Received: 2 May 2023 | Accepted: 18 September 2023
DOI: 10.1111/een.13285

ORIGINAL ARTICLE

Ecological Entomology
Royal Entomological Society

Large-scale bioacoustic monitoring to elucidate the distribution of a non-native katydid

Alexandre P. Caouette[1,2] | **Erin M. Bayne**[3] | **Kevin A. Judge**[2]

[1]Department of Biology, University of New Brunswick, Fredericton, New Brunswick, Canada

[2]Department of Biological Sciences, MacEwan University, Edmonton, Alberta, Canada

[3]Department of Biological Sciences, University of Alberta, Edmonton, Alberta, Canada

Correspondence
Kevin A. Judge, Department of Biological Sciences, MacEwan University, Edmonton, AB T5J 4S2, Canada.
Email: judgek3@macewan.ca

Funding information
Natural Sciences and Engineering Research Council of Canada, Grant/Award Number: RGPIN-2017-04674

Associate Editor: Noelline Tsafack

Abstract

1. For animals that produce species-specific audible sounds, environmental recordings combined with automated acoustic monitoring software (passive acoustic monitoring [PAM]) may be an effective monitoring tool because it allows audio data from many, widely distributed autonomous recording units (ARUs) to be processed in a relatively short period of time. Males of many insect species produce loud, species-specific mating songs, yet acoustic insects have received less attention from PAM relative to vertebrates.
2. We evaluated the use of PAM to monitor, *Roeseliana roeselii* (Orthoptera, Tettigoniidae), an acoustic insect that has expanded its range to Alberta, Canada, far outside its naturalized North American range. We analysed environmental recordings from ARUs: (1) at two control sites known to be occupied by *R. roeselii* and (2) across Alberta established by the Alberta Biodiversity Monitoring Institute (ABMI) to search for new populations.
3. PAM successfully detected *R. roeselii* at the two control sites, but not at any of the 73 ABMI sites that we analysed. Despite the failure to detect new locations of *R. roeselii*, our analysis of ABMI environmental recordings detected several other species of acoustic insects, including *Orchelimum gladiator*, *Gryllus* sp. and *Allonemobius* spp.
4. Our results add to the growing body of work showing the feasibility of using PAM for acoustic insects. We make suggestions for how to maximize the effectiveness of this monitoring tool for the conservation and management of singing insects in North America.

KEYWORDS
bioacoustics, insects, large-scale monitoring, passive acoustic monitoring, *Roeseliana roeselii*, species distribution

INTRODUCTION

Insects are incredibly diverse and provide invaluable ecosystem services (Eggleton, 2020; Losey & Vaughan, 2006). They face several threats including climate change, habitat loss, pollution and invasive species (Wagner, 2004) and are underrepresented in studies assessing the impacts of these threats on biodiversity (Potts et al., 2016; Titley et al., 2017; Troudet et al., 2017). Monitoring changes in insect populations can be time intensive and costly because of their small size and often cryptic nature. As a result, researchers must often invest considerable sampling effort to quantify species' distributions (MacKenzie, 2016; Thomas, 2005). Efficient methods of monitoring species over large spatial scales are critically important for both documenting changes and predicting how species will respond to these threats (Blumstein et al., 2011; Cullen et al., 2017; Lindenmayer et al., 2012; Noss, 1990).

One promising method for monitoring insects over broad geographical and temporal scales is to listen for them. Male—and rarely female—acoustic insects produce species-specific mating songs that are identifiable in audio recordings (Alexander, 1957; Riede, 1998). Large numbers of automated recording units (ARUs) can be deployed across the landscape for long periods of time to record ambient sound. The environmental recordings from these ARUs can be analysed with machine learning algorithms to identify the occurrence of one or more acoustic species of interest, a technique we call passive acoustic monitoring, hereafter PAM. PAM can take much less time and resources and result in minimal to no mortality when compared to a similarly ambitious sampling regime requiring collection of physical specimens (Aide et al., 2013; Shonfield & Bayne, 2017). Previous studies have been successful in using PAM to monitor insects with respect to species abundance (Jeliazkov et al., 2016; Newson et al., 2017; Penone et al., 2013) and community richness (Penone et al., 2013) in specific locations, however, it has not been widely used to monitor acoustic insect species' ranges.

Roesel's katydid (*Roeseliana roeselii*, previously *Metrioptera roeseli*, Orthoptera, Tettigoniidae) is a model organism for studying range limits and range expansion (Gardiner, 2009; Kaňuch et al., 2013; Poniatowski & Fartmann, 2009, 2011; Simmons & Thomas, 2004; Vickery, 1965). Several mechanisms are thought to be responsible for their range expansion, such as an increase in human introductions and climate change causing an increase in long-winged individuals capable of longer distance dispersal (Gardiner, 2009; Hochkirch & Damerau, 2009; Poniatowski & Fartmann, 2011; Simmons & Thomas, 2004). The native range of *R. roeselii* encompasses most of Europe, England and Western Russia (Zacher, 1917) but it has been recorded spreading into North America (Urquhart & Beaudry, 1953), Scandinavia (Ahlén, 1995) and the Russian Republic of Tyva bordering Mongolia (Sergeev et al., 2018). *R. roeselii* was first recorded in North America in 1952 on the island of Montréal, Québec, Canada (Urquhart & Beaudry, 1953) and has since expanded and is now widespread in the eastern part of North America (GBIF.org, 2021). In 2017, researchers found the first population of *R. roeselii* west of the 95th west meridian in Wagner Natural Area, Alberta, Canada (BOLD System, 2019); approximately 2000 km away from the westernmost edge of its naturalized range in eastern North America (iNaturalist, 2023). The discovery of this population raises several questions about the origin and distribution of *R. roeselii* in western Canada. In this study, we apply PAM to search an archive of environmental recordings from ARUs deployed systematically across Alberta for previously unreported populations of *R. roeselii*.

