JNCC Report
No. 708

The potential for acoustics as a conservation tool for monitoring small terrestrial mammals

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April 2022

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ISSN 0963 8091

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This report should be cited as:
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.

Graphs and mapping by S. Gillings.

Note:
This work was supported by the Terrestrial Surveillance Development and Analysis partnership of the UK Centre for Ecology & Hydrology, British Trust for Ornithology and the Joint Nature Conservation Committee.

Acknowledgements:
We are very grateful to the fieldworkers, volunteers and project organisers who have contributed data, or have inputted in some way to inform this report. We also thank Matt Binstead at the British Wildlife Centre, Simon Gillings for input on graphs and mapping, Ian Henderson and Gavin Siriwardena for their role in coordinating the LandSpAES project, Phil Atkinson for leading on the Bailiwick Bat Survey, and to Matt Baxter, Steve Pritchard and Ollie Barratt for their work on the BTO Acoustic Pipeline.

We are also extremely grateful to Anna Robinson, Kirsi Peck and Niki Newton from the Joint Nature Conservation Committee (JNCC) and to Rob Robinson (BTO) for their support and input to the development of this work.

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Summary

The use of acoustics has not previously been assessed as a tool for the large-scale monitoring of small terrestrial mammals (excluding bats). This report provides a first exploratory look at some of the possibilities that acoustics could offer for surveying small terrestrial mammals in the UK.

As a general point, acoustic studies offer a number of benefits over other survey approaches for small mammals: they can be carried out without directly impacting on an animal's behaviour, and the techniques can be deployed by many surveyors across much larger areas than would be possible using more conventional invasive methods, such as live-trapping.

We used a library of known species recordings collected under controlled conditions to estimate likely detection distances under average conditions based on the frequency and intensity of calls. We then compared acoustic recording with live-trapping by pairing a Longworth trap with two acoustic detectors, one placed at a low level (0.3 - 0.5 m) and another placed at a height that is typically used in bat surveys (2.5 - 3 m).

We demonstrate that shrews can be detected using an ultrasonic microphone (bat detector) that is positioned over five metres away from the animal. This means that data on the presence of shrew species can be successfully collected incidentally during routine static bat detector surveys, where bat detectors are typically deployed at between 1.5 and 2 metres in height, into the bat's flyway to record bats. We propose that the use of acoustic surveys in combination with live trapping that uses Longworth traps that are fitted with shrew holes that catch most small mammal species but are specifically designed to allow shrews to escape. This is likely to be more appealing for volunteers and for use in citizen science small mammal monitoring projects. This approach would require less training and experience in small mammal trapping, and therefore has the potential to increase volunteer participation. It could also reduce the survey effort required to check traps if shrews are not likely to be caught, and it should avoid mortality risks associated with the live-trapping and handling of shrews. In addition, by eliminating the need to capture shrews, the sensitivity of the trap treadle could be reduced to avoid triggering by shrews, thus increasing the potential capture incidence of other target species.

There are also important opportunities for monitoring other licenced species / priority species potentially in combination with other traditional monitoring approaches. This includes for climbing and arboreal species, like the Harvest Mouse and Hazel Dormouse that can be difficult to monitor. The use of acoustics is also likely to be valuable for collecting small mammal distribution data from remote areas or habitats that are difficult to survey using traditional methods, as bat detectors can be left out for an extended period.

Rats are highly vocal species that are relatively easy to detect using ultrasonic microphones and are regularly recorded incidentally during static bat detector surveys. Acoustics may therefore provide a cost-effective approach for monitoring the presence of Brown Rats (or Black Rats) on seabird islands where conservation efforts involve predator detection and eradication practices. Similarly, acoustics could be used to monitor the distribution and spread of invasive shrew species: the Greater White-toothed Shrew in the Republic of Ireland for example, where this species is believed to adversely impact on native populations of Pygmy Shrew.

Acoustics could provide opportunities for monitoring mice and voles, but the lower detection distance for both groups and low call rate for voles, would mean that bat detectors would need to be positioned closer to the ground, or be more targeted to where the animal is likely to be found, and for voles, potentially the time of day when they are most active, than would

be ideal for recording bats at the same time. The survey effort needed to record Bank and Field Voles in particular, is likely to be much higher than would be needed for other small mammal species, and therefore acoustics are more likely to provide only a supplementary function to conventional survey methods. The survey effort needed could be informed by the collection and analysis of recordings from captive individuals, comparable to work presented here for Hazel Dormouse.

We examine these findings in relation to the potential role of structured and unstructured monitoring of small mammals and highlight questions that would be useful to address to develop this work further.

Contents

1 Introduction

To the best of our knowledge, the use of acoustics has not previously been assessed as a tool for the large-scale regional or national monitoring of small terrestrial mammals, excluding bats (hereafter small mammals) for anywhere in the world. In addition, for many species of small mammals in the UK, work on sound identification is almost completely restricted to our own work and that of our close collaborators (Middleton 2020; Newson *et al*. 2021).

