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Bioacoustics as a novel approach for detecting the presence of Brown Rats on seabird islands

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SUMMARY

Background Static acoustic bat detectors were deployed over a six-month winter survey season, to explore the possibility for using acoustics to detect and monitor the presence of Brown Rats on Rathlin Island in Northern Ireland. This report provides an overview of the survey coverage and main results from 2022/23.

Coverage During the winter of 2022/23, 48 different locations across Rathlin Island were surveyed. Recording was undertaken on 113 different nights mainly between mid-November and the end of February, amounting to a total of 301 nights of recording effort across sites. Sound recordings (wav files) were uploaded to the BTO Acoustic Pipeline, where a first automated analysis was carried out and provisional results returned. Recordings were then moved to deep glacial storage for later auditing. At the beginning of March, a copy of the recordings was pulled back, and manual auditing of the results / recordings carried out.

Results Overall, 312,768 recordings were collected which, following analyses and validation, were found to include 185 small terrestrial mammal recordings, and 810 bat recordings. Following validation, the study confirmed the presence of three small mammal species, including Brown Rat *Rattus norvegicus*, and four bat species. The timing of fieldwork during the winter was outside the active period for bats, which is why there are so few bat recordings. This is the first acoustics study that we have carried out during the winter, but we expected more recordings of Brown Rats, which means that we are left with some questions. In particular, how active and vocal are Brown Rats during the winter, and whether the distribution of this species during the winter is likely to influence the probability of detecting this species. Work in the Channel Islands between April and October has found Brown Rat to be an easy species to record. For this reason, we recommend that the project is extended to continue to deploy bat detectors into the spring and summer. The report includes a full species-by-species breakdown of spatial, seasonal, and through-the-night patterns of activity.

1. BACKGROUND

Offshore islands provide particularly important breeding habitats for the UK's globally important seabird populations. In Northern Ireland (hereafter 'NI'), islands support the majority of the country's total population of some cliff-nesting species (98% Common Guillemot *Uria aalge*, 91% Razorbill *Alca torda*, 82% Shag *Gulosus aristotelis*) and burrow-nesting species (100% Manx Shearwater *Puffinus puffinus*, 98% Puffin *Fratercula arctica*), based on Seabird 2000 census data (JNCC, 2020; Mitchell *et al*., 2004). Initial results of the most recent census data from 2021 suggest that NI now supports the UK's largest Guillemot colony and third-largest Razorbill colony (Booth Jones *et al*. 2022). Manx Shearwater's breed in the small archipelago of the Copeland Islands, but this species also almost certainly breeds on Rathlin Island, with evidence pointing to a small population breeding across the north cliffs. Although not currently extant in Northern Ireland as a breeding species, European Storm Petrels *Hydrobates pelagicus* were formerly thought to nest on two islands off the north coast of Antrim, likely to be Sheep Island and one of the Skerries (Deane, 1954; Ussher & Warren, 1900), while Rathlin Island may have also held this species in the past.

Seabird nesting cliffs on Rathlin Island, Northern Ireland (Image credit: Katherine Booth Jones).

However, island ecosystems are vulnerable to introduced mammalian predators and seabird species that nest in crevices and burrows are particularly susceptible (Jones *et al*., 2008). On NI's off-shore islands, introduced predators include Brown Rats *Rattus norvegicus*, and Ferrets *Mustela furo*. While undoubtedly NI's seabirds are not immune to threats facing seabirds globally, such as climate change, pollution and bycatch (Dias *et al*., 2019), the presence of Brown Rats and Ferrets will also have an impact on abundance, by reducing breeding success through the predation of eggs and chicks and potentially the loss of adults to Ferret predation. For example, Puffins and Black Guillemots *Cepphus grylle* are both known to be vulnerable to ground-level predation (Ewins, 1985; Johnston *et al*., 2019; Lock, 2006; Zonfrillo, 2002) and appear to have declined by 74% and 64% respectively on Rathlin Island since the Seabird 2000 census (Booth Jones, 2021, Booth Jones *et al*., 2022). Declines caused by predation also have the potential to cause local extinctions; Rathlin Island is thought to hold a breeding colony of Manx Shearwaters in the north cliffs, but because the locations in which they breed are inaccessible, it has been difficult to confirm successful breeding.

Eradication of introduced mammalian predators on islands has been a successful method of improving breeding productivity of seabirds in other parts of the world (Williams *et al*. 2020). However, wildlife monitoring pre-, during and post-eradication is vital to provide evidence of the effectiveness of introduced predator eradication as a conservation method, which is an important ethical consideration. Quantitative studies assessing effectiveness of eradications have historically been limited because monitoring data can be difficult to obtain due to the inaccessible nature of many island seabird colonies, making them expensive and potentially hazardous to survey. One approach is passive acoustic monitoring, which involves the use of acoustic sensors to detect sounds in the natural environment, from which ecological information can be extracted (Browning *et al*., 2017).

Passive acoustic sensing has the potential to allow monitoring to continue over extended time periods that are required to assess ecosystem responses to predator eradication. New advances in passive acoustic detection, including semi-automated analysis and signal detection (Newson *et al*., 2015; Newson & Pearce 2022) may assist in collecting data on presence, abundance and activity patterns in seabird colonies (Raine *et al*., 2017), and sensors have been proven to be an efficient way of collecting long-term monitoring data in other contexts (e.g. Digby *et al*., 2013; Newson *et al*., 2021, 2015).

The BTO's cloud-based Acoustic Pipeline launched in early 2021, provides the infrastructure to allow sound recordings (wav files) to be uploaded to a secure remote server in the cloud, for standardised analyses of the uploaded files to be carried out, and summaries of the results returned soon after they have been collected and uploaded. The current focus of the BTO Acoustic Pipeline is the sound identification of bats, small terrestrial mammals including rats and mice (Newson *et al*., 2020), and bush-crickets (Newson *et al*., 2017), but with work in progress to extend the taxonomic scope to include nocturnal birds and breeding waders. Proof of concept for detecting the presence of Brown Rats was demonstrated through the volunteer Bailiwick Bat Survey which resulted in 5,769 sound recordings of Brown Rats across the islands as 'by-catch' during bat surveys in 2021 (Newson *et al.*, 2022). It is not only Brown Rats (and Black Rats *Rattus rattus*) and Ferrets that may predate seabirds on islands; domestic animals such as cats and dogs, native mammals such as Eurasian Otters *Lutra lutra*, and native bird taxa such as corvids and gulls also have the potential to impact breeding success and adult survival. For example, Lambert *et al*. (2021) found that the in areas of the Isle of Rum where rodenticide was applied to reduce Brown Rat presence, the negative impact of Wood Mouse *Apodemus sylvaticus* on Manx Shearwater breeding success increased, reducing the positive impact of removing Brown Rats.

Bat detector set up on Rathlin Island in November 2022 (Image credit: Katherine Booth Jones).

Acoustics offer great possibilities in reducing the cost, labour and risk involved in monitoring wildlife on offshore islands. We therefore propose to pilot passive acoustic sensing on one or more of NI's off-shore islands. We aim to initially trial the use of passive acoustic sensing on Brown Rats, for which acoustic classifiers already exist via the BTO Acoustic Pipeline. Acoustic sensors set to record the ultrasonic calls of Brown Rats, will also record bats, which will be identified if recorded, whilst work to collect reference sound recordings for Ferrets is in process, and could be used to extend the analysis of collected recordings at a later date, subject to continued funding. Additionally, there is scope in the longer term to use the same acoustic sensors with an acoustic microphone to record seabird vocalisations, to provide baseline data and a call library for future classifier development, which would contribute to future studies on the effectiveness of passive acoustic detection in seabird monitoring.

2. AIMS AND OBJECTIVES

This project aims to:

- Provide baseline acoustic data to complement traditional invasive predator monitoring, to test the efficacy of acoustics and the BTO Acoustic Pipeline in providing quantitative information on the presence of non-native predators, namely Brown Rats;
- Provide information on other small terrestrial mammal species and bats if they are recorded as by-catch and which will be identified by the Acoustic Pipeline (Newson *et al*., 2017b; Newson *et al*., 2021). The full dataset will be collated and retained, with the potential for extending the analysis to consider the sound identification of Ferrets in the future.

Map of Rathlin Island. The aim is to achieve survey coverage across the island.

3. METHODS

3.1 Static detector protocol

Our survey approach is based on the Norfolk Bat Survey, the Southern Scotland Bat Survey (Newson *et al.*, 2015; Newson *et al.*, 2017a), and most recently the Bailiwick Bat Survey (Newson *et al.*, 2021; Newson *et al*, 2022) which were set up to assess the season-wide status of bat species throughout large regions. Our protocol enables fieldworkers to have access to passive real-time bat detectors which they leave outside to automatically trigger and record the calls to a memory card every time a bat passes throughout a night.

Bat detectors (the Song Meter Mini Bat), were placed out to record for a minimum of four, but up to ten consecutive nights at each location. The minimum recommendation of four nights follows analyses of bat data carried out by ourselves as part of a Defra funded project to inform the most cost-effective sampling regime for detecting the effect of local land-use and land management (BTO, unpublished data). Multiple nights of recording are likely to smooth over stochastic and weather related variation, whilst also being easy to implement logistically (once a detector is on site, it is easy to leave it in situ for multiple nights).

The bat detectors were set to record with a sample rate of 384 kHz and to use a high pass filter of 12 kHz which defined the lower threshold of the frequencies of interest for the triggering mechanism. Recording was set to continue until no trigger is detected for a 2 second period up to a maximum of 5 seconds. Detectors were deployed before sunset and detectors set to switch on and record from sunset until sunrise the following day. The detector was mounted on poles at a height of about 1.5 meters to avoid ground noise and reduce recordings of reflected calls. Guidance was provided to fieldworkers on the placement of microphones which were to be deployed at least 1.5-m in any direction from vegetation, water or other obstructions.

3.2 Survey effort and timing

The survey period ran from October to the beginning of March. We note that the timing of the survey season during the winter months is outside the main period of activity for bats, and possibly for Brown Rats and for other small mammals, but running the survey over several months maximises the chance of recording these species.

3.3 Processing recordings and species identification

Automated passive real-time detectors are triggered when they detect sound within a certain frequency range. Monitoring on this scale can generate a very large volume of recordings, efficient processing of which is greatly aided by a semi-automated approach for assigning recordings to species.

At the end of a recording session, the files recorded by the bat detector (uncompressed wav format), were uploaded to the BTO's Acoustic Pipeline http://bto.org/pipeline for processing. Fieldworkers have their own online user account, and desktop software through which they can upload recordings directly to the cloud-based BTO Acoustic Pipeline for processing. This system captures the metadata (name and email address of the person taking part, the survey dates, and locations at which the detectors were left out to record), which are matched automatically to the results. Once a batch of recordings is processed, the user is emailed automatically, and the raw results are then downloadable through the user account as a csv file. These first results are provided with the caveat that additional auditing of the results and recordings is carried out at the end of the survey season.

Because the cost of cloud processing and storage is expensive, and there is a significant cost every time data is pulled out or moved, particularly if it is in the most accessible storage tier, recordings were automatically moved to deep glacial storage after processing. The recordings were then not easily accessible during the survey season itself, but a complete copy of the recordings was pulled back at the end of the survey season for auditing.

The BTO Acoustic Pipeline applies machine learning algorithms to classify sound events in the uploaded recordings. The classifier allows up to four different "identities" to be assigned to a single recording, according to probability distributions between detected and classified sound events. From these, species identities are assigned by the classifier, along with an estimated probability of correct classification. Specifically this is the false positive rate, which is the probability that the Pipeline has assigned an identification to the wrong species. However, we scale the probability, so that the higher the probability, the lower the false positive rate. To give an example, given a species identification with a probability of 0.9, there is a 10% chance that the identification is wrong.

Our recommendation, which is supported in Barré *et al.* (2019), is that identifications with a probability of less than 0.5 (50%) are discarded. However, manually auditing of a sample of recordings (wav files) that are below this threshold, was carried out to be confident that we were losing very little by doing this.

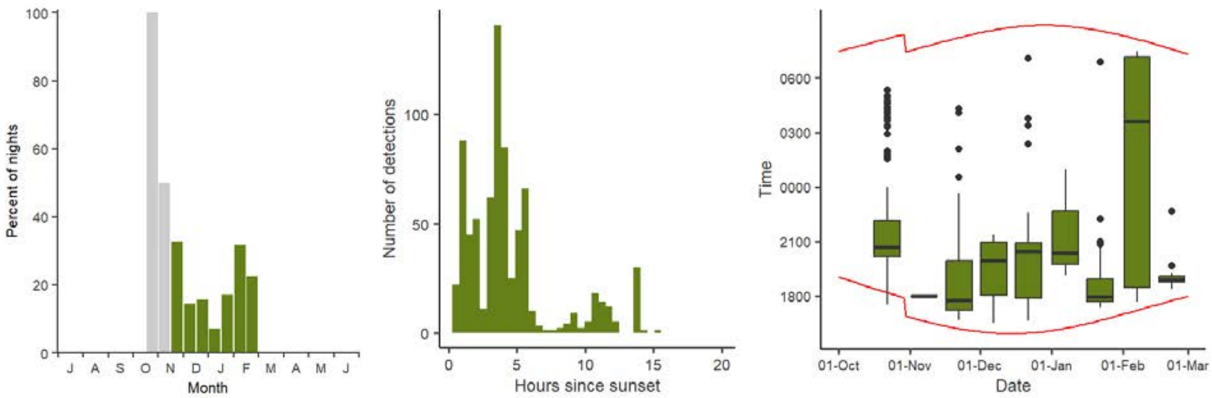
For Brown Rats and other species of small mammals and bats where we were interested in producing a measure of activity, we manually checked all the recordings of a species.

Verification of species identification was carried out through the manual checking of spectrograms using software SonoBat (http://sonobat.com/) which was used as an independent check of the original species identities assigned by pipeline. The spectrograms shown in this report, were also produced using SonoBat. All subsequent analyses use final identities upon completion of the above inspection and (where necessary) correction steps.

3.4 Seasonal and nightly patterns of activity

Potentially important for improving our understanding of Brown Rats and other species present, we examine how activity varied by time of night and by season. Nightly activity was determined for each half-month period and presented according to the percentage of survey nights on which each species was detected. Activity through the night was analysed by first converting all registration times to time since sunset based on the location and date and calculated using the R package suncalc (Thieurmel & Elmarhraoui, 2019) and then assessing the frequency distribution of registrations relative to sunset for the whole season and in half-month periods. By looking at nightly activity in this way, it allows us to visualise general patterns in activity for a species according to time of night and season, accepting that activity on any given night will be influenced by weather and potentially other factors.