METHODS

Study species

R. roeselii is a small (13–26 mm), shield-backed katydid (subfamily Tettigoniinae), identifiable by its green or brown body, yellow accents across its thorax and abdomen and a white cream or yellow coloured band on the lower lateral margins of its pronotum (Marshall & Haes, 1988). *R. roeselii* is wing-dimorphic, adults can be either short-winged (brachypterous) or long-winged (macropterous). *R. roeselii* produces a species-specific mating song with a peak frequency of 17 kHz that sounds like a continuous high-pitched buzz, like that of electrical wires (Iorgu & Iorgu, 2011; Marshall & Haes, 1988). Adult males sing in midsummer to early fall (Berggren, 2004; Kevin A. Judge, personal observation).

Collection and recording

In order to utilize PAM to search for *R. roeselii*, we first needed to train an algorithm to recognize their songs by providing a collection of recordings of individual calls (Figure 1). To record *R. roeselii* songs, we searched for adult males between June and September 2019 at a total of 20 sites across central and eastern Alberta (Table 1). Search time at each site ranged from 20 to 180 min depending on the area. Searching took place on sunny days when temperatures exceeded 19°C because individuals are more likely to sing when the weather is warm (Berggren et al., 2002). We used a combination of visual and acoustic cues to detect male *R. roeselii* who were then captured by hand or with a sweep net. For a haphazard subset of individuals, we recorded songs in the field (Figure 2a) before collection using a shotgun microphone (RODE NTG-2, Sydney, Australia) connected to a digital audio recorder (Tascam DR-100mkIII, Los Angeles, United States; 96 kHz sample rate). We used a foam windscreen on the microphone in the field to limit background noise. Additionally, the microphone was attached to a 150 cm boom held approximately 20 cm above the individual being recorded to limit disturbance to their singing behaviour.

To increase both the sample size as well as the variety, quality and duration of songs, we also recorded male *R. roeselii* in a controlled lab environment. Katydids were housed individually in plexiglass tubes (10 cm diameter, 10 cm high), open at one end (bottom) and sealed at the top by aluminium window screening (see Bussière et al., 2005). Each tube had a piece of plastic window screening lining the inside to provide a climbing surface. Tubes were placed on a plastic tray over

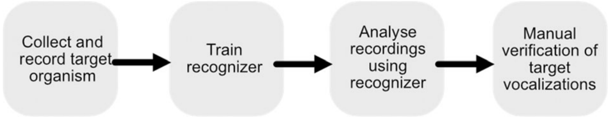

FIGURE 1 Steps involved in the analysis of environmental audio recordings from autonomous recording units using passive acoustic monitoring techniques.

TABLE 1 Locations of *Roeseliana roeselii* field collections with a description of the areas where specimens were collected and the number of individuals collected.

Location	Coordinates	Description	Males	Females
Wagner Natural Area	53°34′ N 113°49′ W	Hay fields and clover-dominated fields, bordered by calcium-rich fens and marl ponds	179 (54)	23
Roy Berg Kinsella Research Ranch	53°05′ N 111°34′ W	Natural prairie grasses, aspen groves and wetlands	50 (21)	4
Tofield	53°22′ N 112°40′ W	Disturbed long grasses	2 (1)	0
Daysland Alberta Conservation Area	53°02′ N 112°15′ W	Open grass fields mixed intertwined with small deciduous forest stands and wetlands	3 (1)	0

Note: For males, the numbers in parentheses indicate the number of individuals recorded.

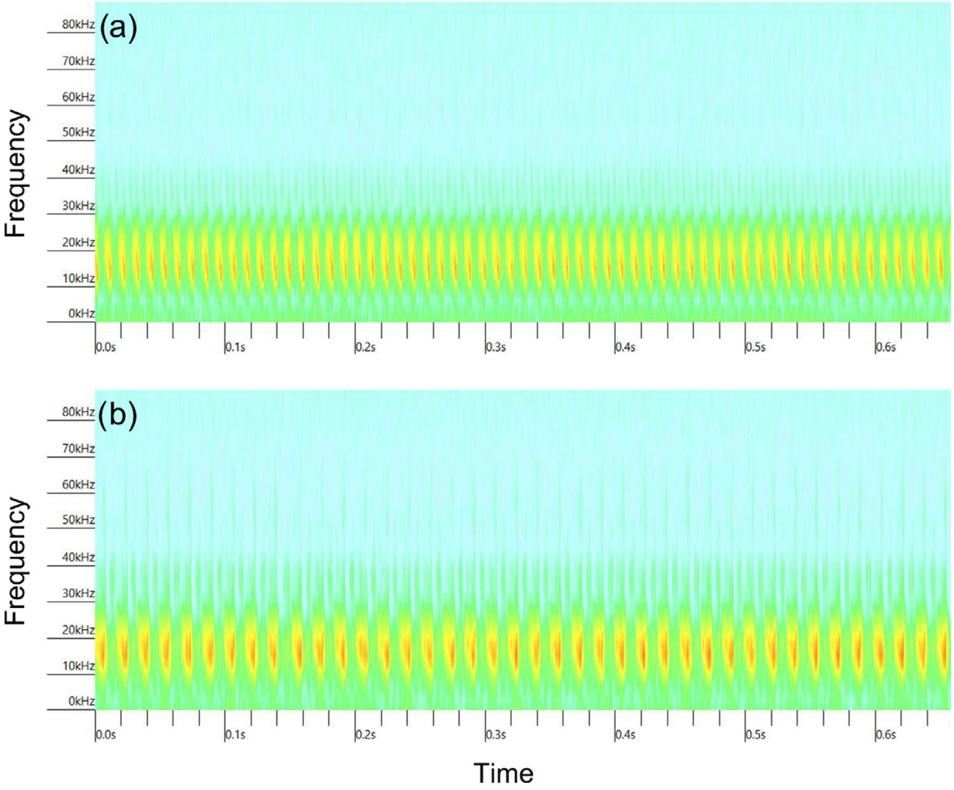

FIGURE 2 Example spectrograms of Roesel's katydid (*Roeseliana roeselii*) song recorded: (a) in the field and (b) in the lab (different males). Signal amplitude is represented by colour with warmer (reds and yellows) and cooler (blues and greens) colours indicating higher and lower amplitudes, respectively. The slower pulse rate in the lab recording is likely due to the singer being much cooler. Lab conditions were held relatively constant at approximately 25°C, whereas field conditions were more variable and often much hotter. Also note the presence of both high-frequency components in the lab recording that likely attenuated too rapidly for detection in the field recordings and low-frequency components in the field recordings from ambient noise such as vehicle traffic that was much reduced indoors in the lab.