This is a novel area of study, where this report and the data that we currently have access to will not provide all the answers. Instead, its purpose is to present a first exploratory look at some of the possibilities that acoustics may offer. In looking at this, we are not expecting acoustics to replace existing monitoring, but we believe it is important to consider how acoustics could complement existing monitoring and recording methods, and to consider whether there are cost-effective opportunities for utilising existing or planned bat, or other large-scale acoustic monitoring data to contribute to our knowledge of small mammals in the UK.

Through this report we make use of data that have been collected via several funded and unfunded projects carried out by the authors presented as case studies here, to address specific questions, or use as case studies or other illustrations of what acoustics could deliver for the survey, monitoring and research of small mammals.

2 Understanding the possibilities for acoustics

2.1 What is the detection distance of small mammals?

It is important to start this section by noting that small terrestrial mammals emit both audible (<20 kHz) and ultrasonic (>20 kHz) sounds. It may be possible to get further with the sound identification of audible calls in the future, but our work, and this report focusses on calls emitted above 10 kHz. For this, full spectrum bat detectors, which are designed to target ultrasound and perform best at these higher 'bat-related' frequencies are required.

The distance at which small mammal calls can be detected by a static bat detector will depend on the frequency in kHz of the calls, and the intensity of the sound - the sound pressure level. Very generally, species that produce intense low frequency calls will be detected at a greater distance than species that produce weak high frequency calls. There are parallels for bats, where Common Noctule *Nyctalus noctula* may be detected up to 100 metres away, compared with Lesser Horseshoe Bat *Rhinolophus hipposideros* where the detection distance is closer to 5 metres (Barataud 2015).

The detection distance is also affected by parameters that will vary locally and temporally. These include for example, the air temperature and relative humidity, the position of the animal in relation to the microphone and the variation in the intensity and frequency (in kHz) of the calls being produced by the animal. The detection distance will also vary according to the sound recording equipment used, which will vary between models, and to some degree between individual microphones of the same make and model of bat detector.

Whilst it would be very difficult to precisely quantify the detection distance of small mammals across a range of conditions, we can produce some reasonable approximations by using information on the frequency (in kHz) of calls and sound pressure level in decibels (dB) of small mammal calls, (based on sample recordings of captive individuals); and, by making some assumptions around the average temperature, humidity, and acoustic properties of the microphone. In the following we make use of calculations carried out by Agranat (2014), and extend a table in Appendix A of Agranat (2014), that allows us to estimate the detection distance of an animal by using the sound pressure level of the call (measured at 10 cm from the animal) and the frequency of the calls (in kHz) that are produced by the animal, assuming a temperature of 20ºC and 50% relative humidity and, applying the properties of a FG microphone, which is commonly used in bat detectors.

To develop an automatic acoustic classifier for small mammals (BTO Acoustic Pipeline, http://bto.org/pipeline), we already needed to build an extensive reference library of known species recordings. We are continuing to build on this, but an earlier version of the reference library, formed the basis of our current understanding of the sound identification of small mammals in Britain (Newson *et al*. 2021). From previous experience of building classifiers for bats and bush-crickets, we knew that we would need many hundreds (potentially thousands) of recordings for each species for the classifier to perform well. This would need to include recordings of multiple individuals of each species, to try to ensure that we adequately covered the range of vocalisations that are likely to be produced. In addition, individuals would preferably need to be studied under conditions that are likely to be encountered in the field.

From these known species recordings, we used the software SCAN'R produced by Binary Acoustic Technology to randomly select one call from each recording, and to produce an output file containing the sound pressure level and the peak frequency of these calls. From these samples, we estimated the average sound pressure level and peak frequency of the calls for each species (see Table 1) and in turn, an approximation of the detection distance of each species (Figure 1).

Table 1. Species along with sample size of triggered recordings and calls, average sound pressure level (SPL) (dB) and average peak frequency (Fmax) (kHz) of calls.

Species	No. of Recordings	No. of Calls	Average SPL	Average Fmax
Hazel Dormouse	2,019	46,117	58.62	31.74
Bank Vole	250	1,708	49.97	36.59
Field Vole	586	10,584	52.28	21.52
European Water Vole	1,185	8,130	56.88	32.50
Eurasian Harvest Mouse	1,572	25,255	54.57	55.31
Wood Mouse	1,205	9,027	42.92	67.84
Yellow-necked Mouse	2,489	15,249	47.30	58.45
House Mouse	495	5,183	57.72	72.43
Brown Rat	1,828	55,842	67.02	32.91
Black Rat	2,265	51,126	65.98	27.34
Common Shrew	2,489	85,299	65.10	25.01
Eurasian Pygmy Shrew	1,257	38,162	63.96	33.93
Eurasian Water Shrew	217	8,130	74.70	22.03
Greater White-toothed Shrew	694	29,833	56.88	24.69
Lesser White-toothed Shrew	7	890	58.65	22.08