To explain the figures in the following results section, we show an example below for Common Pipistrelle. The left plot shows the percentage of nights on which the species was detected every half-month through the season, showing the periods of main activity for this species. If present, pale grey bars represent periods with fewer than 10 nights of recording where accuracy of the reporting rate may be low.The middle plot shows the overall spread of recordings with respect to sunset time, calculated over the whole season. The right plot shows the spread of recordings with respect to sunset and sunrise times (red lines) summarised for each half-month through the season. For this last seasonal plot, the individual boxplot show quartiles (lower, median and upper) with lines extended to 1.5 times the interquartile range, and small dots show outliers.



3.5 Spatial patterns of activity and distribution

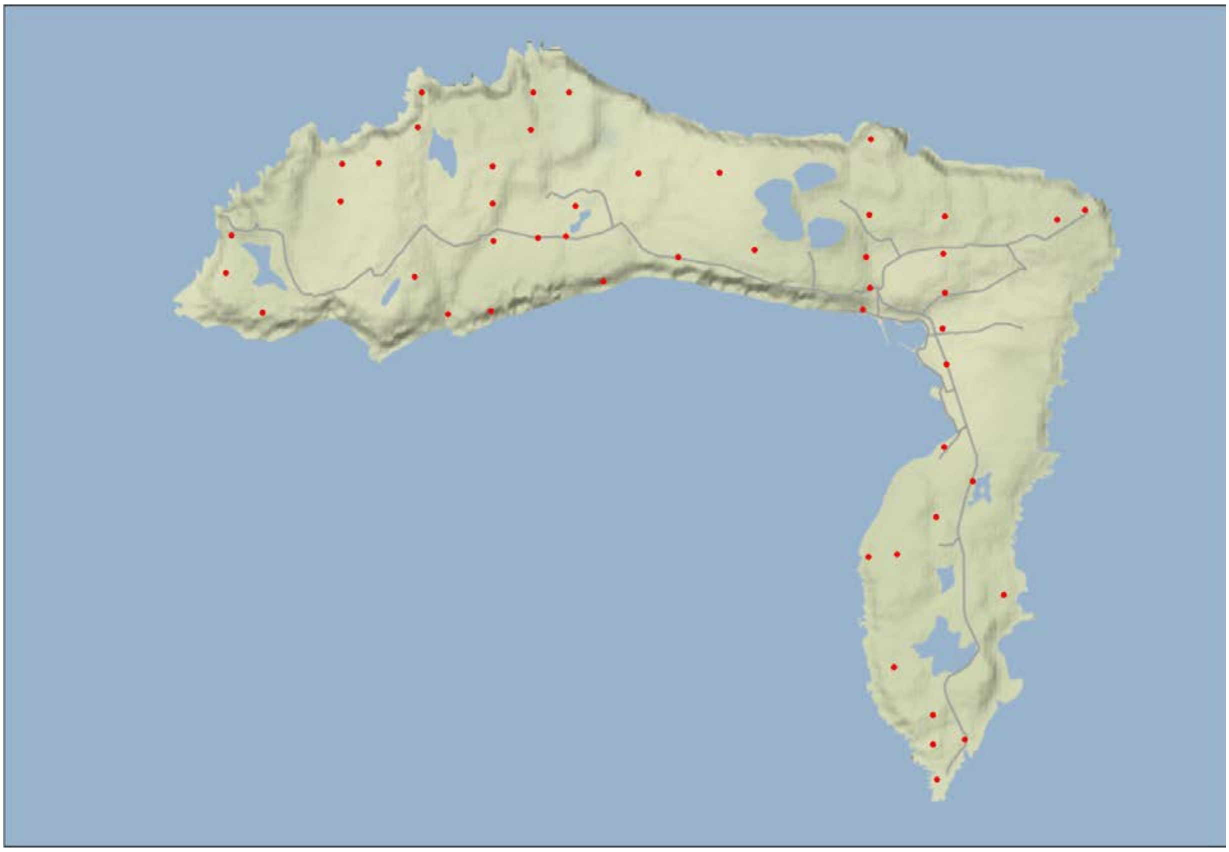
We produce maps of small mammal and bat activity. With these, dots are scaled according to the total number of recordings of this species at each location. Activity here represents usage of an area, which will be a combination of species abundance, and time spent in the area.

4. RESULTS

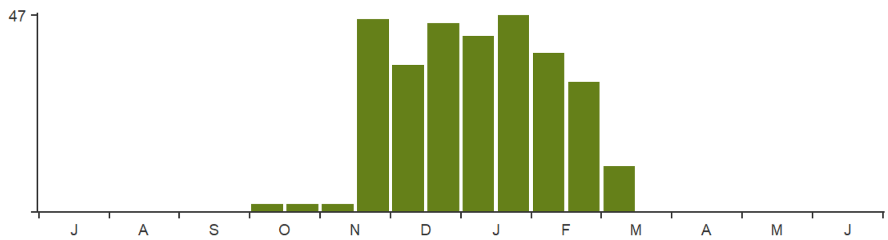
4.1 Survey coverage

During 2022-2023, 48 different locations were surveyed for rats, with all recordings uploaded and processed through the BTO Acoustic Pipeline. The distribution of these locations is shown below. Collectively across all these sites, 301 complete nights of recording effort was conducted. The recording effort spanned 113 different nights and 6 months. The seasonal pattern of recording effort is shown in the bottom figure.

Map of the study area showing locations where detectors were deployed in 2022-2023.



Number of locations surveyed.



4.2 General results

Overall, 312,768 recordings were collected which, following analyses and validation, were found to include 810 bat recordings, and 185 small terrestrial mammal recordings. Following validation, the presence of at least four bat species, and three small mammal species were confirmed.

Species detected, number of recordings of each species following validation and a summary of the scale of recording.

Small mammals

Species	No. of recordings following validation	No. of different locations (% of total)
Brown Rat, Rattus norvegicus	5	1 (2.1%)
Wood Mouse, Apodemus sylvaticus	153	3 (6.2%)
Eurasian Pygmy Shrew, Sorex minutus	27	9 (18.8%)

Bats

Species (/call type)	No. of recordings following validation	No. of different locations (% of total)
Natterer's Bat, Myotis nattereri	3	2 (4.2%)
Leisler's Bat, Nyctalus leisleri	6	2 (4.2%)
Common Pipistrelle, Pipistrellus pipistrellus	762	27 (56.2%)
Brown Long-eared Bat, Plecotus auritus	39	1 (2.1%)

4.3 Species and call-type results

The following sections provide results for each species and/or call type.

4.3.1 Small terrestrial mammal species

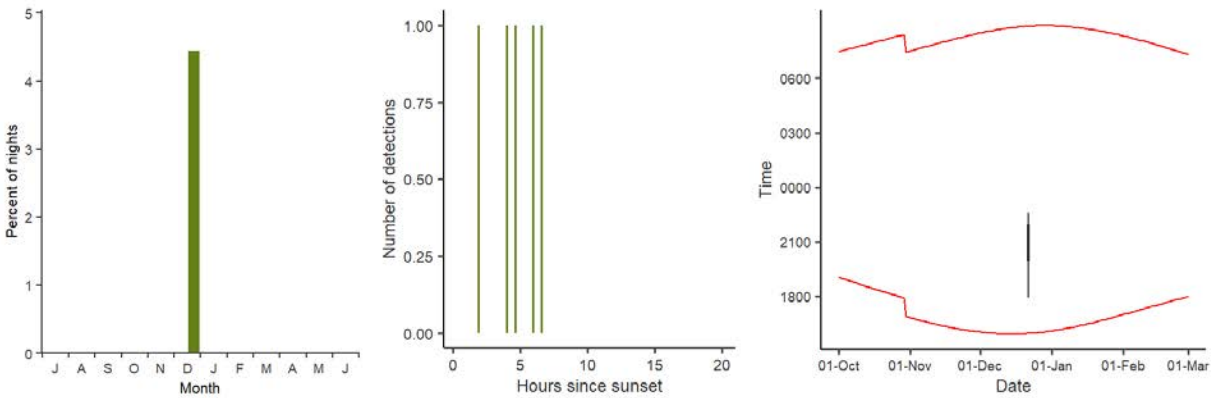
In this section we look at the recordings that we can assign to small terrestrial mammals.

Brown Rat

Brown Rat *Rattus norvegicus* was recorded on two nights, from one location, giving a total of 5 recordings.

Spatial pattern of activity

Seasonal and nightly activity



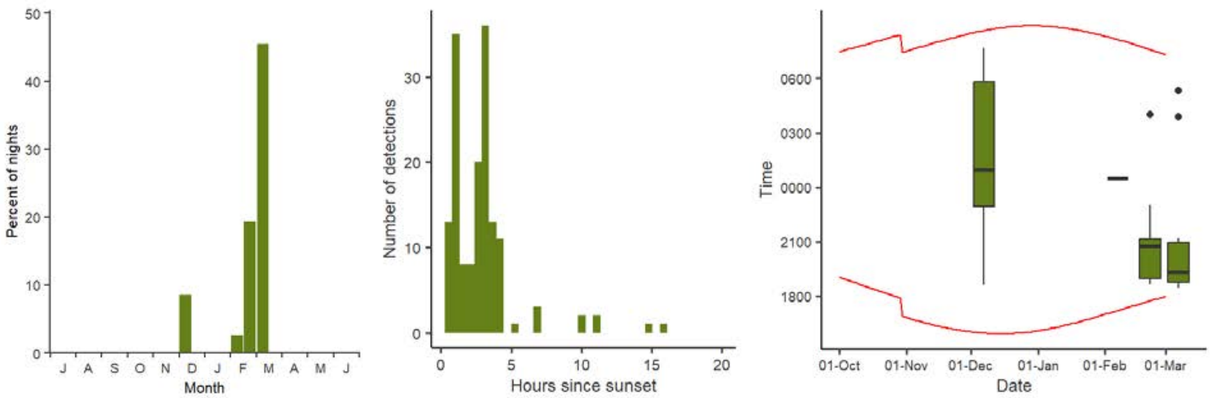
Brown Rat was recorded from one location during the nights of the 19th and 20th December. The location was within 200-m of the docks and close to the main area of human habitation on the island. However, the small number of recordings of Brown Rat recorded through this project leaves us with some questions. Similar deployment of bat detectors in the Channel Islands, but from Spring to early Autumn has found Brown Rat to be an easy species to record. We do not know how the number of Brown Rats on Rathlin Island compares to those in the Channel Islands, but this does raise another possibility, whether it becomes harder to record Brown Rats during the winter. It could be that the call rate of Brown Rats is lower during the winter months, and are potentially less territorial during this period. Alternatively, if the distribution of Brown Rats during the winter becomes more aggregated and localised, the number of locations where Brown Rats may be recorded at this time of year, may be less during the winter than at other times of year. There is also some evidence that Brown Rats may be more concentrated around the coastline (Else *pers. comm.*), so our sampling strategy to deploy bat detectors at the same locations as the camera trapping grid may be less likely to record Brown Rats than if they were placed along the coast. For these reasons, we recommend that we continue to deploy bat detectors into the spring and summer, and potentially think further about the sampling design.

Wood Mouse

Wood Mouse *Apodemus sylvaticus* was recorded on 15 nights, from three locations, giving a total of 154 recordings.

Spatial pattern of activity

Seasonal and nightly activity

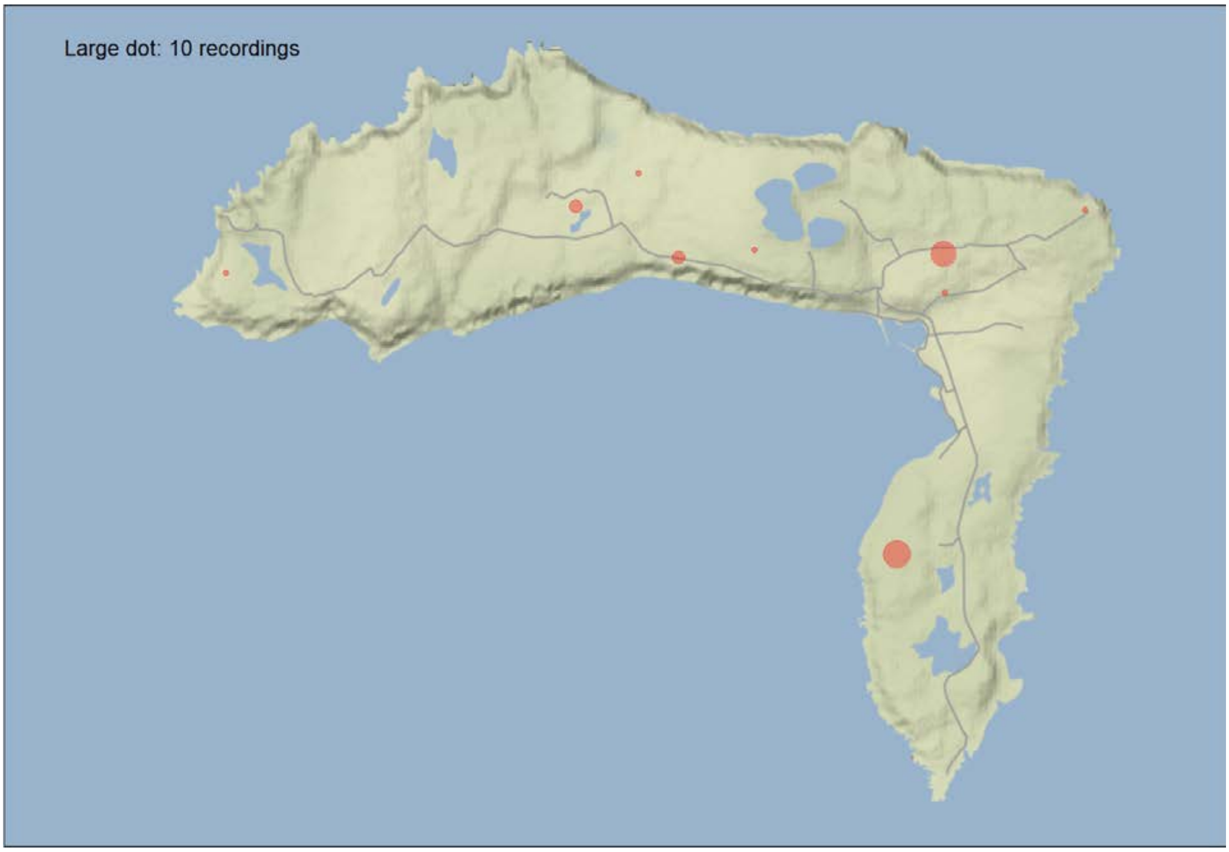


Wood Mouse Compared with the other small terrestrial mammal species here, the calls of Wood Mouse are not as loud, and so are likely to be under-recorded compared with shrews and rats. The detection distance of Wood Mouse is only about 1.5-m and so mounting the detector high on a pole, whilst ideal for bats, is likely to under-record this species (Newson *et al.* 2022). For more information on the sound identification of Wood Mouse see Newson *et al.*, (2021).