top of food and water. We fed males a modified orthopteran food mix adapted from Henderson et al. (2008) with added pollen. We provided individuals with water in two 2-mL microfuge tubes plugged with cotton, and katydid enclosures were sprayed twice a day with water to maintain moisture within the plexiglass tube. We cleaned containers twice a week by replacing the bottom tray, water tubes and food. Individuals were kept at a temperature ranging from 23°C to 25°C and experienced a natural/ambient photoperiod. Following the recording, individuals were euthanized in a freezer at -20°C and stored in either 70% or 100% ethanol.

We used the same microphone (without the windscreen) and audio recorder (again 96 kHz sampling rate) to record *R. roeselii* song in the lab (Figure 2b). We first transferred individuals from their individual plexiglass cylinders into individual mesh-walled cylinders to reduce reverberations caused by the hard walls of the plexiglass. Additionally, we placed the mesh cylinders in a cardboard box (30 cm x 30 cm x 30 cm) lined with acoustic foam to reduce background noise. The box had one open side to allow for microphone positioning. During recording, the temperature of the room ranged from 21°C to

25°C. We placed four males in each corner of the foam-lined box along with a female at the centre to stimulate male singing. To increase male motivation to sing, we extracted female cuticular hydrocarbons by placing five frozen females into a jar containing acetone, allowed the specimens to sit for 12 h and then placed a drop of the resulting fluid on the mesh of each male's enclosure. This acetone drop evaporated quickly and left behind any cuticular hydrocarbons (CHCs) extracted from the females; CHCs are known to convey information about sex (Tregenza & Wedell, 1997). We allowed individuals 15 min to acclimate, and once a singing individual was identified, the other katydids were removed for the duration of the recording. During recording, we positioned the microphone approximately 5 cm above the male's enclosure. Recording was terminated after at least 1 min of singing to ensure a useable sample for the creation of an acoustic recognition algorithm.

Acoustic recognizer construction

We used similar methodology as Knight and Bayne (2019) to train the recognizers. Briefly, using the program Song Scope (Wildlife Acoustics, Maynard, MA, USA), we trained two recognizers to capture differences among recordings in both sound quality and background noise; one was created for recordings taken in the field and one for recordings taken in the lab. Each recognizer was created using a minimum of 20 annotated songs taken from either lab or field recordings (see Table S1 for recognizer details). *R. roeselii* has only one song type, but with high variability in the number of syllables in each song (Cusano et al., 2016; Heller, 1988), so we created our recognizers using training data that both varied in the number of syllables and were shorter than 9 s in length. Both the field and lab recognizers varied in their performance statistics (see Table S2 for a detailed list of performance statistics of recognizers).

ARU site selection

The Alberta Biodiversity Monitoring Institute (ABMI) is an organization that monitors ecological changes in the province of Alberta using audio and video recordings and physical sampling (Burton et al., 2014). The ABMI has a large archive of audio recordings (primarily using Song Meter SM2+ or SM3 recorded at 44100 Hz from Wildlife Acoustics, Maynard, MA, USA) collected by a standardized provincial monitoring grid (20 km spacing across the entire province) as well as recordings collected by researchers. We processed recordings collected between 2013 and 2017 (Figure 3). Due to logistical constraints, it was not possible to analyse all of the available environmental recordings (30,000+ locations), so we selected a subset of recordings that met criteria that would improve search efficiency. Because male *R. roeselii* typically begins to sing in mid-July (Berggren & Low, 2004; Kevin A. Judge, personal observation), we omitted ARUs that were retrieved from the field (i.e., stopped recording) before July 15. Because the probability of detecting *R. roeselii* likely declines with distance from known locations, we conducted a proximity analysis in ArcGIS (Ver. 10.8.1), using the near tool, to measure the distance between the known populations of *R. roeselii* and the ARUs. We started with ARUs closest to known populations of *R. roeselii* and then moved outwards analysing recorders up to a distance of 420 km from the known populations of *R. roeselii*.

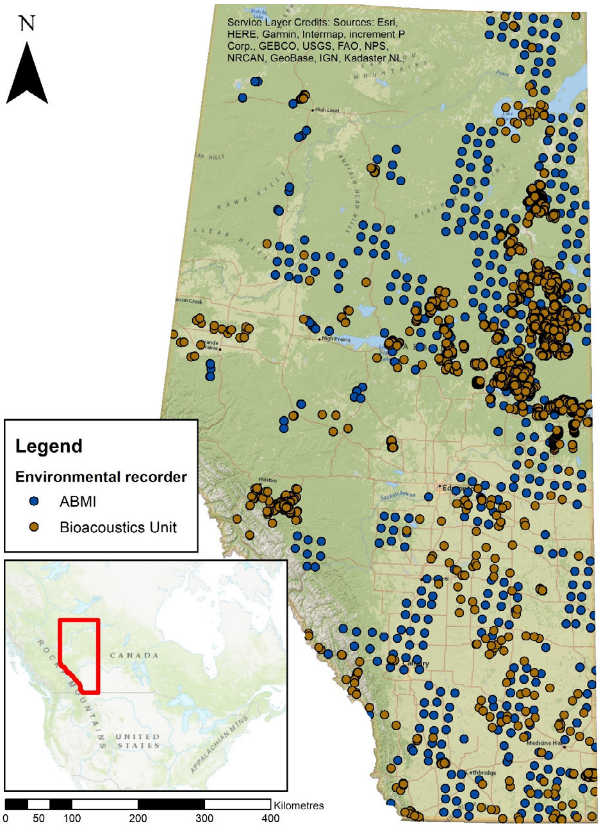

FIGURE 3 Locations of Alberta Biodiversity Monitoring Institute (ABMI) and University of Alberta Bioacoustics Unit environmental recorders set out between 2013 and 2017.