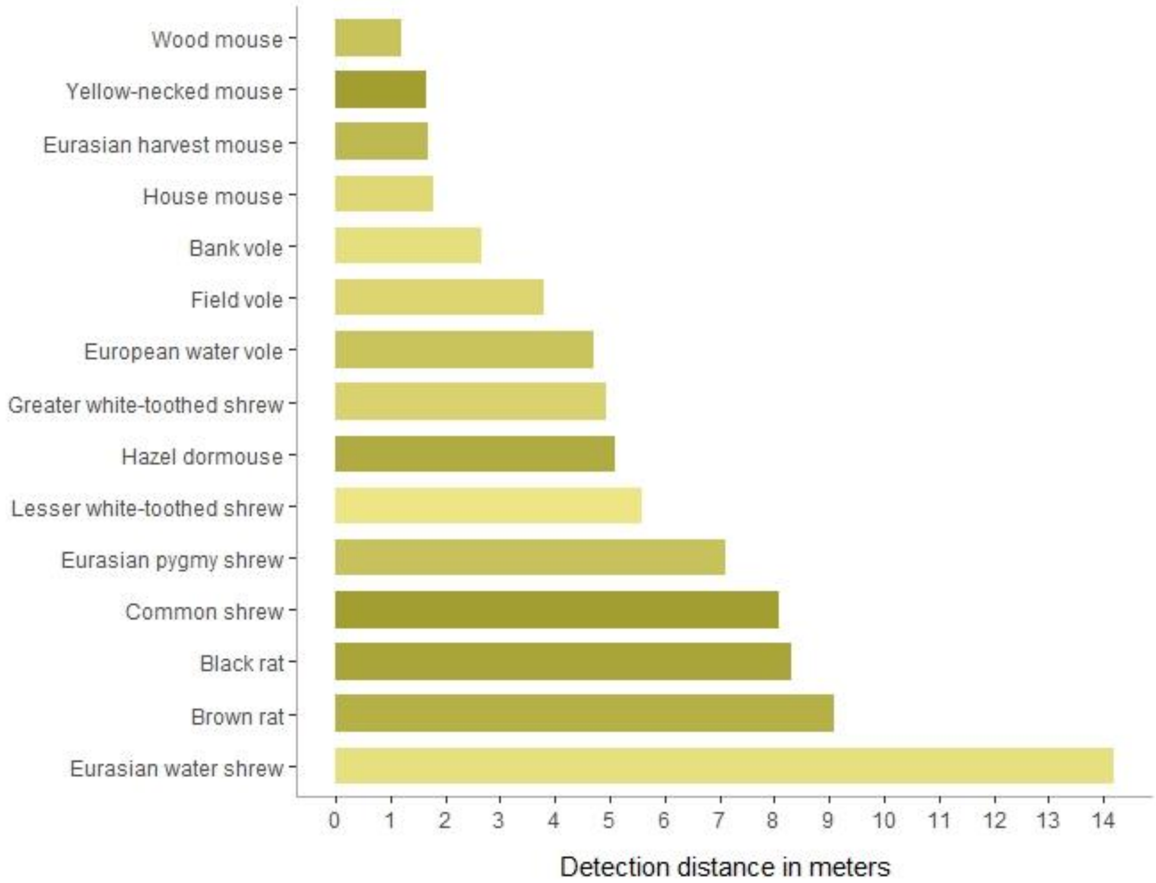


Figure 1. Estimated detection distance of small terrestrial mammals in the UK, ordered according to increasing detection distance. The sample size of calls used is denoted by the colour of the horizonal bar, where the darker the colour, the greater the sample size of calls.

In addition to the detection distance, the probability of detecting a particular species (if present) will depend on how vocal the species is. We know from our work on captive individuals and supported by the literature that Field and Bank Voles rely much more on olfactory cues than sound, and subsequently they call less often than other small mammal species (Newson *et al*. (2021). Considerably more effort and time was taken to try and record captive Field and Bank Voles than most other small mammals in the UK that we have worked on, but this still resulted in fewer recordings being collected. In comparison, Wood and Yellow-necked Mice are vocal, and will even call when they are not in the presence of conspecifics. Whilst shrews generally elicited vocalisations in response to being in the proximity of another individual of the same species, they may also use sound for echo-orientation when moving around dense habitats such as leaf litter (Siemers *et al*. 2009).

2.2 Field comparison of live trapping and acoustics

In the above, we estimate the distance at which the calls of different species of small mammal may be recorded using a bat detector. To get the best quality bat recordings, the bat detector (or microphone if on a lead) needs to be deployed at height, so that it is within the bat's flyway. A typical approach would be to pole-mount the bat detector at a height of 1.5 metres or more.