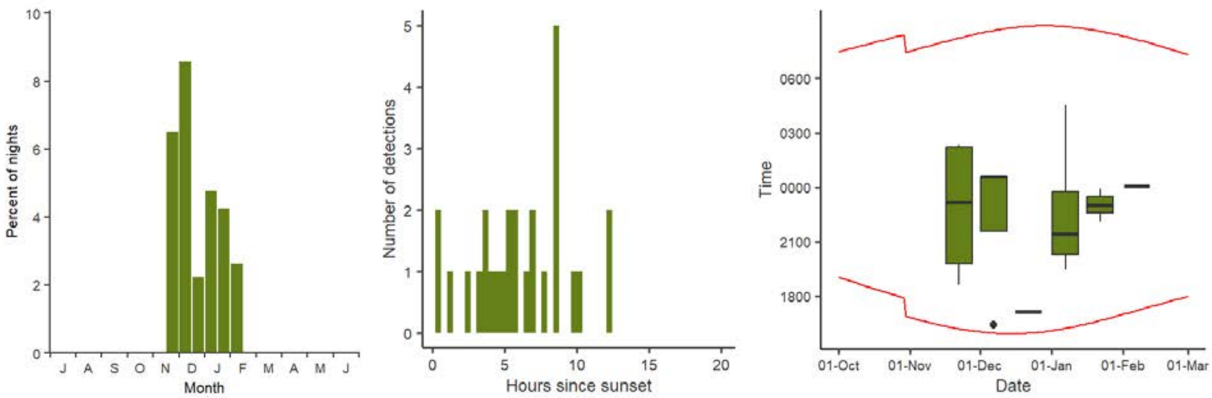
Eurasian Pygmy Shrew

Eurasian Pygmy Shrew *Sorex minutus* was recorded on 11 nights, from nine locations, giving a total of 27 recordings.

Spatial pattern of activity



Seasonal and nightly activity



Pygmy Shrew produce calls that are notably different from those of Rodents in having multiple harmonics that when played slowed down, produces a warbling sound. The most common calls of Pygmy Shrew are complex and often include five or more harmonics, where no two calls in a single recordings being quite the same. For more information on the sound identification of shrews, see Newson *et al*., (2021). The recordings of Pygmy Shrew from this study, are less typical of the territorial calls that we have recorded most commonly during the spring and summer, but are within the range of what we have recorded for this species.

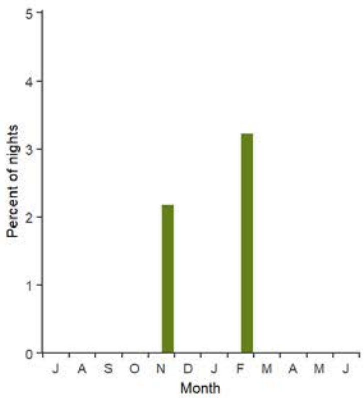
4.3.2 Bat species

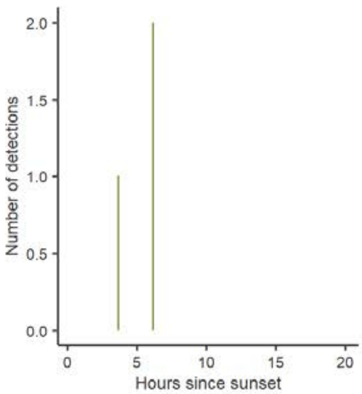
Natterer's Bat

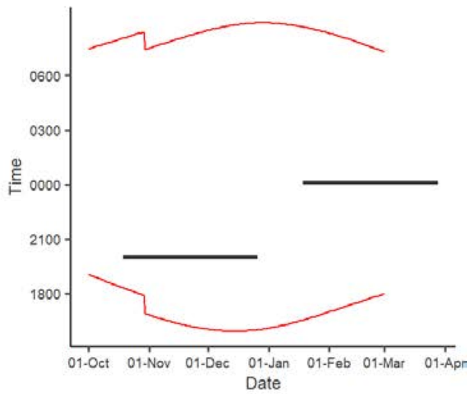
Natterer's Bat *Myotis nattereri* was recorded on two nights, from two locations, giving a total of 3 recordings.

Spatial pattern of activity

Seasonal and nightly activity







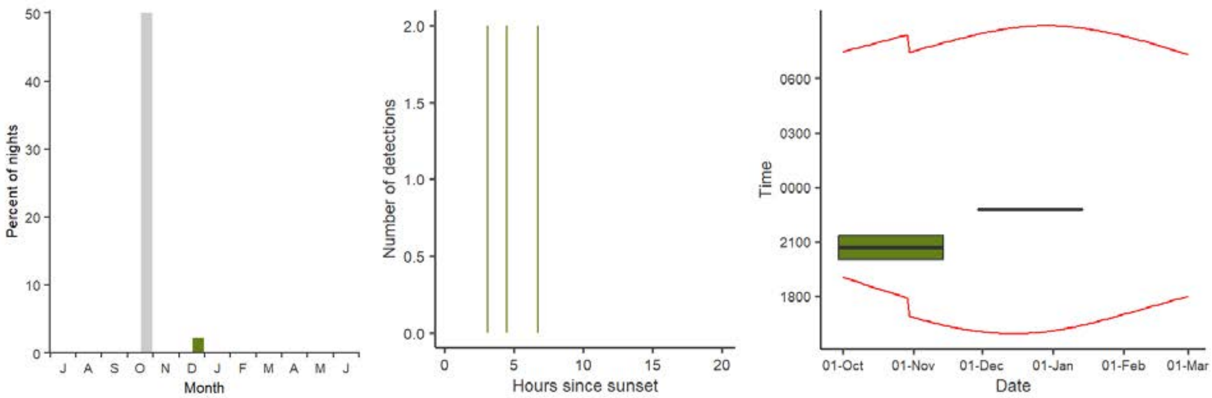
Natterer's Bat was recorded from two locations on Rathin Island. One recording from from the 17th November from close to Brockley House, and the second was from close to the town and comprising two recordings from likely the same individual on the 27th February. As with other species of bats recorded here, bats spend most of the winter hibernating, so the number of recordings at this time of year will be at its lowest level. However bats may leave the roost on warmer nights to find food and a drink of water. See Identification Appendix 1 for more information on the sound identification of Natterer's Bat.

Leisler's Bat

Leisler's Bat *Nyctalus leisleri* was recorded on two nights, from two locations, giving a total of 6 recordings.

Spatial pattern of activity

Seasonal and nightly activity



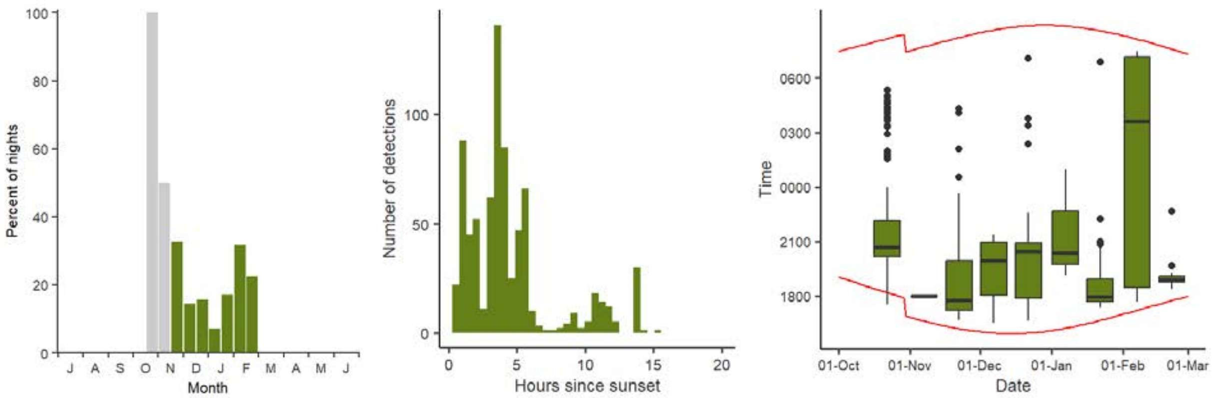
Leisler's Bat was recorded from two locations on a single date each. The first was close to the port on the 31st October, and the second was from the south-west arm of the island on the 23rd December. In Ireland, where Noctule and Serotine are believed to be absent there is no likely confusion species, but regardless of this, the alternating calls combined with the frequency of the calls are typical for Leisler's Bat. For more information on the sound identification of Leisler's Bat see Identification Appendix 2.

Common Pipistrelle

Common Pipistrelle *Pipistrellus pipistrellus* was recorded on 42 nights, from 27 locations, giving a total of 762 recordings.

Spatial pattern of activity

Seasonal and nightly activity



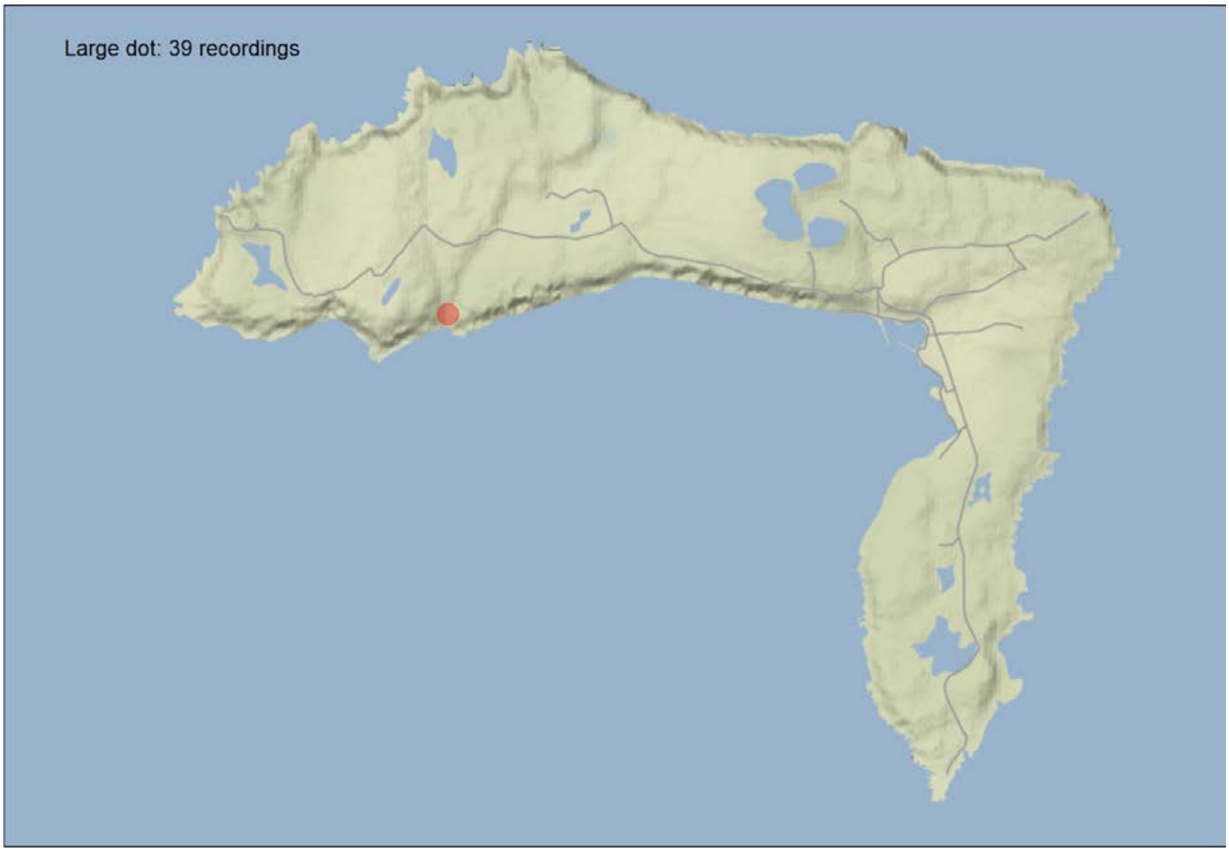
Common Pipistrelle was by far the most common and widely recorded bat species, with 762 recordings from 27 different locations (56% of survey locations) and a maximum of 529 recordings per night at an individual site in late October.

Common Pipistrelle is normally straightforward to identify acoustically, but particular care is needed given calls at the low or high frequency end of the range for this species, which could be mis-identified as Nathusius' Pipistrelle or Soprano Pipistrelle respectively. For these it is important to consider the call duration, and not just the peak or end frequency of the calls. In addition, where there are multiple individuals of the same species present, there can be frequency shifting as one or both individuals 'shift' their frequencies to avoid acoustic interference, which again can result in some calls in a sequence that are higher in frequency than would be typical for the species.

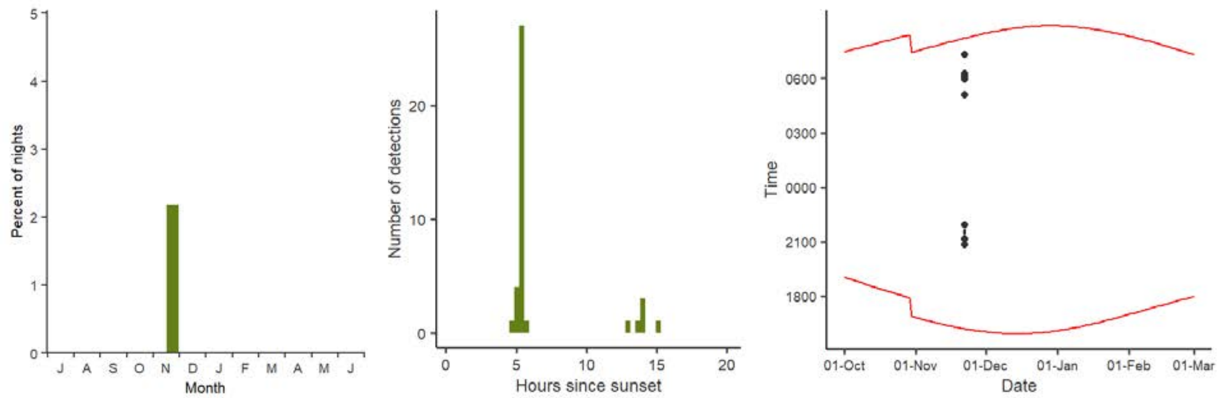
Brown Long-eared Bat

Brown Long-eared Bat *Plecotus auritus* was recorded on one night, from one location, giving a total of 39 recordings.