Recognizer validation

To test the recognizers' ability to detect *R. roeselii*, two ARUs were set in Wagner Natural Area to record in an area with a confirmed population of *R. roeselii*. An environmental recorder was placed in each of two locations representing: (1) high density, a hay- and clover-dominated field where *R. roeselii* is known to oviposit and which has served as a principle collecting site, and (2) low density, an old field 125 m away to which a few *R. roeselii* apparently disperse from the high-density location (i.e., no nymphs have been collected from this site indicating that recruitment is low or absent). The ARUs at these two sites serve as positive controls and recorded continuously from 8 to 16 August 2019 (except 13 August when the batteries were replaced).

Passive acoustic monitoring

Each environmental recording was analysed using both recognizers. To process audio recordings, both the recognizers were loaded into

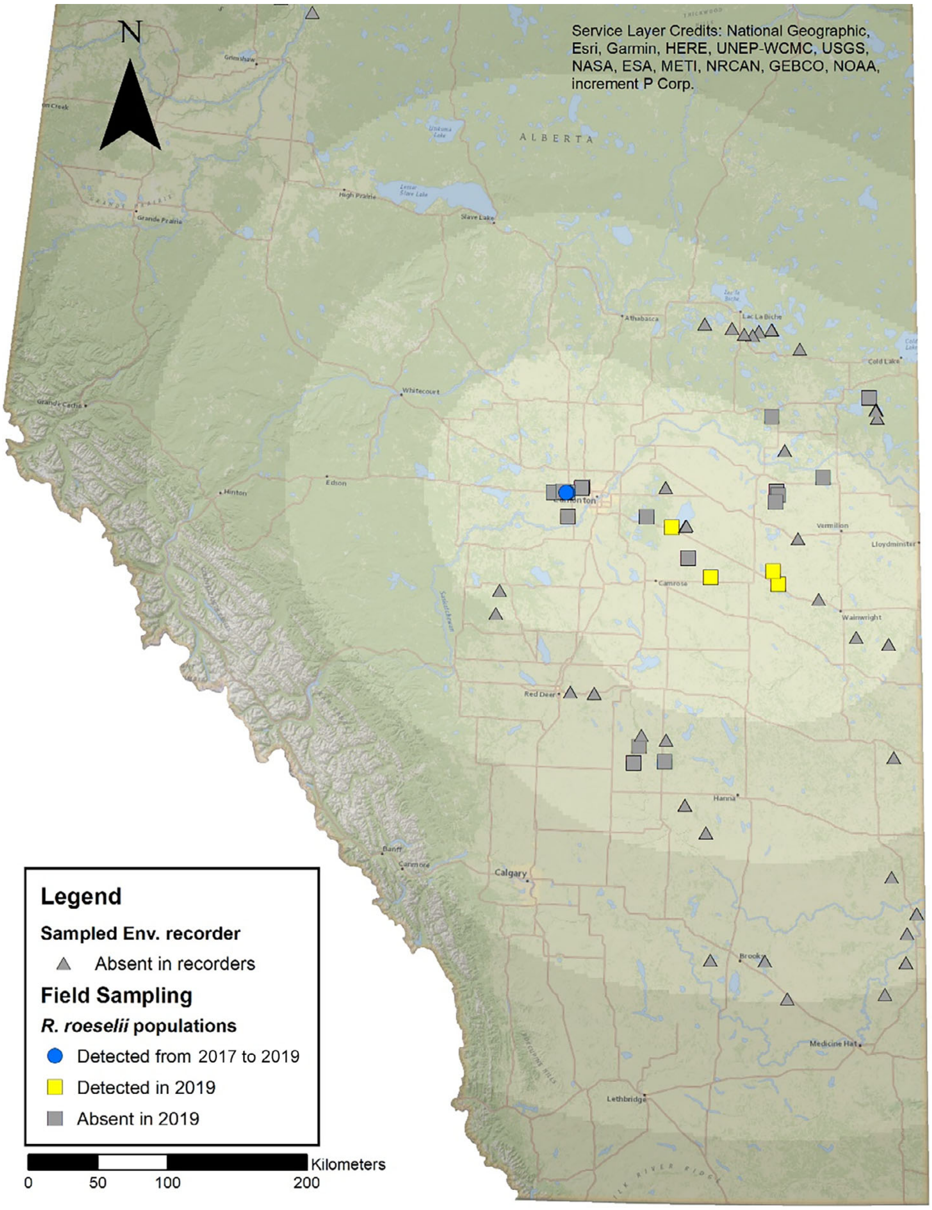

FIGURE 4 Map of Alberta showing locations and years of sampling efforts for *Roeseliana roeselii*. Symbol shape represents the type of sampling employed: acoustic only (triangles), field capture only (squares) and both acoustic and field capture (circle). Symbol colour represents the results of sampling: *R. roeselii* detected via both acoustic and field capture (blue), *R. roeselii* detected by field capture (yellow) and *R. roeselii* not detected (grey). A shaded 100-km isocline originating from the locations where populations were confirmed represents distances of environmental recorders to origin areas.

Song Scope and references to various sections of the recordings meeting our threshold criteria (hereafter referred to as hits) were detected and returned as a list. When running our recognizers through audio recordings, we set scores for both threshold and quality at 50 to decrease the likelihood of missing *R. roeselii* songs (Knight & Bayne, 2019). We then reviewed the recognizer results by visually inspecting the frequency diagrams and listening to each recognizer hit. Using information on audio clip frequency profiles and temporal patterns, we assigned each hit to one of three classifications: (1) *R. roeselii*, identified primarily by having: (a) a broadband song ranging from approximately 5 to 25 kHz with a peak frequency at approximately 19–21 kHz, a buzz sound similar to an electrical discharge from electrical wires, (b) a single syllable lasting approximately 100th of a second and (c) a large number of quickly repeating syllables lasting from a few seconds to minutes; (2) other acoustic insects, identified chiefly by having: (a) highly repetitive songs with short (i.e., milliseconds duration) syllables, (b) no detectable frequency modulation, and (c) a very broadband frequency spectrum (grasshoppers: Acrididae; and katydids: Tettigoniidae), a narrowband frequency spectrum with carrier frequencies in the 4–8 kHz range (crickets: Gryllidae and Trigonidiidae) or a narrowband frequency spectrum in the 6–10 kHz range (cicadas: Cicadoidea), (d) a variable number of repeated

TABLE 2 Classification of candidate sounds recorded by automated recording units at the two positive control sites (both at Wagner Natural Area) and 73 ABMI and Bioacoustics Unit sites.