Wood Mice would need to be within about 1.2 metres of a bat detector on average to be detected. Whilst they are a vocal species and partially arboreal, they spend significantly more time at ground level, and there are some obvious implications of this if the aim is to record Wood Mouse as 'by-catch' during bat surveys. For Bank and Field Vole, which predominantly reside at ground level, the detection distance is greater than for Wood Mouse, but there is a question around how the low call rate of Bank and Field Vole that we have observed in captive individuals, is likely to influence the number of recordings obtained as 'by-catch', and in turn the possibilities for using acoustics for these species.

Whilst deploying detectors a height may be the optimum for recording bats, if the primary interest is small mammals on the ground, we explore whether it may be better to position bat detectors closer to the ground, at least for some species.

There is also a question of how the results from live trapping, which are commonly used in the study of small mammals, are likely to compare with acoustics. To explore some of these questions further, we carried out a study in London between March and June 2000 where live-trapping capture-mark-recapture surveys (BioEcoSS Tube Traps) were carried out concurrently with acoustic surveys (Wildlife Acoustics Song Meter Mini Bats). A variety of woodland, scrub and grassland habitats were surveyed to increase the likelihood of encountering a diversity of small mammal species found in Greater London: Wood Mouse, Yellow-necked Mouse, Bank Vole, Field Vole, Common Shrew and Pygmy Shrew.

Figure 2 depicts the layout of study areas, which comprised 30 x 30 metre trapping grids, consisting of 32 live-traps (16 locations), paired and spaced at 10 metre intervals. Paired bat detectors were deployed at the centre of each grid. One bat detector was deployed low down at a height of between 0.3 and 0.5 metres and a second deployed at height, between 2.5 and 3 metres above the ground. Following three nights of pre-baiting (where baited traps are left open with the trigger mechanism not set), five trap nights and five trap days were completed. All animals caught were identified to species, sexed and marked by fur clipping. The detectors were active during the entire survey period (i.e. recording day and night for 8 days per site). Twenty sites were surveyed, which is equivalent to 3,840 hours of sound recording and 100 trap nights and 100 trap days.

A comparison of the main results from live-trapping and acoustics are shown in Figure 3. With live-trapping, 558 individuals were caught, of which 45% were *Apodemus* species (mainly Wood Mouse, a further 45% were Bank or Field Voles, and 10% were *Sorex* species (a combination of Common and Pygmy Shrews).

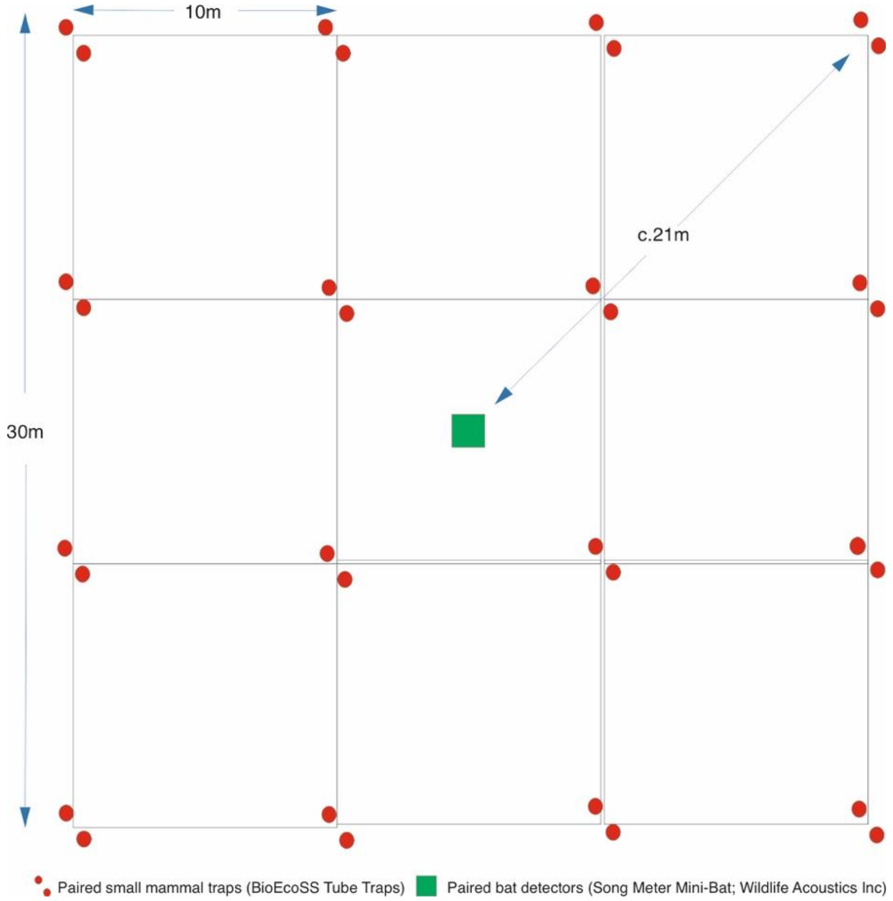


Figure 2. Layout of small mammal live-capture-mark-recapture and acoustic survey study areas. Small mammal traps were laid-out in a 30 x 30 metre trapping grid. Bat detectors were deployed at the centre of the grid; one low to the ground (0.3-0.5 metres) and one at height (2.5-3 metres above ground).