Spatial pattern of activity



Seasonal and nightly activity



Brown Long-eared Bat. All recordings of this species, which comprised of social calls (c-type social calls, Middleton *et al*. 2022) were from location in the west of the island close to Oweyburne Cave on the 26th November. For more information on the sound identification of Brown Long-eared Bat see Identification Appendix 3.

5. DISCUSSION

The current 2022 dataset has been very valuable in adding to our understanding of the patterns of occurrence and activity of small mammals and bats on Rathlin Island during the winter. The timing of fieldwork during the winter was outside the active period for bats. This is the first acoustics study that we have been invoved with during the winter months, and given the small number of recordings of Brown Rat it leaves some important questions. In particular, how active and vocal are Brown Rats during the winter, and whether the distribution of this species during the winter is likely to influence the probability of detecting this species. It is also possible that the current sampling strategy is missing key concentrations of Brown Rats around the coast. Work in the Channel Islands between April and October has found Brown Rat to be an easy species to record (Newson *et al*. 2021; Newson *et al*. 2022). For this reason, we recommend that we can extend and continue to deploy bat detectors into the spring and summer.

6. ACKNOWLEDGEMENTS

We would like to thank the landowners that gave us access to their land. We are also extremely grateful for support from the EU LIFE [LIFE20 NAT/UK/000349], the National Lottery Heritage Fund, DAERA, the RSPB and the Rathlin Development and Community Association. We would also like to thank the Northern Ireland Environment Agency for funding this project through the NIEA Environment Fund. Lastly we would like to thank Matt Baxter, Steve Pritchard from the BTO IS team for development and support of the BTO Acoustic Pipeline that was used in this project.

7. REFERENCES

Barataud, M. 2015. *Acoustic Ecology of European Bats: Species identification, study of their habitats and foraging behaviour*. Collection Inventaires et biodiversité, Biotope Editions, Mèze et Publications scientifiques du Muséum National d'Histoire Naturelle, Paris.

Barataud, M. & Skals, N. 2018. Émissions ultrasonores de communication sociale enregistrées en canopée : attribution au lépidoptère Pseudoips prasinana (L.) (Noctuoidea ; Nolidae ; Chloephorinae) grâce à une analyse bibliographique. *Plume de naturalistes* 2, 11-22. http://www.plume-de-naturalistes.fr/wp-content/uploads/2018/11/02_BARATAUD-M_05-2018_Emissions-ultrasonores-Pseudoips-prasinana_Plume2_11-22.pdf

Barré, K., Le Viol, I., Julliard, R., Pauwels, J., Newson, S.E., Julien, J.F., Claireau, F., Kerbiriou, C. & Bas, Y. 2019. Accounting for automated identification errors in acoustic surveys. *Methods in Ecology and Evolution*.

Booth Jones, K.A. 2021. *Northern Ireland Seabird Report 2020*. Thetford.

Booth Jones, K.A., Allen, D., Archer, E., Colhoun, K., Leonard, K., Mackie, K., Mawhinney, K., McFaul, L., Weir, D., Humphreys, E.M. & Burton, N.H.K., 2022. Cliff Nesting Seabird Surveys at Colonies in Northern Ireland. *Final report for the Agri-Food and Biosciences Institute and Marine Scotland Science*. Thetford.

Browning, E., Gibb, R., Glover-Kapfer, P., & Jones, K.E. (2017). *Passive acoustic monitoring in ecology and conservation*. WWF Conservation Technology Series, 1.

Cutler, T.L., & Swann, D.E. 1999. Photography in Wildlife Ecology. *Wildlife Society Bulletin*, 27, 571–581.

Deane, C.D. 1954. *Handbook of the birds of Northern Ireland (Vol. 1)*. Belfast Museum and Art Gallery.

Dias, M.P., Martin, R., Pearmain, E.J., Bur, I.J., Small, C., Phillips, R.A., Croxall, J.P. 2019. Threats to seabirds: A global assessment. *Biological Conservation*, in press.

Digby, A., Towsey, M., Bell, B.D., & Teal, P.D. 2013. A practical comparison of manual and autonomous methods for acoustic monitoring. *Methods in Ecology and Evolution*, 4, 675– 683.

Edney, A.J., & Wood, M.J. 2021. Applications of digital imaging and analysis in seabird monitoring and research. *Ibis*, 163, 317–337.

Ewins, P.J. 1985. Colony attendance and censusing of Black Guillemots *Cepphus grylle* in Shetland. *Bird Study*, 32, 176–185.

JNCC. 2020. *Seabird Population Trends and Causes of Change: 1986–2018 Report*. Peterborough.

Johnston, D.T., Furness, R.W., Robbins, A.M.C., Tyler, G.A., & Masden, E.A. 2019. Camera traps reveal predators of breeding Black Guillemots *Cepphus grylle*. *Seabird*, 32, 72–83.

Jones, H.P., Tershy, B.R., Zavaleta, E.S., Croll, D.A., Keitt, B.S., Finkelstein, M.E., & Howald, G.R. 2008. Severity of the Effects of Invasive Rats on Seabirds: A Global Review. *Conservation Biology*, 22, 16–26.

Jones, J.P.G. 2011. Monitoring species abundance and distribution at the landscape scale. *Journal of Applied Ecology* 48, 9-13.

Lambert, M., Carlisle, S., Cain, I., Douse, A., & Watt, L. 2021. Unexpected involvement of a second rodent species makes impacts of introduced rats more difficult to detect. *Scientific Reports 2021 11:1*, 11, 1–10.

Lock, J. 2006. Eradication of brown rats *Rattus norvegicus* and black rats *Rattus rattus* to restore breeding seabird populations on Lundy. *Conservation Evidence*, 3, 111–113.

Middleton, N., Froud, A. & French, K. 2022. *Social Calls of the Bats of Britain and Ireland.* Second Edition. Pelagic Publishing.

Mitchell, P.I., Newton, S.F., Ratcliffe, N.R., & Dunn, T.E. 2004. *Seabird Populations of Britain and Ireland. Seabird Populations of Britain and Ireland: results of the Seabird 2000 census (1998-2002)*. London: T & A D Poyser.

Newson, S.E., Evans, H.E. & Gillings, S. 2015. A novel citizen approach for large-scale standardised monitoring of bat activity and distribution, evaluated in eastern England. *Biological Conservation* 191, 38-49.

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

Newson, S. E., Boughey, K. L., Robinson, R. A., & Gillings, S. 2021. Designing effective survey and sampling protocols for passive acoustic monitoring as part of the national bat monitoring. *JNCC Report No. 688*. Peterborough.

Newson, S.E., Evans, H.E., Gillings, S., Jarret, D., Raynor, R., Wilson, M.W. 2017a. Large-scale citizen science improves assessment of risk posed by wind farms to bats in southern Scotland. *Biological Conservation* 215, 61-71.

Newson, S.E., Middleton, N., & Pearce, H. 2020. The acoustic identification of small terrestrial mammals in Britain. *British Wildlife* 32, 186-194

Newson, S.E. & Pearce, H. 2022. The potential for acoustics as a conservation tool for monitoring small terrestrial mammals. JNCC Report No. 708, JNCC, Peterborough, ISSN 0963-8091.

Newson, S.E., Allez, S.L., Coule, E.K., Gillings, S., Harper, J., Henney, J.M., Higgins, L., Simmons, M.C., Sweet, E., Whitelegg, D. & Atkinson, P.W. 2022. Bailiwick Bat Survey: 2021 season report. *BTO Research Report 743*. BTO.

Pereira, H.M. & Cooper, H.D. 2006. Towards the global monitoring of biodiversity change. *Trends Ecology and Evolution* 21, 123-129.

Raine, A.F., Boone, M., McKown, M., & Holmes, N. 2017. The breeding phenology and distribution of the Band-rumped Stormpetrel *Oceanodroma castro* on Kaua'i and Lehua Islet, Hawaiian Islands. *Marine Ornithology*, 45, 73–82.

Rendall, A.R., Sutherland, D.R., Cooke, R., & White, J. 2014. Camera Trapping: A Contemporary Approach to Monitoring Invasive Rodents in High Conservation Priority Ecosystems. *PLOS ONE*, 9, e86592.

Russ, J. (ed.) 2021. *Bat calls of Britain and Europe. A guide to species identification.* Pelagic Publishing.

Thieurmel, B. & Elmarhraoui, A. 2019. suncalc: Compute Sun Position, Sunlight Phases, Moon Position and Lunar Phase. R package version 0.5.0. https://CRAN.R-project.org/package=suncalc.

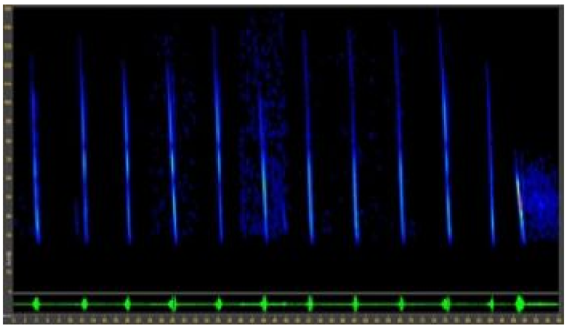
Ussher, R.J., & Warren, R. 1900. *The Birds of Ireland: An account of the distribution, migrations and habits of birds as observed in Ireland, with all additions to the Irish list*. Gurney and Jackson, London.

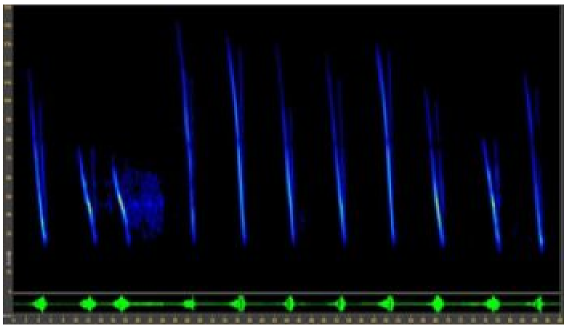
Williams, D.R., Child, M.F., Dicks, L.V., Ockendon, N., Pople, R.G., Showler, D.A., Walsh, J.C., zu E.K., Ermgassen, H.J. & Sutherland, W.J. 2020. Bird Conservation. Pages 137-281 in: W.J. Sutherland, L.V. Dicks, S.O. Petrovan & R.K. Smith (eds) *What Works in Conservation 2020*. Open Book Publishers, Cambridge, UK.

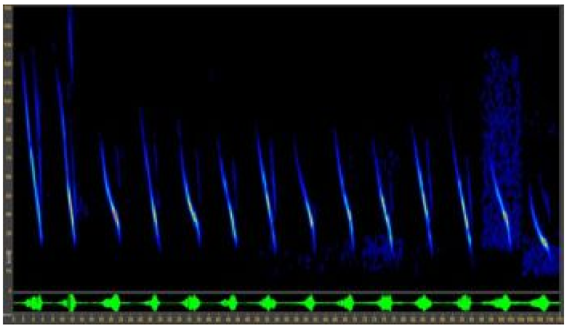
Zonfrillo, B. 2002. Puffins return to Ailsa Craig. *Scottish Bird News*, 66, 1–2.

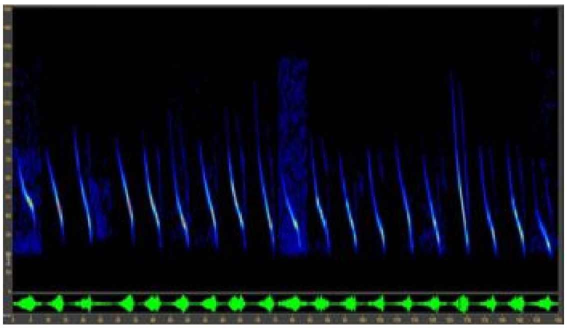
Identification appendix 1: Natterer's Bat *Myotis nattereri*

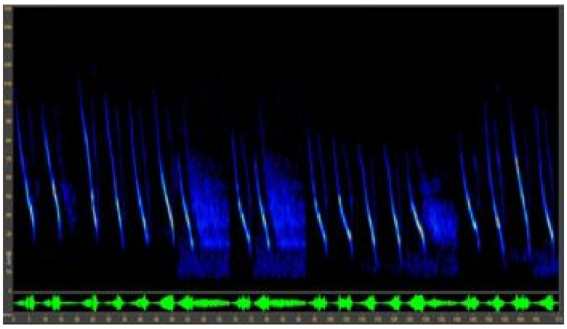
The first consideration when looking at recordings is the quality of the recording, to consider whether the quality is good enough to try to assign the recording to species. Given a good recording, Natterer's Bat can occasionally produce atypical calls that could be mistaken for other *Myotis* species, however, such unusual calls rarely continue for long. Where neighbouring recordings are present, these can provide context to understand what is going on. By carefully considering the atypical calls in a recording in relation to the calls in neighbouring recordings, it should be possible to assign most of these still to species with confidence. In the below, we illustrate some of the range of variation in calls of Natterer's Bat from very short calls produced when flying in extreme clutter (a very closed habitat or environment) to long duration calls produced when flying in the open.