					Classification		
		Number of sites	Median hits (range)	Total hits	Roeseliana roeselii	Other acoustic insects[a]	Other sounds
Positive controls	High density	1	488	488	438	6	44
	Low density	1	278	278	5	288	45
ABMI and Bioacoustics Unit		73	2 (0–405)	3656	0	698	2958

Abbreviation: ABMI, Alberta Biodiversity Monitoring Institute.

[a] Other than *R. roeselii*.

syllables, and (e) a song that otherwise did not conform to the criteria for *R. roeselii*; or (3) other sounds, which was any hit that could not be assigned to classifications 1 or 2, including birdsong, bat calls, wind, rain and any unidentifiable sounds.

RESULTS

Collection and recording

A total of 29 h was spent searching for and collecting *R. roeselii* specimens in all locations with sampling effort varying from one to three people. Of the 21 sites that we searched for *R. roeselii*, we found four new locations with previously unreported populations (Figure 4). We collected 179 *R. roeselii* mostly from Wagner Natural Area and the Roy Berg Kinsella Research Ranch, 152 of which were male (Table 1). Macropterous individuals accounted for 17.9% of all collected katydids. We used a total of 77 separate individuals in the recognizer including 20 katydids recorded in the field and 57 in the lab.

Passive acoustic monitoring

Based on our inclusion criteria and the available time, we analysed environmental recordings from 73 ARU locations. None of these 73 ARU locations was within 8400 m of any of the locations from which we either collected or failed to collect *R. roeselii*, meaning that we could not use the ARU data to confirm or check in-person sampling results. From these 73 ARUs, we analysed a total of 61,456 ten-min audio files equalling 10,242 h of audio. Our two recognizers identified 3656 hits across 50 of the 73 ARUs, none of which was classified as *R. roeselii* (Table 2 and Figure 5). Of the 3656 hits, 698 hits were other acoustic insects, which represents 19.1% of the total. Other acoustic insects were identified in 20 of the 50 ARUs with hits (Figure 5). There were 174 calls that were identified as Tettigoniidae (mostly *Orchelimum gladiator*), 140 Acrididae (likely *Pseudochorthippus curtipennis* and *Chloealtis*) and 326 Grylloidea (including *Gryllus*, *Oecanthus* and *Allonemobius*). From the 338 h of audio recordings from both of the two positive control ARUs, PAM identified 766 hits, 443 of which were *R. roeselii*, 234 other acoustic insects and 89 other sounds. As predicted, the high-density positive control had a much higher number of *R. roeselii* hits than the low-density positive control (Figure 5). The high-density site had 488 total hits (438 *R. roeselii*, 6 other acoustic insects and 44 other sounds), whereas the low-density site had 278 total hits (5 *R. roeselii*, 228 other acoustic insects and 45 other sounds; Table 2).

DISCUSSION

We successfully demonstrated the use of PAM to search for a non-native acoustic insect, Roesel's katydid. Our PAM analysis did not detect any new populations of *R. roeselii* on the systematic grid, which suggests that they remain relatively rare and potentially localized in Alberta. However, our results suggest that this approach of searching audio archives, usually established for bird and amphibian monitoring, has the potential to provide insight into the distributions of singing insects. Furthermore, results from both our positive control sites reflected our qualitative assessment of population density, suggesting both that PAM is useful for detecting the occurrence and density of *R. roeselii*, and that the lack of hits from ABMI ARUs likely represents the actual absence of *R. roeselii* in those locations.

Previous studies have monitored Orthoptera using many resource-intensive sampling methods including field sampling and manual analysis of environmental recordings (Fischer et al., 1997; Gardiner et al., 2005; Gardiner & Hill, 2006; Lehmann et al., 2014). However, the relatively few studies that have used PAM (i.e., using automated species recognition software to search through environmental recordings) to monitor Orthoptera have focused on either community abundance (Jeliazkov et al., 2016; Newson et al., 2017) or richness (Penone et al., 2013) despite the greater spatial and temporal coverage of this method (Marques et al., 2013). These studies were capable of detecting thousands of hits belonging to several Orthoptera species in the United Kingdom and France. Additionally, both Penone et al. (2013) and Newson et al. (2017) detected *R. roeselii* using their audio recording algorithms in areas where *R. roeselii* is abundant. Our results are consistent with these previous studies that have used PAM and automated species recognition software to look at populations of Orthoptera.

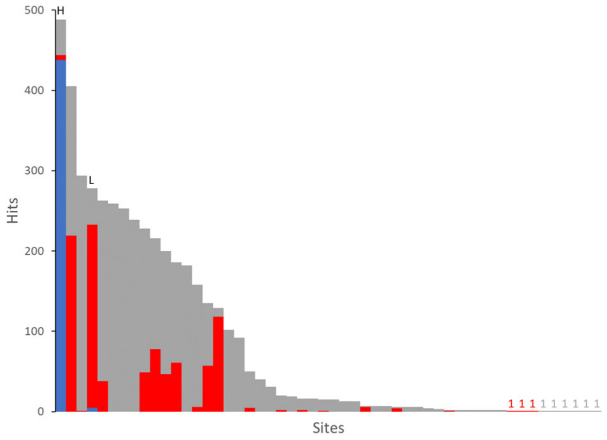

FIGURE 5 Frequency histogram of the number of hits classified as either *Roeseliana roeselii* (blue), other acoustic insects (red) or other sounds (grey) in environmental recordings at 52 sites where our automated recognizers detected candidate sounds. Sites are arranged in decreasing order of total hits. The 23 sites where our recognizers failed to detect any candidate sounds are not pictured. H and L represent the positive control recorders placed in the high-density and low-density sites in Wagner Natural Area, respectively. Numbers above the horizontal axis represent sites with only a single hit.