Before moving on to look at the results from the acoustics, it is useful to consider some of the biases with live-trapping data.

- The chance of catching a species that occurs at low density will be influenced by the density of other species present in the survey area, i.e. species that occur at high density may be captured more often, limiting opportunities for successful capture of less common species in the small mammal community.
- There are problems with trap happy individuals which readily occupy traps following setting and reduce the number of traps available and the potential for catching other species / individuals.
- Shrews (especially Pygmy Shrews), may not trigger the traps, depending on the sensitivity of the treadle.
- Bait can attract / bring in animals from outside the study area, leading to more animal captures at the perimeter of the trapping grid.
- Where traps are deployed only at ground level, climbing or arboreal species such as Yellow-necked Mouse will likely be captured less often.
- It should also be noted that, once captured within a trap, an animal is temporarily removed from the small mammal community of the study area and therefore will no longer be available to gather acoustic recordings from, until it is released.

With acoustics, *Sorex* species (a combination of Common and Pygmy Shrews) comprised about 90% of recordings. *Apodemus* species and Field and Bank Vole were recorded, but these comprised only a small proportion of the total small mammal recordings (Figure 3), despite Wood Mouse and Bank Voles being the more commonly recorded small mammals. There is no evidence that deploying a bat detector low down (at between 0.3 and 0.5 metres) increases the chances of recording shrews. If anything, the converse was true, with shrews being more likely to be recorded by bat detectors that were deployed at height than low down (1,434 shrew recordings compared with 764 shrew recordings). However, it is clear from Figure 3 that recording closer to the ground increased the chances of recording *Apodemus* species and Field and Bank Vole, with the greatest benefit for *Apodemus* species (an increase from 3 to 58 recordings here). Yellow-necked Mouse is rare in London, and few were caught by live trapping or recorded acoustically. Given that Yellow-necked Mouse is more arboreal compared to Wood Mouse, it is plausible that the deployment of bat detectors at height may benefit the acoustic detection of this species.

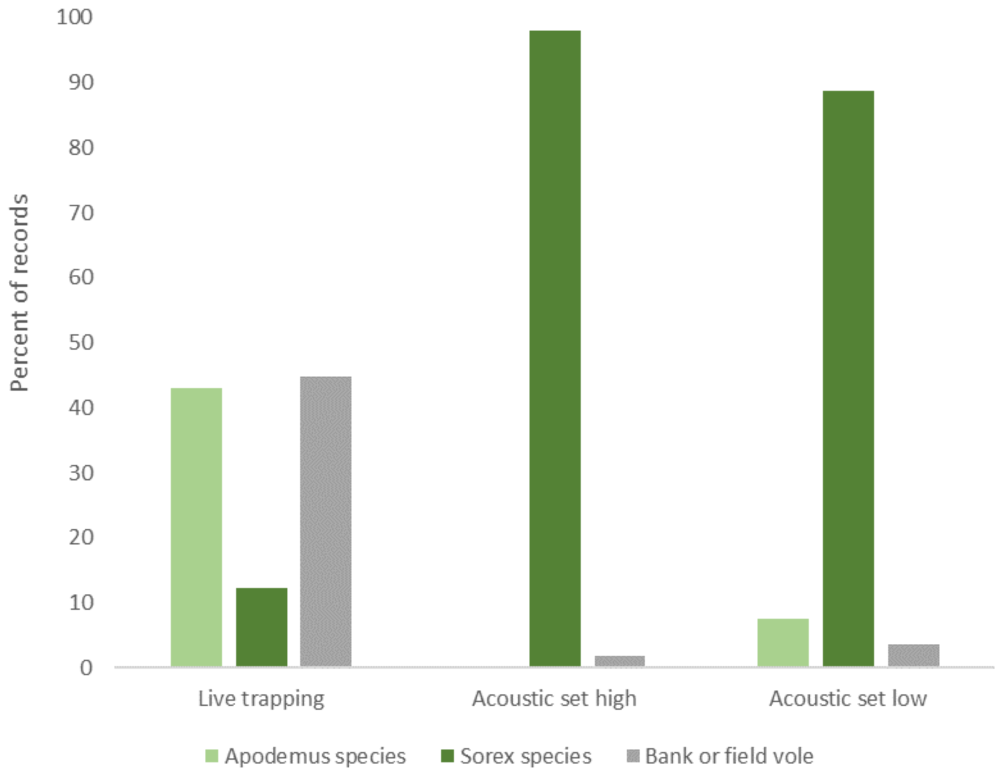


Figure 3. Comparison of the taxonomic composition of records from live trapping (individuals caught) and acoustics (number of triggered recordings) for a detector deployed at height (between 2.5 - 3 m), and a detector deployed low down (between 0.3 - 0.5 m).