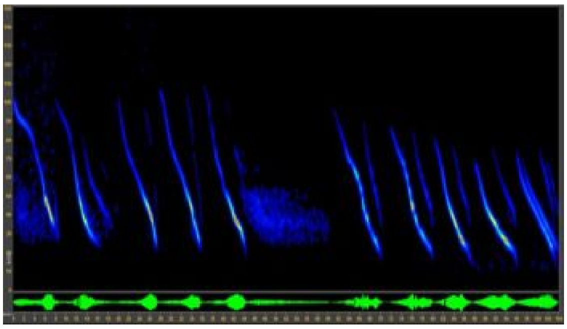

Natterer's Bat - call duration up to 1.2 ms


Natterer's Bat - call duration 2.7-2.8 ms

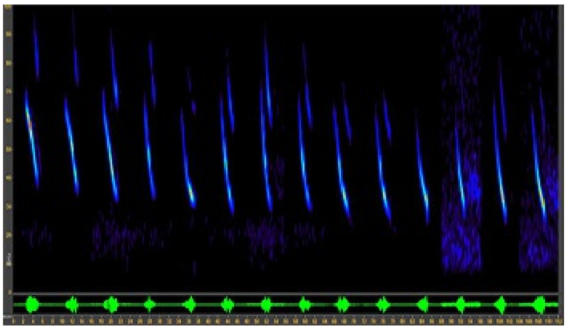

Natterer's Bat - call duration 3.9-4.0 ms

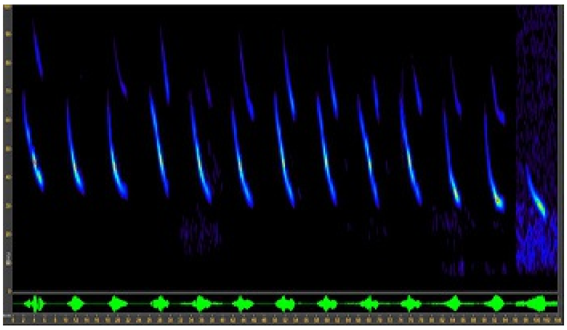

Natterer's Bat - call duration 4.9-5.0 ms

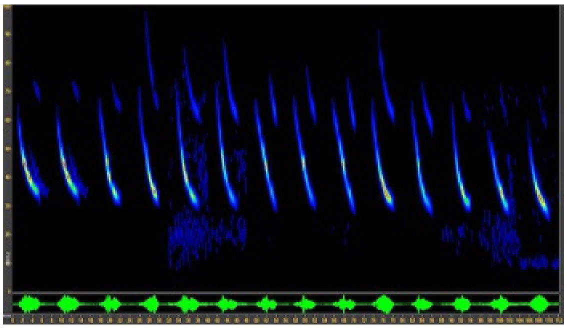

Natterer's Bat - call duration 5.9-6.0 ms

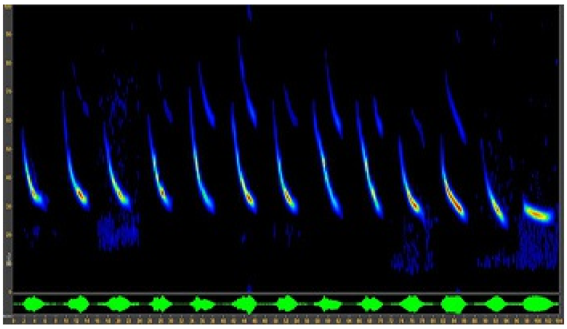

Natterer's Bat - call duration 7.1-9.4 ms

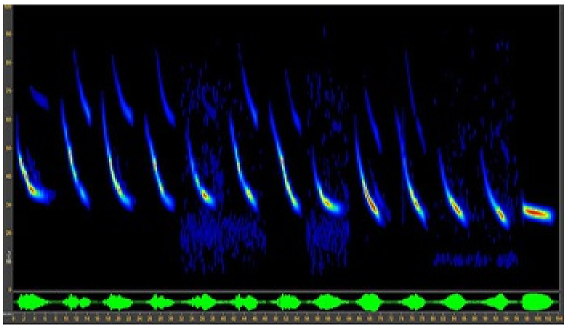
Identification appendix 2: Leisler's Bat *Nyctalus leisleri*

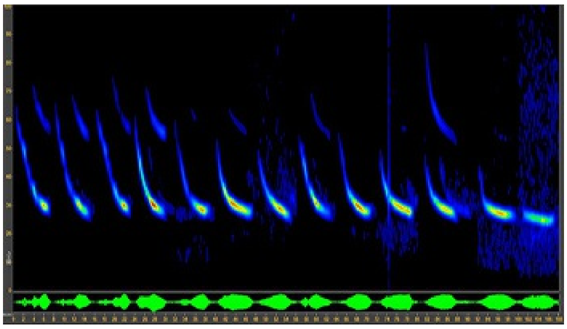

Leisler's Bat - call duration 1.4-3.0 ms

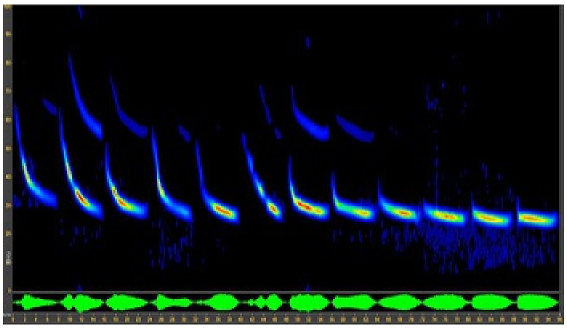

Leisler's Bat - call duration 3.1-3.7 ms

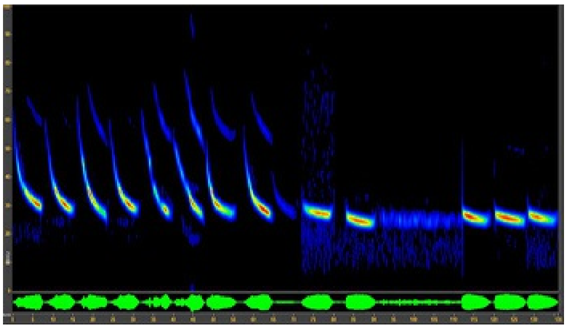

Leisler's Bat - call duration 3.8-4.3 ms

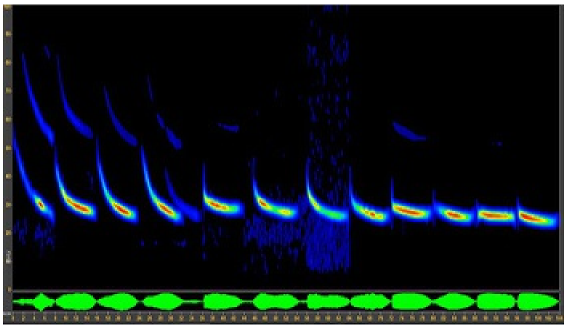

Leisler's Bat - call duration 4.4-4.9 ms

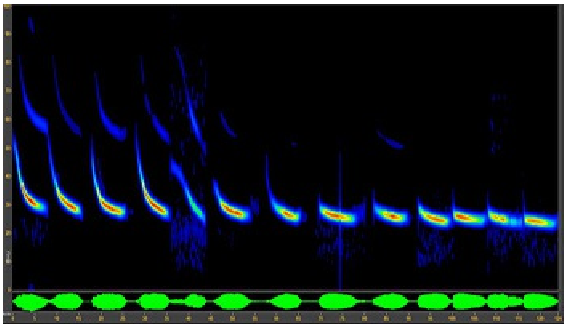

Leisler's Bat - call duration 5.0-5.9 ms

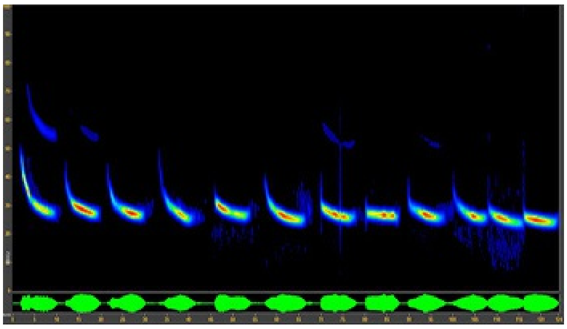

Leisler's Bat - call duration 6.0-6.8 ms

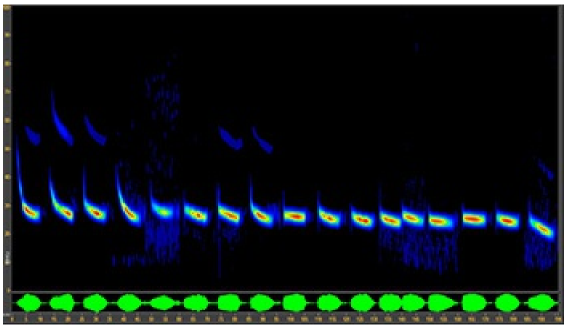

Leisler's Bat - call duration 6.9-7.2 ms

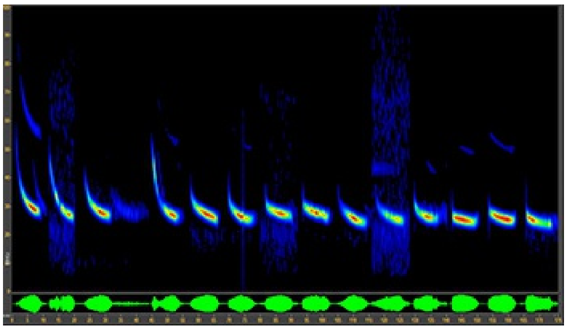

Leisler's Bat - call duration 7.3-7.6 ms

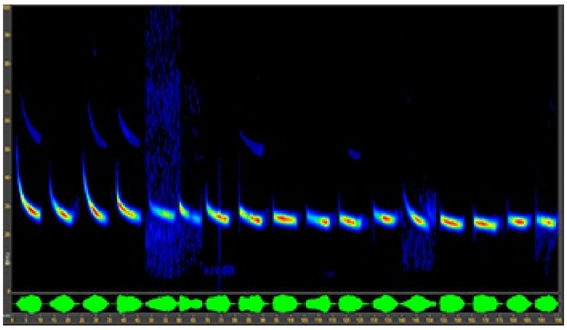

Leisler's Bat - call duration 7.7-7.8 ms

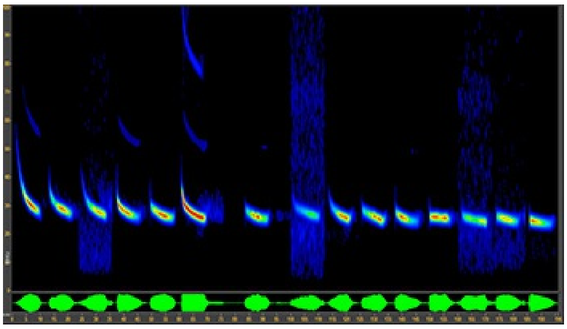

Leisler's Bat - call duration 7.9-8.0 ms

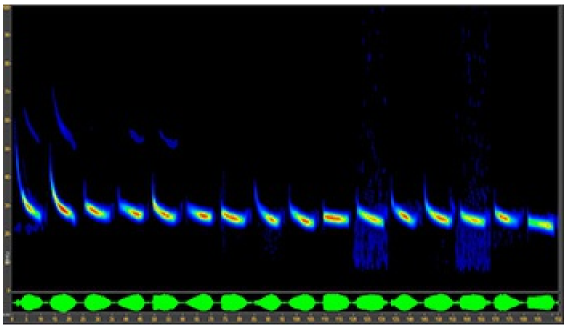

Leisler's Bat - call duration 8.1-8.3 ms

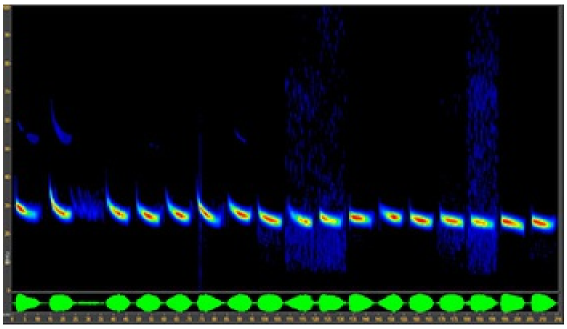

Leisler's Bat - call duration 8.4-8.5 ms

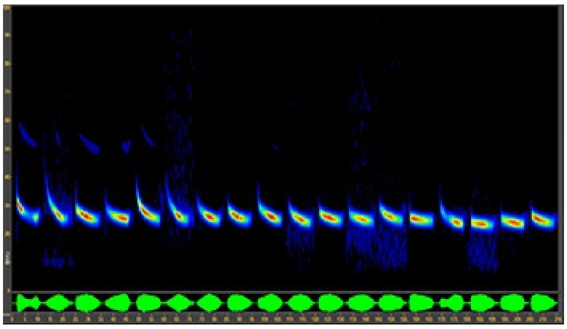

Leisler's Bat - call duration 8.6-8.7 ms

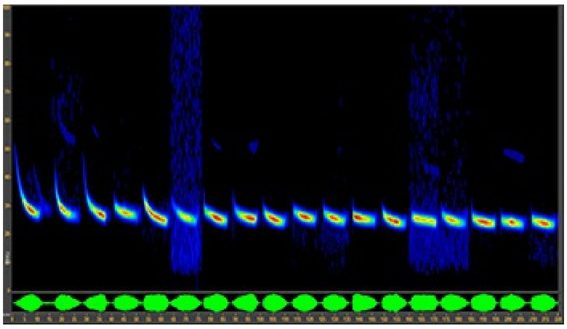

Leisler's Bat - call duration 8.8-8.9 ms


Leisler's Bat - call duration 9.0-9.1 ms

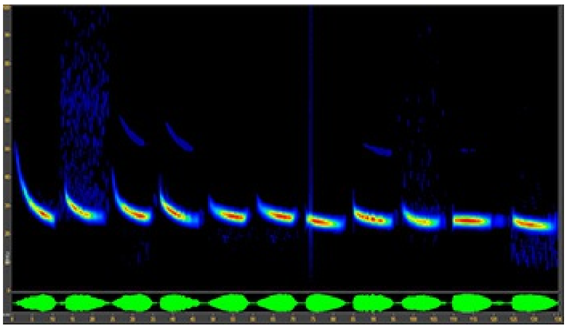

Leisler's Bat - call duration 9.2-9.3 ms


Leisler's Bat - call duration 9.4-9.5 ms

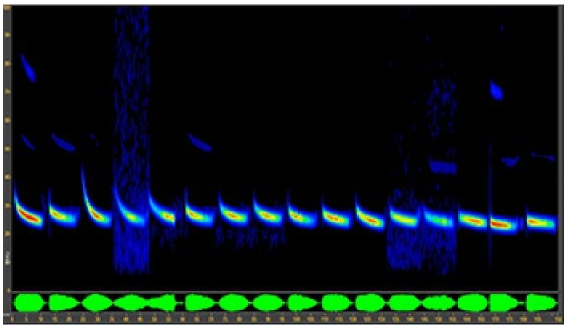

Leisler's Bat - call duration 9.6-9.7 ms



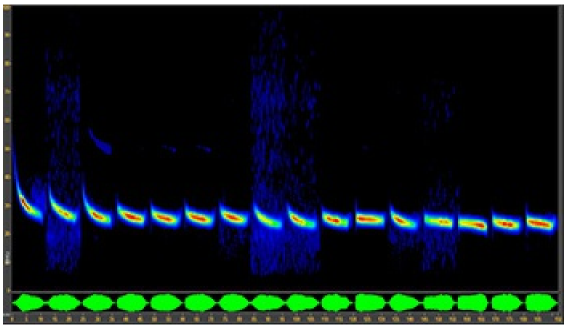
Leisler's Bat - call duration 9.8-9.9 ms



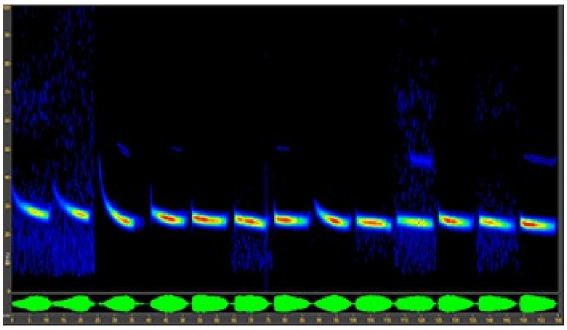
Leisler's Bat - call duration 10.0-10.1 ms