In our study, we were able to find numerous hits that were not *R. roeselii* but that belonged to other orthopteran taxa. Future research should consider similar PAM methods to measure the abundance and distribution of Orthoptera in North America for conservation and monitoring. For example, PAM could be an efficient method to monitor the Mormon cricket, *Anabrus simplex* (Tettigoniidae). Although present in low-density populations in southern Alberta, it is an agricultural pest in the United States that is thought to be increasing both its range and abundance in Alberta in response to climate change (Cannon, 1998; Wang et al., 2014).

During our field sampling, we found four previously unreported *R. roeselii* populations in Alberta. These populations were all separated by at least 10 km and although we did not exhaustively search the intervening habitat, in addition to the present sampling and PAM results, haphazard searches by two of the authors (Kevin A. Judge and Alexandre P. Caouette) suggest that *R. roeselii* is not continuously distributed in the area around known populations. Furthermore, we found that the majority of captured individuals were brachypterous—a phenomenon that has been associated with established populations rather than those that are newly formed (Poniatowski & Fartmann, 2009, 2011; Vickery, 1965). If indeed the Albertan distribution of *R. roeselii* is made up of few, geographically isolated but established populations, then this suggests a more complicated biogeographic history than natural dispersal from its naturalized range in eastern North America. *R. roeselii* is thought to have been spread to Sweden from mainland Europe by humans through the shipment of hay (Kaňuch et al., 2013). Interestingly, the populations detected during field sampling are all within 17 km of a major cross-Canada rail and highway corridor, and in 2002, over 45,000 metric tons of hay were shipped to Alberta and Saskatchewan by farmers in eastern Canada via train and truck (Le Roy & Klein, 2003). Analysing the genetic relatedness of populations of *R. roeselii* (Kaňuch et al., 2013) from across Alberta, eastern North America and Europe could help answer the question of how and when *R. roeselii* arrived in Alberta and is the subject of ongoing research (Kevin A. Judge and Alexandre P. Caouette, unpublished data).

Although our data suggest that *R. roeselii* is not widespread, there is still the possibility that *R. roeselii* remained undetected in the ARUs deployed by ABMI. ABMI places recorders using a systematic 20 km grid (Burton et al., 2014), while other Orthoptera monitoring studies placed recorders near the roadside (Jeliazkov et al., 2016; Penone et al., 2013). In future studies, ARUs should be placed near roadsides both because these are vectors of introduction for non-native species and because *R. roeselii* is commonly found in disturbed grasslands. Furthermore, ABMI ARUs are often collected before mid-July (Burton et al., 2014) but, like many other singing insects, *R. roeselii* sings from July to September. This leaves only a small time period where it is possible to detect *R. roeselii* songs based on current deployment schedules (Kaňuch et al., 2014; Newson et al., 2017). Therefore, to better detect *R. roeselii* and other acoustic insects, ARU deployments should be lengthened.

Automated acoustic monitoring of large-scale audio datasets (i.e., PAM) can give us a greater understanding of both species' abundance and distribution and community composition across large spatial scales. This has the potential to be enormously beneficial for the conservation and management of both pests and vulnerable species by reducing the time and costs associated with surveying these animal populations (Lehmann et al., 2014; Newson et al., 2017; Shonfield & Bayne, 2017; Zwart et al., 2014). Despite not finding the target species via PAM, we did demonstrate that PAM has significant potential to monitor singing insects, like orthopterans and cicadas, whose ranges will likely continue to shift in response to climate change (Robinet & Roques, 2010; Walters et al., 2006). As the collection of large-scale audio data for monitoring vertebrate fauna becomes more and more frequent, we have the opportunity to use these databases to monitor sound-producing insects as well.

AUTHOR CONTRIBUTIONS

Alexandre P. Caouette: Conceptualization; methodology; software; data curation; investigation; validation; formal analysis; visualization; project administration; writing – original draft; writing – review and editing. **Erin M. Bayne:** Software; writing – review and editing; resources; conceptualization; methodology; data curation. **Kevin A. Judge:** Conceptualization; methodology; investigation; validation; formal analysis; supervision; funding acquisition; resources; writing – review and editing; project administration; visualization.

ACKNOWLEDGEMENTS

We would like to thank J. Van Der Linden, Z. Vydra and R. Hender for their help with specimen collection and the Wagner Natural Area Society for permission to collect on the property. We thank N. Annich for their technical assistance with the recognizer, Alex McPhail and Hedwig Lankau for support and the Alberta Biodiversity Monitoring Institute for the use of their data.

FUNDING INFORMATION

This research was supported by Natural Sciences and Engineering Research Council (NSERC) Discovery Grant to Kevin A. Judge (RGPIN-2017-04674) and an NSERC Undergraduate Student Research Award to Alexandre P. Caouette.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in Dryad at https://doi.org/10.5061/dryad.79cnp5j17.

ORCID

Alexandre P. Caouette https://orcid.org/0000-0001-9518-7338
Erin M. Bayne https://orcid.org/0000-0002-0679-4521
Kevin A. Judge https://orcid.org/0000-0003-3390-3532

REFERENCES

Ahlén, I. (1995) En isolerad population av ängsvårtbitare (*Metrioptera roeseli*) på skånska sydkusten. *Entomologisk Tidskrift*, 116, 187–188 (in Swedish).

Aide, T.M., Corrada-Bravo, C., Campos-Cerqueira, M., Milan, C., Vega, G. & Alvarez, R. (2013) Real-time bioacoustics monitoring and automated species identification. *PeerJ*, 1, 1–19.

Alexander, R.D. (1957) Sound production and associated behavior in insects. *The Ohio Journal of Science*, 57, 101–113.

Berggren, Å. (2004) Impact of grazing on individual male movement in Roesel's bush-cricket *Metrioptera roeseli*: one possible clue to species range expansion. *Journal of Insect Behavior*, 17, 419–429.