If we extract data that would have been collected during a typical static bat detector survey i.e. with the detector positioned at height and set to record at night only (specifically from sunset minus 30 minutes up until sunrise plus 30 minutes), 95% of *Apodemus* contacts were at night, but only 9% of these were recorded at height. Voles and shrews were recorded more often during the day, with only 21% and 27% of the total recordings for these species recorded during the night according to a typical static bat survey period. When also including the height of the detector as a factor, this was reduced to 18% and 9% of the total call contacts for these species, respectively.

The outcomes of this study support the idea that deploying a bat detector at height, which may be optimal for recording bats, would not be optimal for recording all species of small terrestrial mammal. It also suggests that restricting the times over which data is collected in line with typical bat survey periods, further reduces the detection of some species, particularly voles.

2.3 The value of captive individuals for informing survey design

When thinking about acoustics and the possibilities for detecting or monitoring small mammals, it is important to consider how much survey effort is needed, and how best to target surveys according to time of year, and time of day or night. For some small mammal species, like Hazel Dormouse which are difficult to study in the field, captive individuals can help inform some of these decisions.

As an example, we deployed a bat detector (Wildlife Acoustics Song Meter Mini Bat) to record a pair of captive Hazel Dormice at the British Wildlife Centre from the last week of April until the end of October, with young from July 2021. The recording period was from sunset to sunrise on all nights, in line with minimum nightly survey period that would be applied during static bat detector surveys. At the end of the period, the recordings were manually checked, and 20,680 recordings that contained Hazel Dormouse calls identified.

The left plot in Figure 4 below shows the percentage of nights on which the Hazel dormouse was detected every half-month through the season, showing the periods of main activity for this species. 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 extend to 1.5 times the interquartile range, and small dots show outliers.

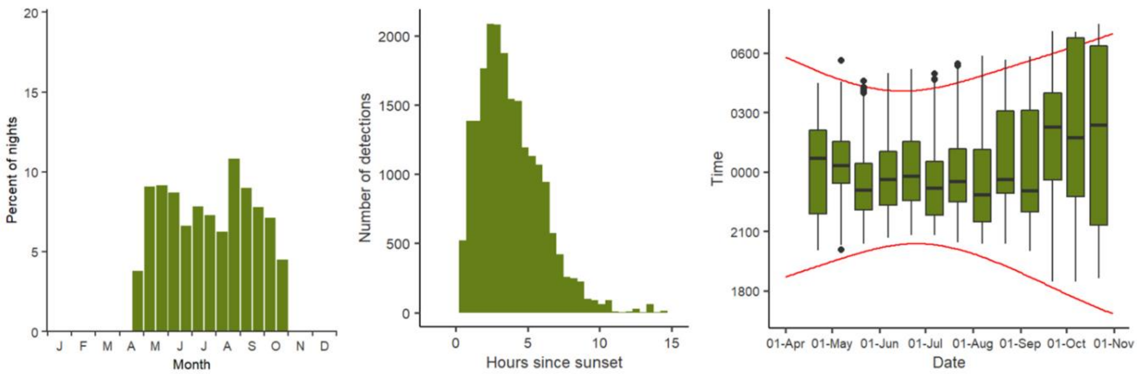


Figure 4. Seasonal and nightly activity of a pair of captive Hazel Dormice.

From the left plot above, we can see that Hazel Dormice were recorded on about 6-7% of nights between May and mid-October. This is valuable for guiding the level of survey effort needed to detect the presence of Hazel Dormice, and that Hazel Dormice are likely to be vocal across this period. The middle plot suggests that Hazel Dormice are most likely to call several hours after sunset. This is useful to know, as it means that walked transect surveys for bats, which are usually carried out during the first 1-2 hours after sunset, would be completed before the peak time in the night that Hazel Dormice are most likely to call. Lastly the right plot, shows that the main period of activity in the centre of the night is largely consistent across the season, but that calling may continue for longer into the early hours of the morning late in the season.

Extracting the number of vocal events per night; where a vocal event is defined as a single sound file containing a dormouse call/s or consecutive files with less than one minute between calls; we found dormouse vocalisations were recorded most often between mid-May and mid-August, with peaks in activity in the second half of June and July (Figure 5). Together these findings suggest that it may be most cost-effective to survey Hazel Dormice acoustically between mid-May and mid-August.