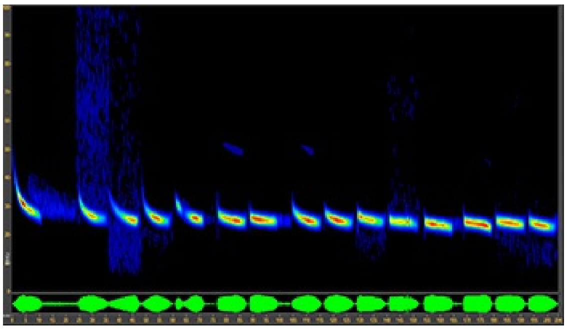
Leisler's Bat - call duration 10.2-10.3 ms



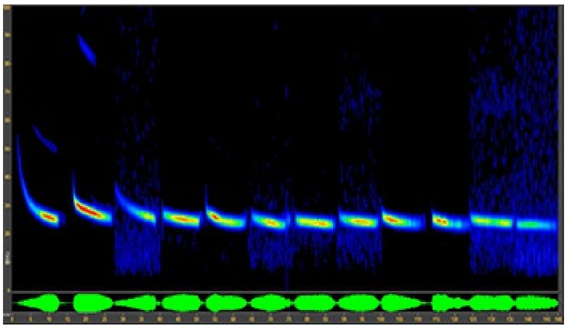
Leisler's Bat - call duration 10.4-10.5 ms



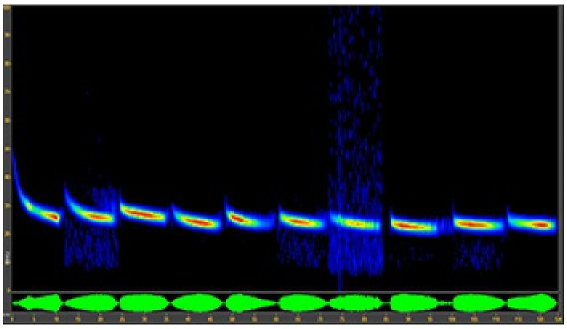
Leisler's Bat - call duration 10.6-10.7 ms



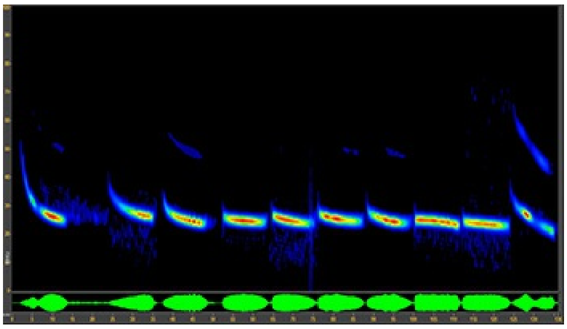
Leisler's Bat - call duration 10.8-10.9 ms



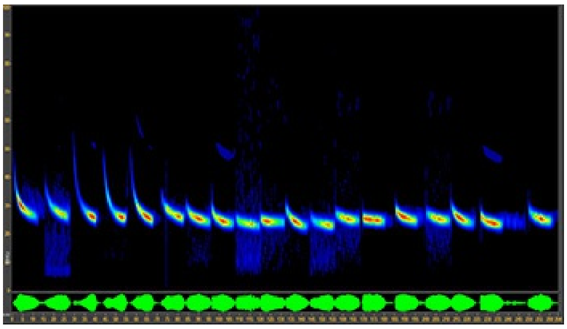
Leisler's Bat - call duration 11.0-11.1 ms



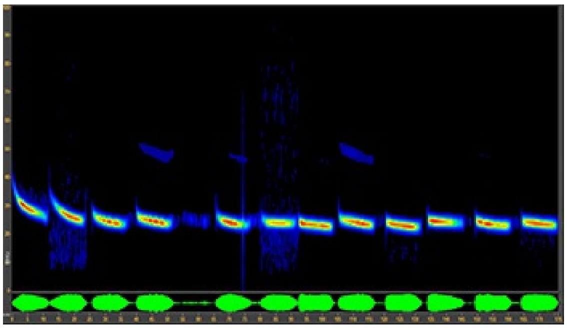
Leisler's Bat - call duration 11.2-11.3 ms

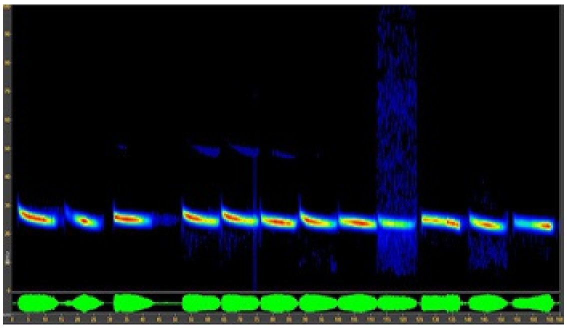


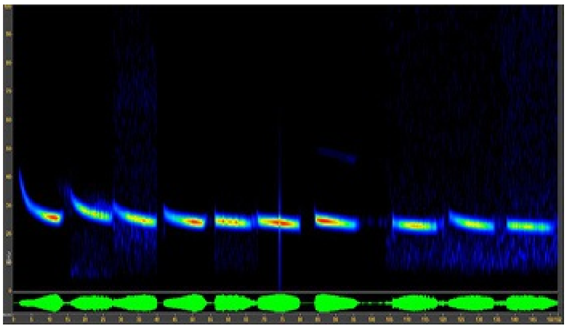
Leisler's Bat - call duration 11.4-11.5 ms

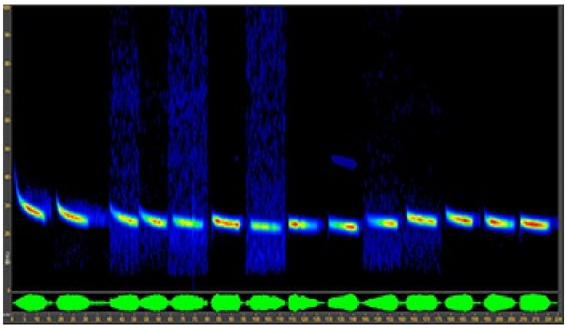


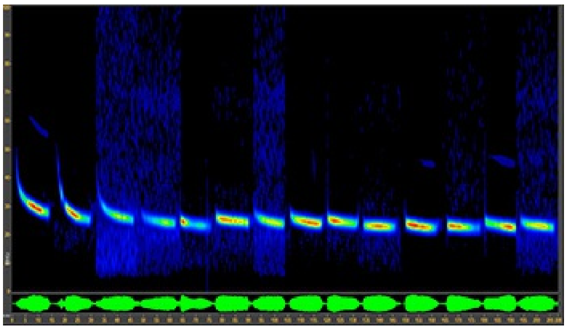
Leisler's Bat - call duration 11.6-11.7 ms

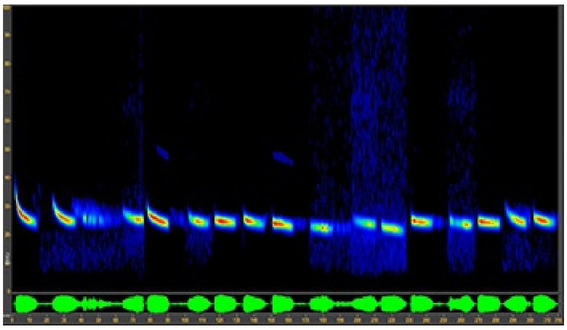

Leisler's Bat - call duration 11.8-11.9 ms


Leisler's Bat - call duration 12.0-12.2 ms


Leisler's Bat - call duration 12.3-12.4 ms


Leisler's Bat - call duration 12.5-12.7 ms


Leisler's Bat - call duration 12.8-12.9 ms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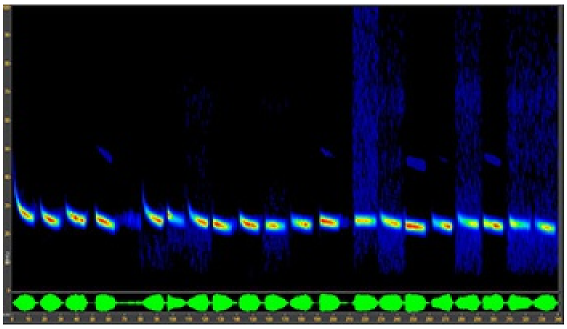
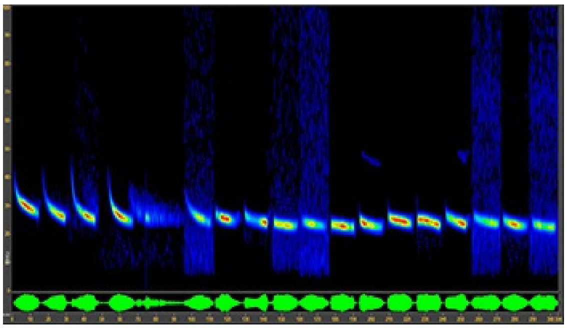
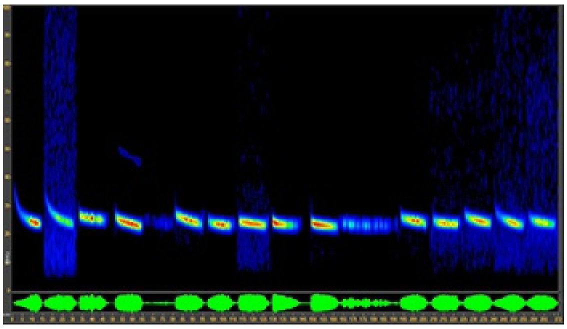
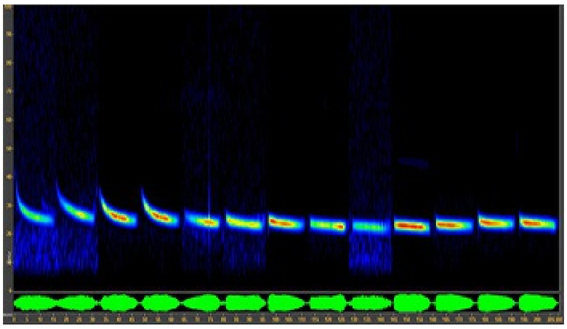
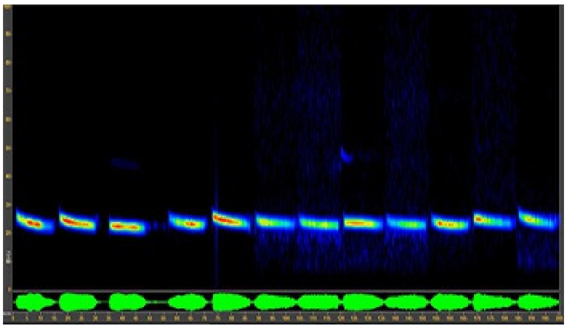

Leisler's Bat - call duration 13.2-13.3 ms

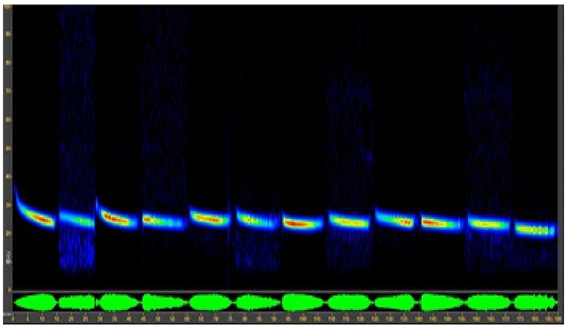

Leisler's Bat - call duration 13.4-13.5 ms


Leisler's Bat - call duration 13.6-13.7 ms

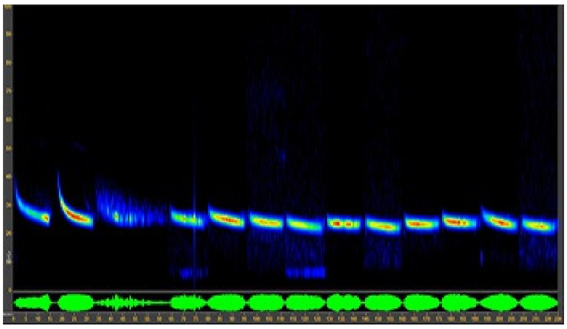

Leisler's Bat - call duration 13.8-14.0 ms



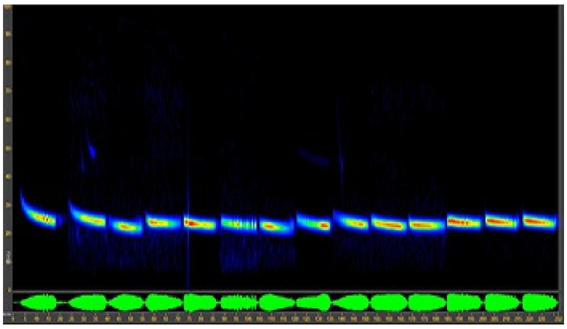
Leisler's Bat - call duration 14.1-14.3 ms



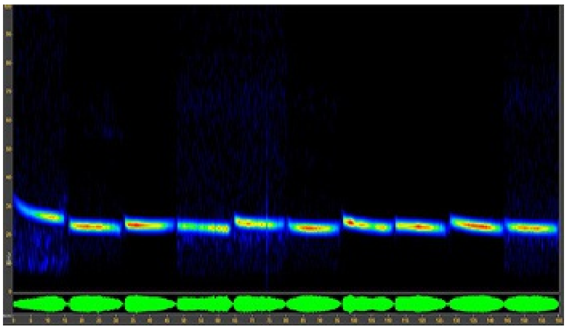
Leisler's Bat - call duration 14.4-14.5 ms



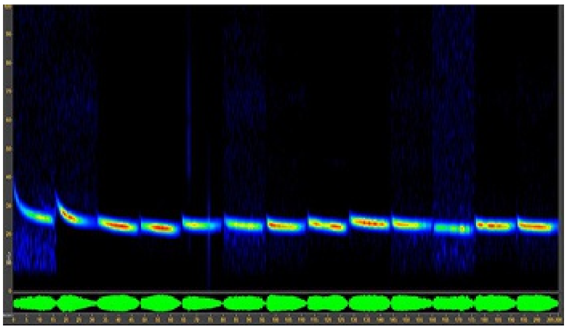
Leisler's Bat - call duration 14.6-14.8 ms



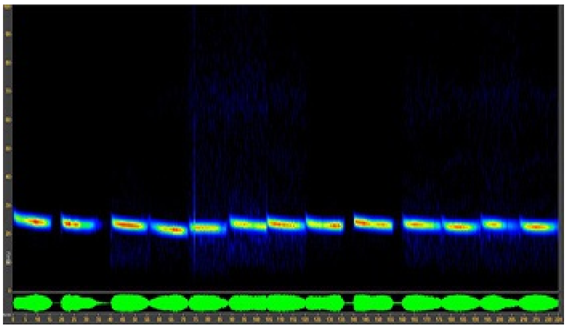
Leisler's Bat - call duration 14.9-15.1 ms



