMyo
4	2020-12-24	18:23:04	9.026		Noise	40kMyo

*Files identified as noise by software did not have the pulses counted.

Appendix B

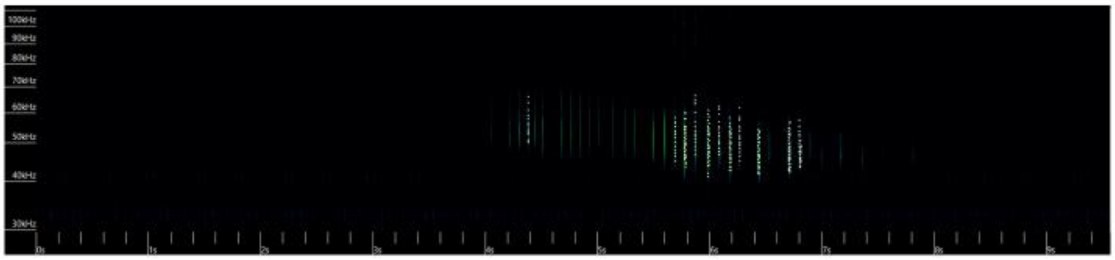
Bat activity detected by Unit 3 Audiomoth of two suspected *Myotis* bats on Dec. 20, 2020 at ~20:40. Top image compressed view of pulses, removing time between pulses to view all calls simultaneously whereas the bottom image shows pulses in real time.

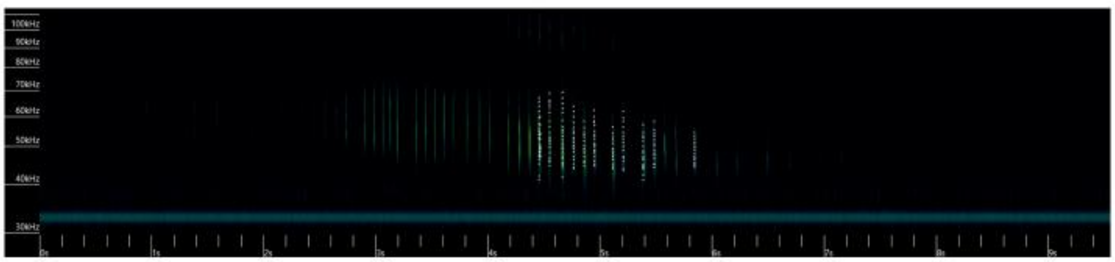


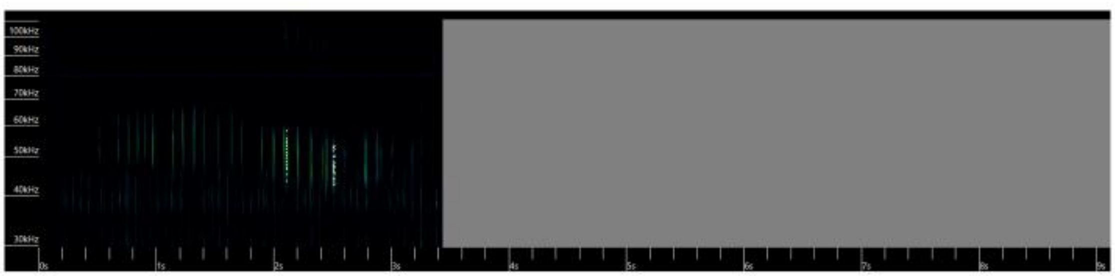


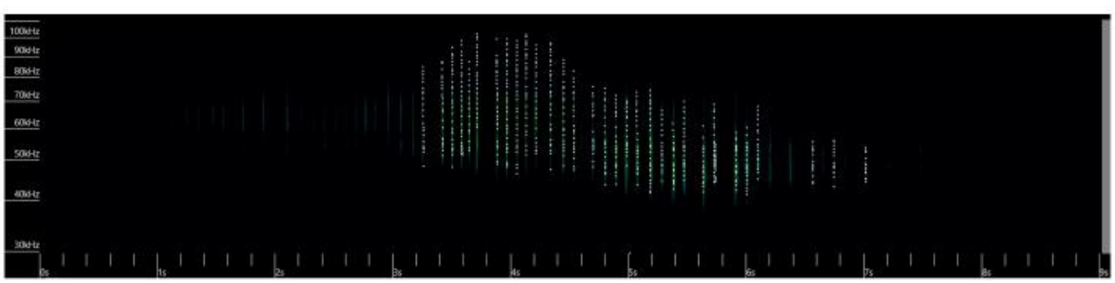
Appendix C

Bat activity recorded on Dec. 24, 2020 at a similar time interval (18:23-18:29) by all 4 acoustic recording units. Images show compressed view of bat calls/pulses - top to bottom: Unit 1, 2, 3 (Audiomoths) and final image from the SM4. Time recording initiated and duration of recording can be found in Appendix A. Estimated time of concentration of pulses to be: Unit 1 ~18:33, Unit 2 ~18:33, Unit 3 18:27 and SM4 ~18:28.









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