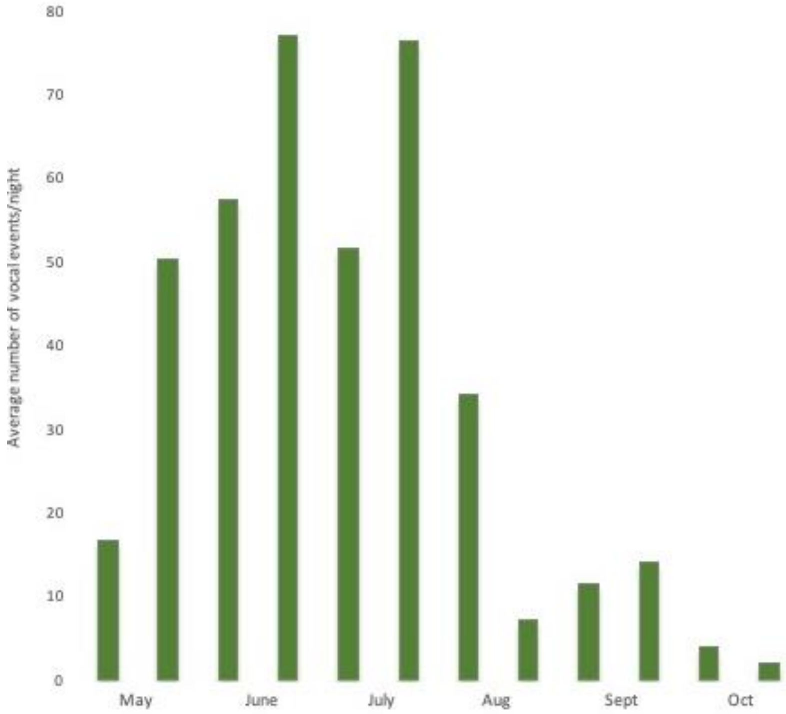


Figure 5. Average number of nightly vocal events detected every half-month by a pair of captive Hazel Dormice.

3 Case studies

3.1 LandSpAES, Natural England-funded - RP04114

Building on previously funded TSDA work on the sound identification of small terrestrial mammals published in *British Wildlife* (Newson *et al*. 2021), we have since made a lot of progress in building tools to automatically identify unknown recordings of small mammals to species when they are recorded as ‘by-catch’ during bat surveys.

Parallel to this, a Natural England-funded project (LandSpAES, RP04114) collected extensive acoustic data for bats on farmland over four years, in 54 1-km squares across six Natural Character Areas in England, to inform decision making in relation to agri-environment scheme (AES) options for bats. The sampling sites were selected to provide both gradients in AES management at the local (1×1 km) and landscape (3×3 km) scales, and a contrast between AES and counterfactual habitats at the field scale. As with all our bat projects, the microphone of the bat detector in this case (Wildlife Acoustics SM4Bat FS) was pole-mounted and raised up 1.5 and 2-metres into the bat’s flyway to record bats. Whilst bats were the focus of this project, our interest here is in the incidental data for small mammals.

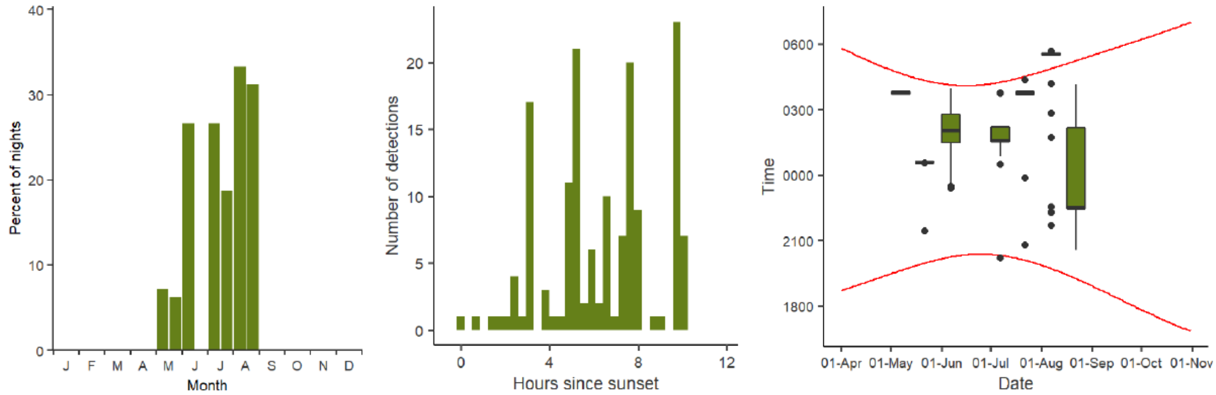
In the following we carry out an analysis of recordings from 2021. The BTO Acoustic Pipeline was not used in this project, but we apply the same species classifiers that are used in the Pipeline so the results will be the same. Following processing, verification of small mammal species identification was then 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 classifier.