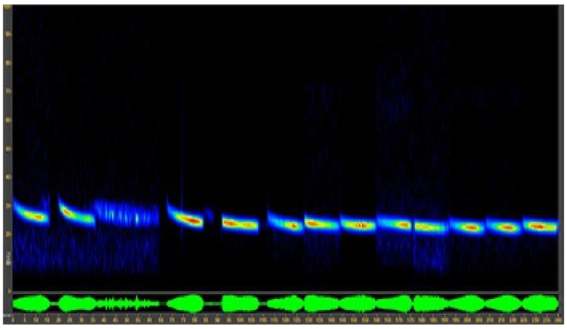
Leisler's Bat - call duration 15.2-15.3 ms



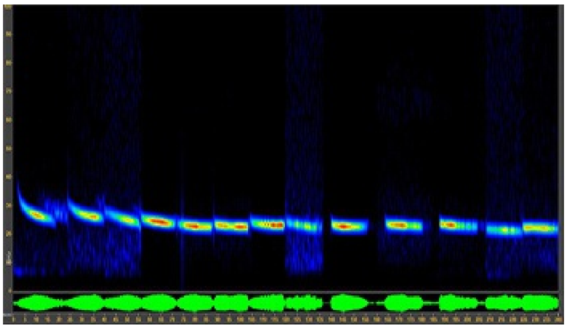
Leisler's Bat - call duration 15.4-15.7 ms



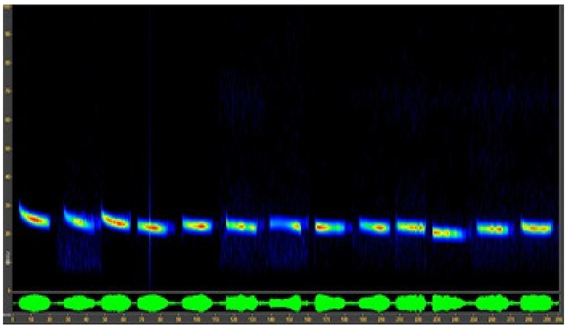
Leisler's Bat - call duration 15.8-16.0 ms



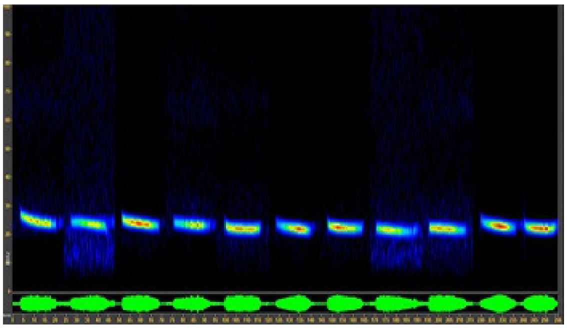
Leisler's Bat - call duration 16.1-16.3 ms

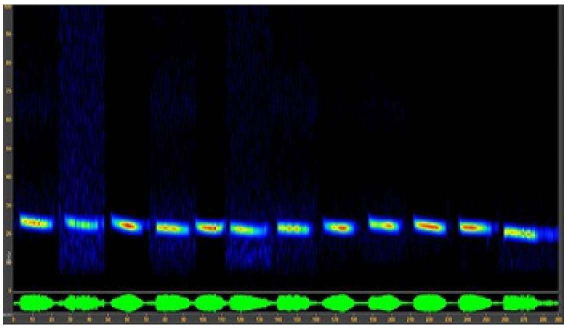


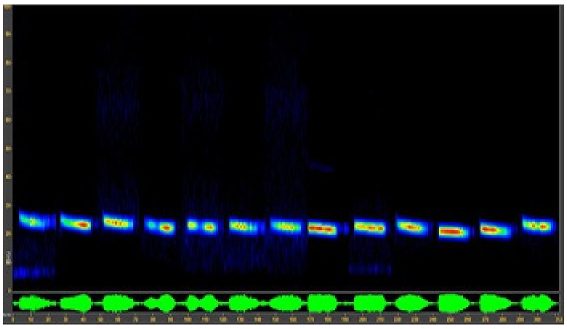
Leisler's Bat - call duration 16.4-16.6 ms

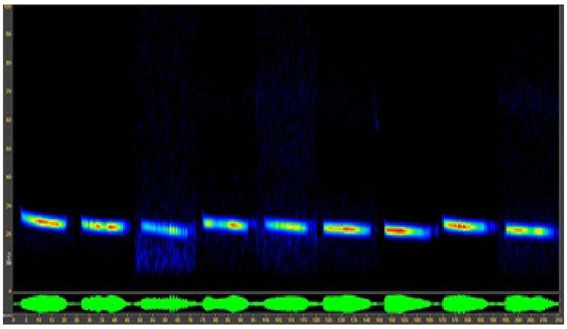


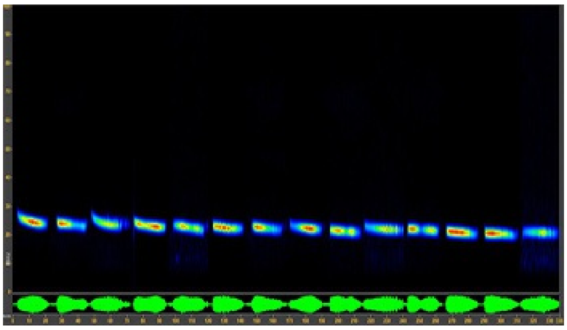
Leisler's Bat - call duration 16.7-17.0 ms


Leisler's Bat - call duration 17.1-17.2 ms

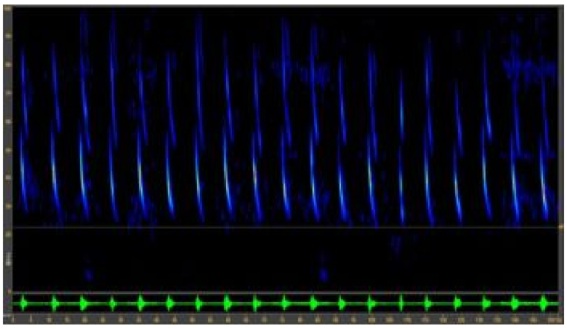

Leisler's Bat - call duration 17.3-17.4 ms


Leisler's Bat - call duration 17.5-18.2 ms

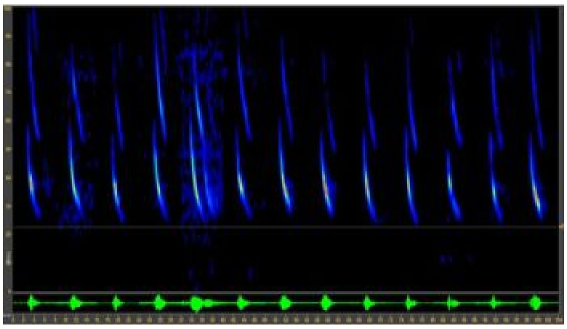

Leisler's Bat - call duration 18.3-18.7 ms


Leisler's Bat - call duration 18.8-24.0 ms

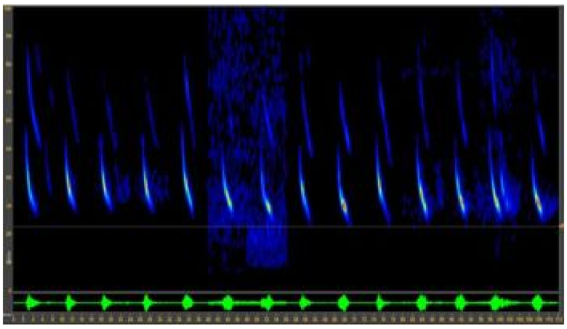
Identification appendix 3: Brown Long-eared Bat *Plecotus auritus*



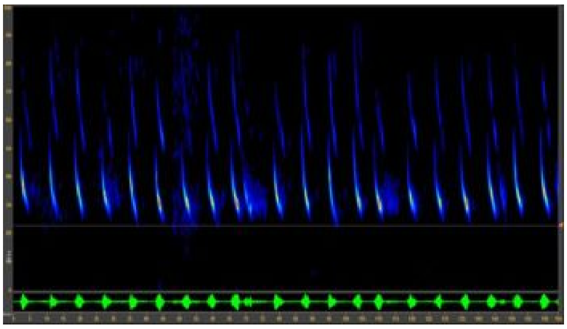
Brown Long-eared Bat - call duration 1.0-1.8 ms



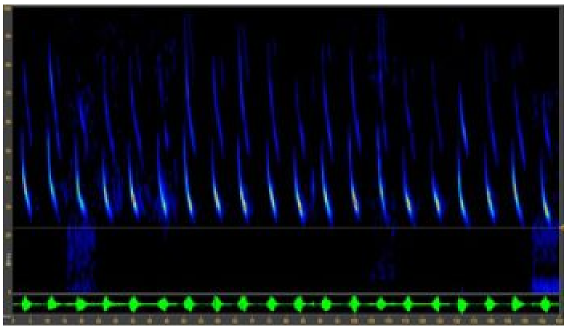
Brown Long-eared Bat - call duration 1.9-2.0 ms



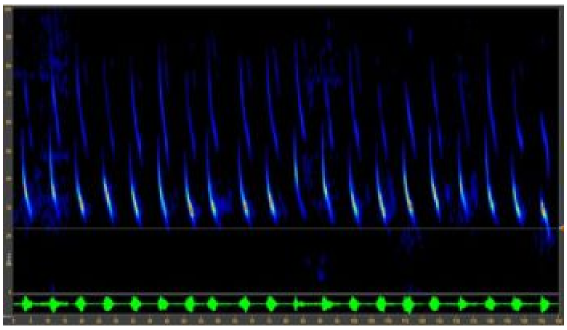
Brown Long-eared Bat - call duration 2.1-2.2 ms



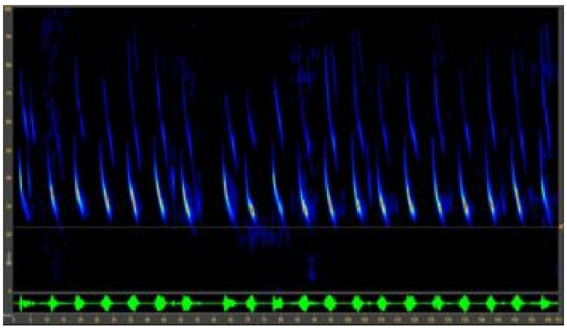
Brown Long-eared Bat - call duration 2.5-2.6 ms



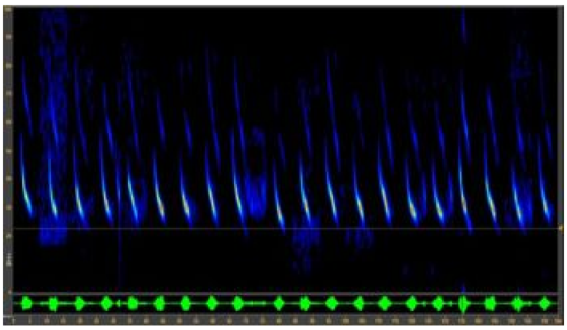
Brown Long-eared Bat - call duration 2.7-2.8 ms



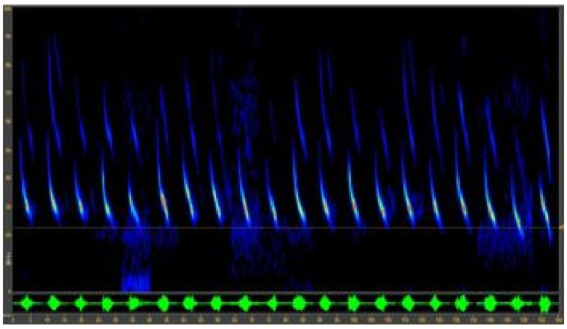
Brown Long-eared Bat - call duration 2.9-3.0 ms



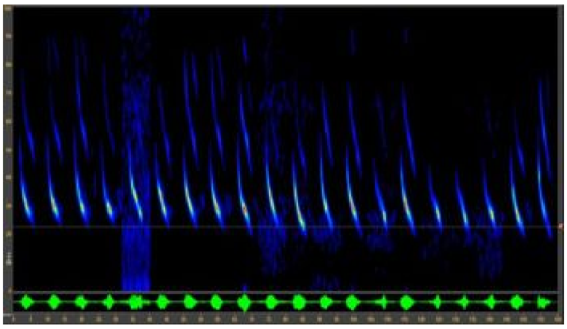
Brown Long-eared Bat - call duration 3.1-3.2 ms



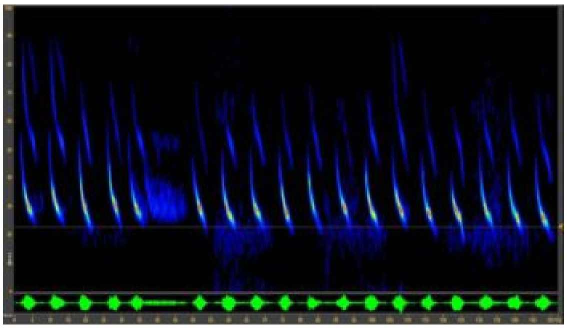
Brown Long-eared Bat - call duration 3.3-3.4 ms



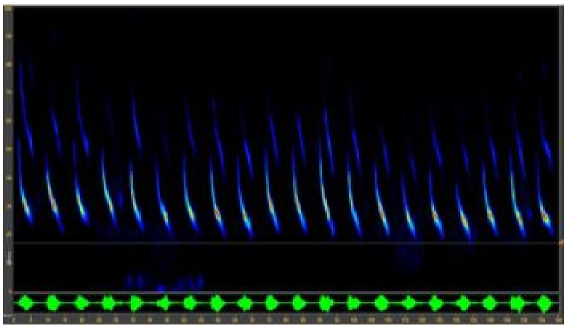
Brown Long-eared Bat - call duration 3.5-3.6 ms



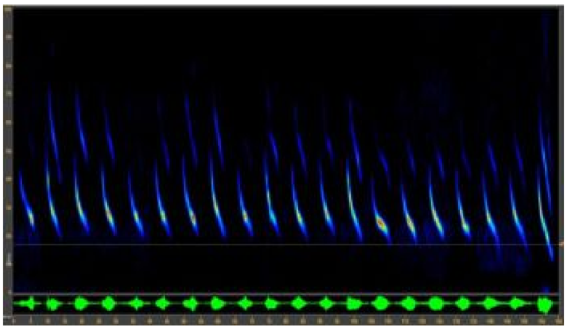
Brown Long-eared Bat - call duration 3.7-3.8 ms