Berggren, Å., Birath, B. & Kindvall, O. (2002) Effect of corridors and habitat edges on dispersal behavior, movement rates, and movement angles in Roesel's bush-cricket (*Metrioptera roeseli*). *Conservation Biology*, 16, 1562–1569.

Berggren, Å. & Low, M. (2004) Exclusion of the native bog bush-cricket *Metrioptera brachyptera* by the currently invading Roesel's bush-cricket *Metrioptera roeseli*. *Entomologisk Tidskrift*, 125, 125–132.

Blumstein, D.T., Mennill, D., Clemins, P., Girod, L., Yao, K., Patricelli, G. et al. (2011) Acoustic monitoring in terrestrial environments using microphone arrays: applications, technological considerations and prospectus. *Journal of Applied Ecology*, 48, 758–767.

BOLD System. (2019) Barcode of Life Data System v4:Taxonomy browser *Roeseliana roeselii*.

Burton, A.C., Huggard, D., Bayne, E., Schieck, J., Sólymos, P., Muhly, T. et al. (2014) A framework for adaptive monitoring of the cumulative effects of human footprint on biodiversity. *Environmental Monitoring and Assessment*, 186, 3605–3617.

Bussière, L.F., Basit, H.A. & Gwynne, D.T. (2005) Preferred males are not always good providers: female choice and male investment in tree crickets. *Behavioral Ecology*, 16, 223–231.

Cannon, R.J.C. (1998) The implications of predicted climate change for insect pests in the UK, with emphasis on non-indigenous species. *Global Change Biology*, 4, 785–796.

Cullen, D.A., Cease, A.J., Latchininsky, A.V., Ayali, A., Berry, K., Buhl, J. et al. (2017) From molecules to management: mechanisms and consequences of locust phase polyphenism. *Advances in Insect Physiology*, 53, 167–285.

Cusano, D.A., Matthews, L.P., Grapstein, E. & Parks, S.E. (2016) Effects of increasing temperature on acoustic advertisement in the Tettigoniidae. *Journal of Orthoptera Research*, 25, 39–47.

Eggleton, P. (2020) The state of the world's insects. *Annual Review of Environment and Resources*, 45, 61–82.

Fischer, F.P., Schulz, U., Schubert, H., Knapp, P. & Schmöger, M. (1997) Quantitative assessment of grassland quality: acoustic determination of population sizes of orthopteran indicator species. *Ecological Applications*, 7, 909–920.

Gardiner, T. (2009) Macropterism of Roesel's bushcricket *Metrioptera roeselii* in relation to climate change and landscape structure in eastern England. *Journal of Orthoptera Research*, 18, 95–102.

Gardiner, T. & Hill, J. (2006) A comparison of three sampling techniques used to estimate the population density and assemblage diversity of orthoptera. *Journal of Orthoptera Research*, 15, 45–51.

Gardiner, T., Hill, J. & Chesmore, D. (2005) Review of the methods frequently used to estimate the abundance of orthoptera in grassland ecosystems. *Journal of Insect Conservation*, 9, 151–173.

GBIF.org. (2021) GBIF occurrence download [WWW document]. *The Global Biodiversity Information Facility*. Available from: https://doi.org/10.15468/dl.52renh [accessed on 2021].

Heller, K.-G. (1988) *Bioakustik der Europäischen Laubheuschrecken*. Weikersheim, Germany: Verlag Josef Margraf.

Henderson, A., Henderson, D. & Sinclair, J. (2008) *Bugs alive: a guide to keeping Australian invertebrates*, 1st edition. Melbourne, Australia: Museum Victoria.

Hochkirch, A. & Damerau, M. (2009) Rapid range expansion of a wing-dimorphic bush-cricket after the 2003 climatic anomaly. *Biological Journal of the Linnean Society*, 97, 118–127.

iNaturalist. (2023) Distribution of *Roeseliana roeselii* [WWW Document]. https://inaturalist.ca/observations?d2=2017-12-31&place_id=any&subview=map&taxon_id=458944 [Accessed on 2023].

Iorgu, I.S. & Iorgu, E.I. (2011) Bioacoustics in bush-crickets, crickets and grasshoppers (Insecta: Orthoptera) from Ciucaş Mountains (Eastern Carpathians, Romania). *Bruckenthal Acta Musei*, 6, 427–446.

Jeliazkov, A., Bas, Y., Kerbiriou, C., Julien, J.F., Penone, C. & Le Viol, I. (2016) Large-scale semi-automated acoustic monitoring allows to detect temporal decline of bush-crickets. *Global Ecology and Conservation*, 6, 208–218.

Kaňuch, P., Berggren, Å. & Cassel-Lundhagen, A. (2013) Colonization history of *Metrioptera roeselii* in northern Europe indicates human-mediated dispersal. *Journal of Biogeography*, 40, 977–987.

Kaňuch, P., Berggren, Å. & Cassel-Lundhagen, A. (2014) Genetic diversity of a successful colonizer: isolated populations of *Metrioptera roeselii* regain variation at an unusually rapid rate. *Ecology and Evolution*, 4, 1117–1126.

Knight, E.C. & Bayne, E.M. (2019) Classification threshold and training data affect the quality and utility of focal species data processed with automated audio-recognition software. *Bioacoustics*, 28, 539–554.

Le Roy, D.G. & Klein, K.K. (2003) Say Hay and Hay west: charity, government and farmer responses to the 2002 drought in western Canada. *Western Economics Forum*, 2, 1–4.

Lehmann, G.U.C., Frommolt, K.H., Lehmann, A.W. & Riede, K. (2014) Baseline data for automated acoustic monitoring of orthoptera in a Mediterranean landscape, the Hymettos, Greece. *Journal of Insect Conservation*, 18, 909–925.

Lindenmayer, D.B., Gibbons, P., Bourke, M., Burgman, M., Dickman, C.R., Ferrier, S. et al. (2012) Improving biodiversity monitoring. *Austral Ecology*, 37, 285–294.

Losey, J.E. & Vaughan, M. (2006) The economic value of ecological services provided by insects. *Bioscience*, 56, 311–323.