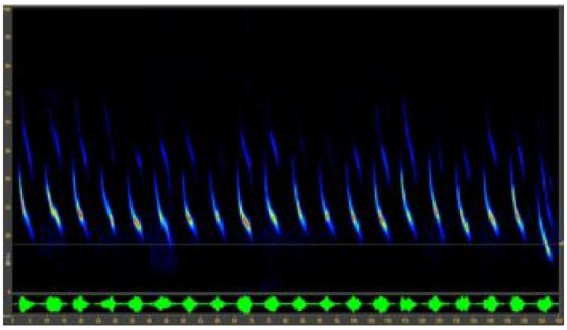
Brown Long-eared Bat - call duration 3.9-4.0 ms



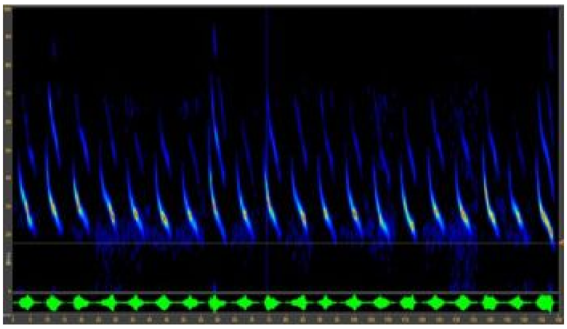
Brown Long-eared Bat - call duration 4.1-4.2 ms



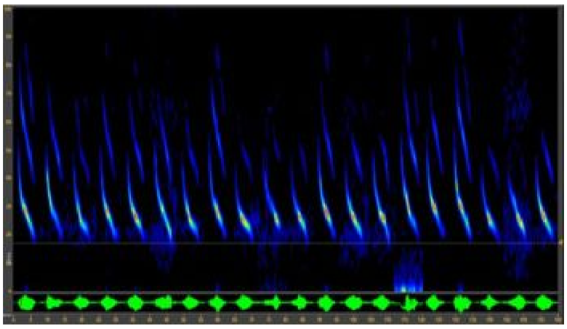
Brown Long-eared Bat - call duration 4.3-4.4 ms



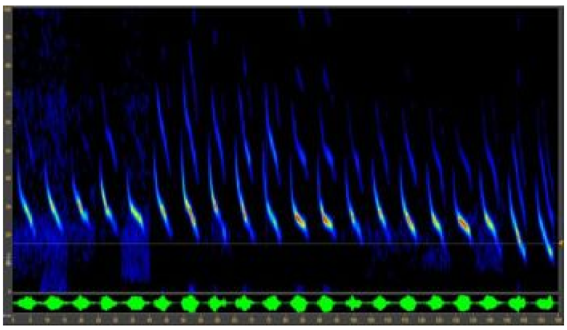
Brown Long-eared Bat - call duration 4.5-4.6 ms



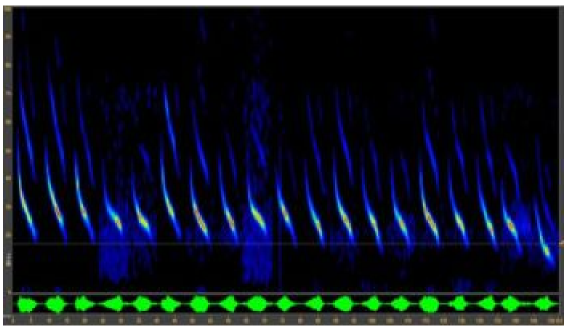
Brown Long-eared Bat - call duration 4.7-4.8 ms



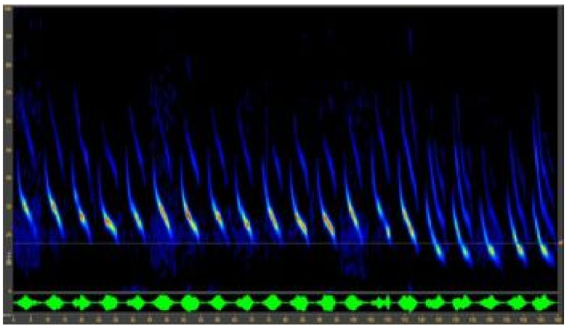
Brown Long-eared Bat - call duration 4.9-5.0 ms

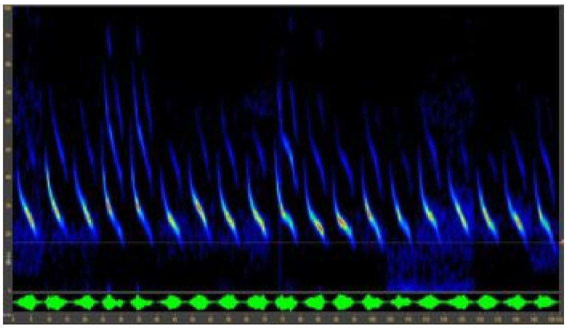


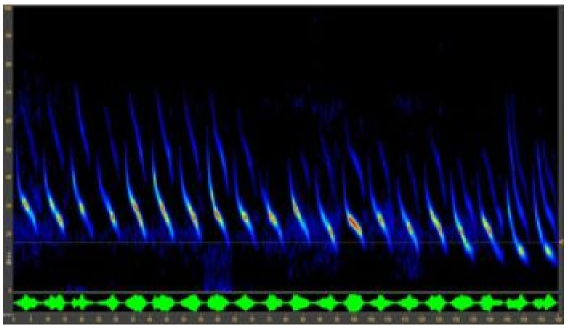
Brown Long-eared Bat - call duration 5.1-5.2 ms

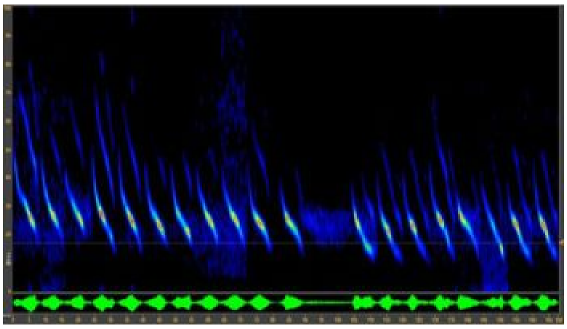


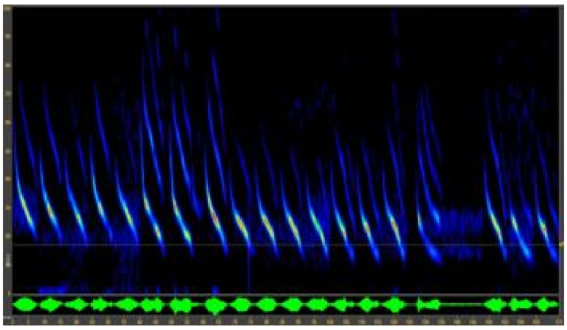
Brown Long-eared Bat - call duration 5.3-5.4 ms

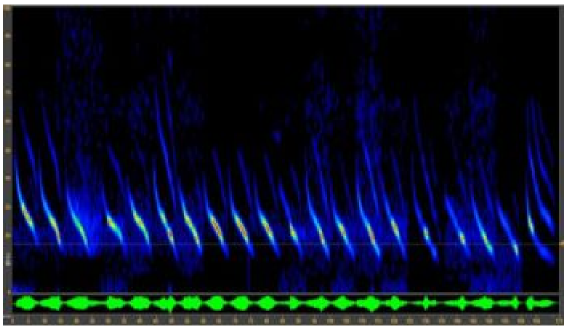

Brown Long-eared Bat - call duration 5.5-5.8 ms

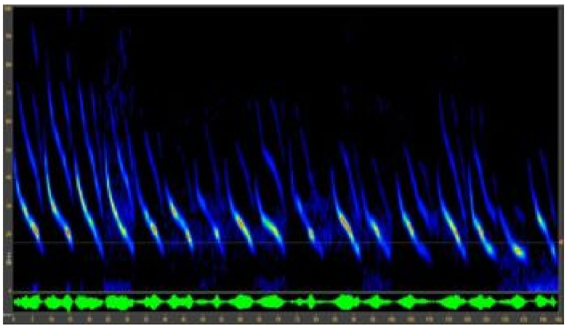

Brown Long-eared Bat - call duration 5.9-6.2 ms

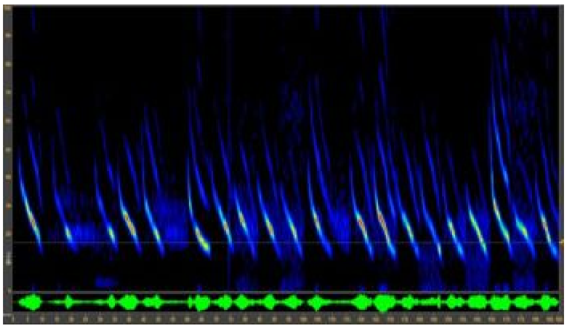

Brown Long-eared Bat - call duration 6.3-6.4 ms

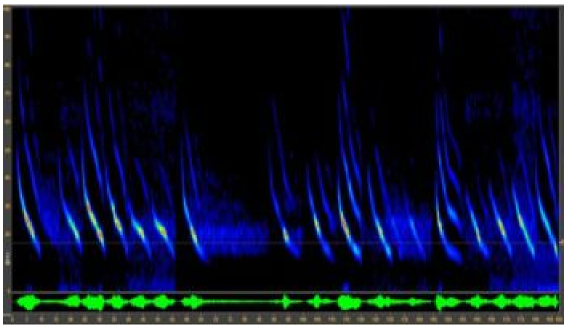

Brown Long-eared Bat - call duration 6.7-6.8 ms

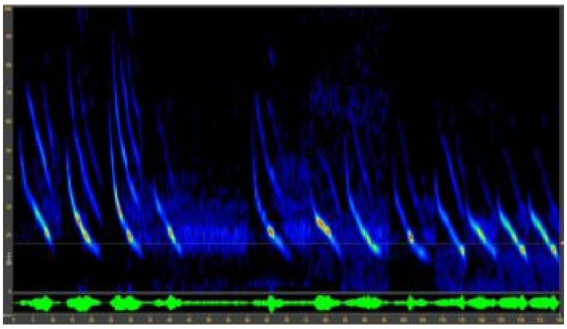

Brown Long-eared Bat - call duration 6.9-7.0 ms

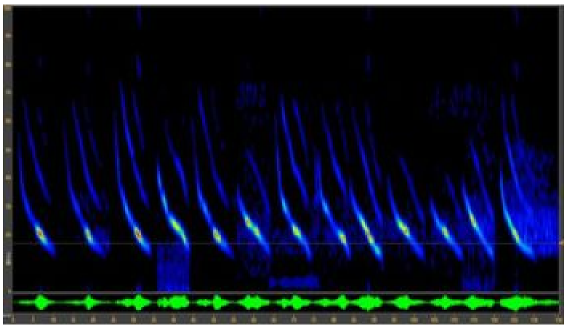

Brown Long-eared Bat - call duration 7.3-7.4 ms


Brown Long-eared Bat - call duration 7.5-7.6 ms

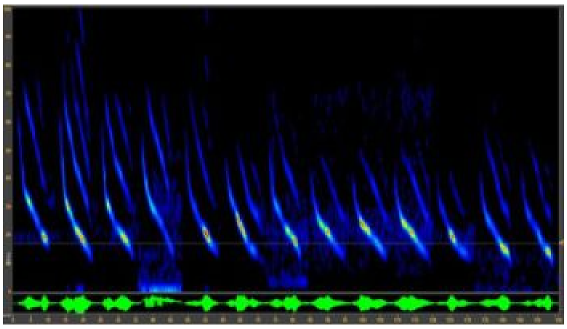

Brown Long-eared Bat - call duration 7.7-7.8 ms


Brown Long-eared Bat - call duration 7.9-8.1 ms

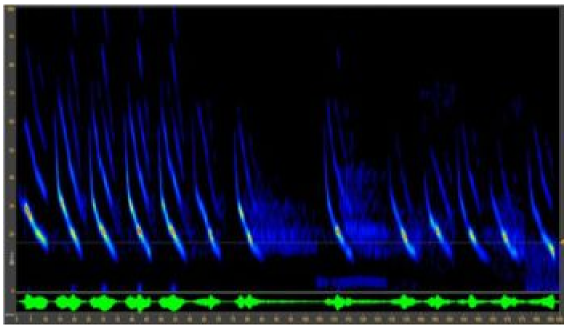

Brown Long-eared Bat - call duration 8.2-8.3 ms



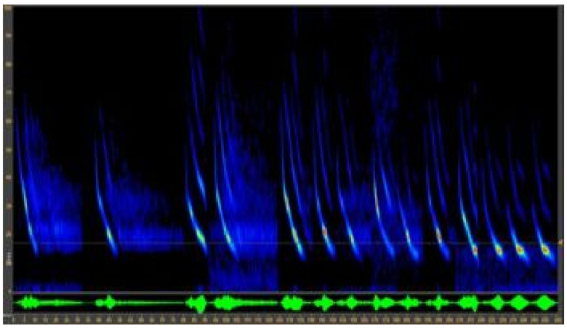
Brown Long-eared Bat - call duration 8.4-8.6 ms



Brown Long-eared Bat - call duration 8.7-9.0 ms



Brown Long-eared Bat - call duration 9.1-9.5 ms



Brown Long-eared Bat - call duration 9.6-11.4 ms

Images: Common Pipistrelle by John Black, Wood Mouse by Moss Taylor, Brown Rat by Edmund Fellowes, Leisler's Bat by Mark Carmody. Cover image: Katherine Booth Jones

Bioacoustics as a novel approach for detecting the presence of Brown Rats on seabird islands

This report presents the main findings from survey work delivered using passive acoustic monitoring devices deployed across Rathlin Island in Northern Ireland. The focus of this study is to explore the possibilities for using acoustics to detect the presence of Brown Rats. Through the acoustic projects that we support, we aim to improve knowledge and understanding of species distribution and activity, covering a range of taxonomic groups, including small terrestrial mammals, bats and insects. Through this approach we provide robust datasets that can be used to inform better decision-making processes.

The use of acoustic monitoring can be particularly useful for species that are rare or unexpected in the survey area, or that are traditionally regarded as too difficult to identify (such as bats in the genera *Myotis*). Where such species are recorded, we provide additional information to support their identification. A secondary aim of our work is to improve the wider understanding of species identification, inspiring a culture of critical thinking and the use of emerging technologies to improve the current knowledge base..

Newson, S.E., Else, R., Crymble, J., Gilbert, G., Tosh, D.G. & Booth Jones, K.A. (2023) Bioacoustics as a novel approach for detecting the presence of Brown Rats on seabird islands. *BTO Research Report* **755**, BTO, Thetford, UK.

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