MacKenzie, D.I. (2016) What are the issues with presence-absence data for wildlife managers? *The Journal of Wildlife Management*, 69, 849–860.

Marques, T.A., Thomas, L., Martin, S.W., Mellinger, D.K., Ward, J.A., Moretti, D.J. et al. (2013) Estimating animal population density using passive acoustics. *Biological Reviews*, 88, 287–309.

Marshall, J.A. & Haes, E.C.M. (1988) *Grasshoppers and allied insects of Great Britain and Ireland*. Colchester, England: Harley Books.

Newson, S.E., Bas, Y., Murray, A. & Gillings, S. (2017) Potential for coupling the monitoring of bush-crickets with established large-scale acoustic monitoring of bats. *Methods in Ecology and Evolution*, 8, 1051–1062.

Noss, R.F. (1990) Indicators for monitoring biodiversity: a hierarchical approach. *Conservation Biology*, 4, 355–364.

Penone, C., Le Viol, I., Pellissier, V., Julien, J.F., Bas, Y. & Kerbiriou, C. (2013) Use of large-scale acoustic monitoring to assess anthropogenic pressures on orthoptera communities. *Conservation Biology*, 27, 979–987.

Poniatowski, D. & Fartmann, T. (2009) Experimental evidence for density-determined wing dimorphism in two bush-crickets (Ensifera: Tettigoniidae). *European Journal of Entomology*, 106, 599–605.

Poniatowski, D. & Fartmann, T. (2011) Weather-driven changes in population density determine wing dimorphism in a bush-cricket species. *Agriculture, Ecosystems and Environment*, 145, 5–9.

Potts, S.G., Imperatriz-Fonseca, V. & Ngo, H.T. (2016) *IPBES*. The assessment report of the intergovernmental science-policy platform on biodiversity and ecosystem services on pollinators, pollination and food production. Secretariat of the intergovernmental science-policy platform on biodiversity and ecosystem services, Bonn, Germany.

Riede, K. (1998) Acoustic monitoring of orthoptera and its potential for conservation. *Journal of Insect Conservation*, 2, 217–223.

Robinet, C. & Roques, A. (2010) Direct impacts of recent climate warming on insect populations. *Integrative Zoology*, 5, 132–142.

Sergeev, M.G., Storozhenko, S.Y. & Benediktov, A.A. (2018) An annotated check-list of orthoptera of Tuva and adjacent regions. Part 1. Suborder Ensifera. *Far Eastern Entomologist*, 372, 1–24.

Shonfield, J. & Bayne, E.M. (2017) Autonomous recording units in avian ecological research: current use and future applications. *Avian Conservation & Ecology*, 12, 14.

Simmons, A.D. & Thomas, C.D. (2004) Changes in dispersal during species' range expansions. *American Naturalist*, 164, 378–395.

Thomas, J.A. (2005) Monitoring change in the abundance and distribution of insects using butterflies and other indicator groups. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 360, 339–357.

Titley, M.A., Snaddon, J.L. & Turner, E.C. (2017) Scientific research on animal biodiversity is systematically biased towards vertebrates and temperate regions. *PLoS One*, 12, e0189577.

Tregenza, T. & Wedell, N. (1997) Definitive evidence for cuticular pheromones in a cricket. *Animal Behaviour*, 54, 979–984.

Troudet, J., Grandcolas, P., Blin, A., Vignes-Lebbe, R. & Legendre, F. (2017) Taxonomic bias in biodiversity data and societal preferences. *Scientific Reports*, 7, 9132.

Urquhart, F.A. & Beaudry, J.R. (1953) A recently introduced species of European grasshopper. *Canadian Entomologist*, 85, 78–79.

Vickery, V.R. (1965) Factors governing the distribution and dispersal of the recently introduced grasshopper, *Metrioptera roeseli* (Hgb.) (orthoptera: Ensifera). *Annals of the Entomological Society of Québec*, 10, 165–171.

Wagner, C. (2004) Passive dispersal of *Metrioptera bicolor* (Phillipi 1830) (Orthopteroidea: Ensifera: Tettigoniidae) by transfer of hay. *Journal of Insect Conservation*, 8, 287–296.

Walters, R.J., Hassall, M., Telfer, M.G., Hewitt, G.M. & Palutikof, J.P. (2006) Modelling dispersal of a temperate insect in a changing climate. *Proceedings of the Royal Society B: Biological Sciences*, 273, 2017–2023.

Wang, Y., Huang, Q., Zhang, X. & Ren, B. (2014) Application of insect songs in monitoring population density level of locusta migratoria (orthoptera: Acrididae). *Zoological Studies*, 53, 1–7.

Zacher, F. (1917) *Die Geradflügler Deutschlands und ihre Verbreitung: Systematisches und synonymisches Verzeichnis der im Gebiete des Deutschen Reiches bisher aufgefundenen Orthopteren-Arten (Dermaptera, Oothecaria, Saltatoria)*. Gustav Fischer, Jena. (in German).

Zwart, M.C., Baker, A., McGowan, P.J.K. & Whittingham, M.J. (2014) The use of automated bioacoustic recorders to replace human wildlife surveys: an example using nightjars. *PLoS ONE*, 9, e102770.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Data S1. Table S1. Details of the settings used for the two automated computer recognizers built in Song Scope 4.1.3A (Wildlife Acoustics Inc., Maynard, MA U.S.A.) to detect calls of Roesel's katydid (*R. roeselii*). The lab and field recognizers were trained on lab and field recorded *R. roeselii* respectively.

Table S2. Recognizer performance statistics of two automated computer recognizers built in Song Scope 4.1.3A (Wildlife Acoustics, Inc., Maynard, MA U.S.A.) to detect calls Roesel's katydid (*R. roeselii*). The lab and field recognizers were trained on lab and field recorded *R. roeselii* respectively.

How to cite this article: Caouette, A.P., Bayne, E.M. & Judge, K.A. (2024) Large-scale bioacoustic monitoring to elucidate the distribution of a non-native katydid. *Ecological Entomology*, 49(1), 119–127. Available from: https://doi.org/10.1111/een.13285