During 2021, 243 different locations across the 54 1-km squares were surveyed over 1,836 complete nights, which resulted in 4,366,304 triggered recordings. Of these, 1,051 recordings (0.02% of the total recordings) contained the calls of small mammals of three species: Brown Rat, Common Shrew and Pygmy Shrew (Table 2). This compares with 431,887 bat recordings. It is helpful to make this comparison between the number of small mammal recordings and the number of bat recordings to illustrate that amount of recording effort that is normally needed to produce what is a fairly modest number of small mammal recordings / records. Figure 6 provides some further information on the seasonal and nightly activity of these species. The fact that these species commonly call at any time in the night, highlights the value of using passive acoustic monitoring, where recording equipment can be left out to automatically, rather than carrying out active surveys for these species.

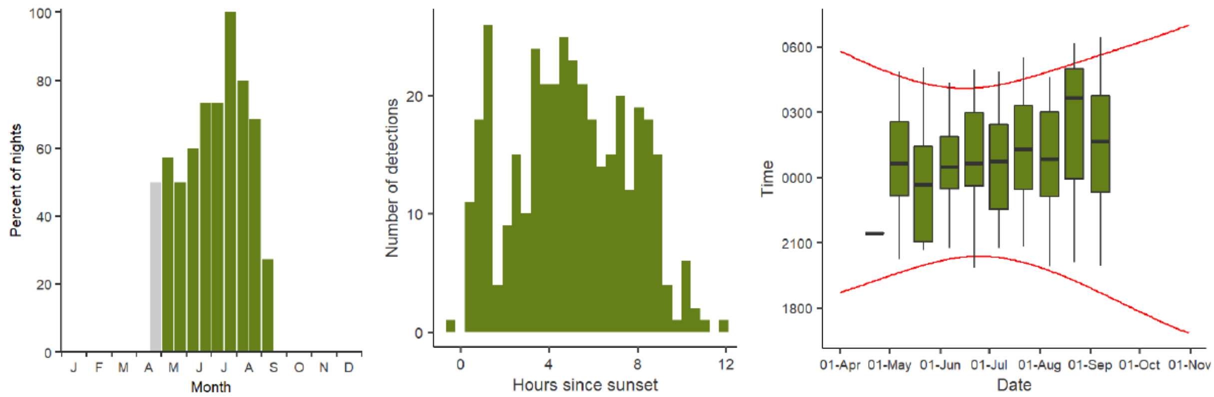
Table 2. Species detected, number of recordings of each species following validation and a summary of the scale of recording.

Species	**No. of Recordings**	**No. of different locations (% of total)**	No. of nights
Brown Rat	15	13 (5%)	23
Common Shrew	375	93 (38%)	90
Eurasian Pygmy Shrew	523	113 (47%)	94

Brown Rat



Common Shrew



Pygmy Shrew

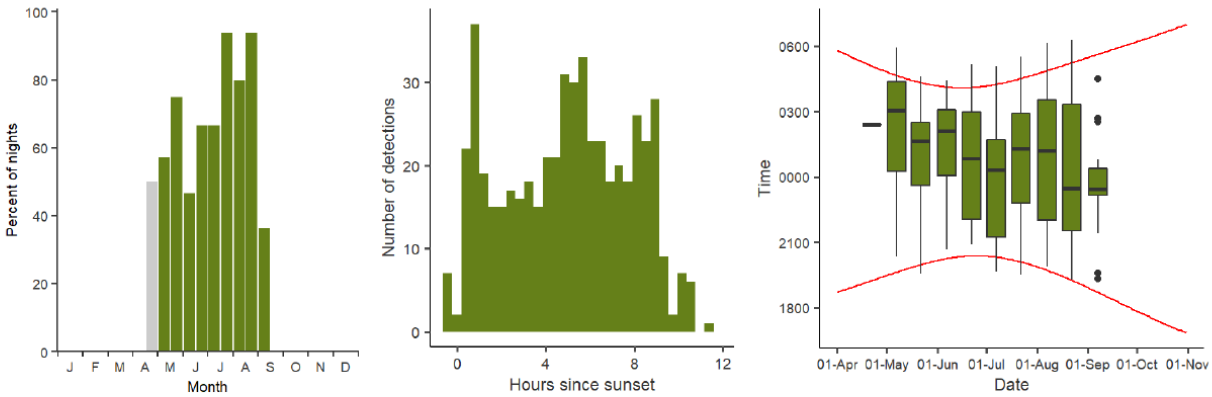


Figure 6. Seasonal and nightly activity of small mammals recorded through the project LandSpAES. If present, pale grey bars represent periods with fewer than 10 nights of recording where accuracy of the reporting rate may be low.

3.2 Bailiwick Bat Survey

The Bailiwick Bat Survey was set up in 2021 to capitalise on the interest and enthusiasm of volunteers to participate in biodiversity monitoring to systematically collect bat distribution and activity data across Guernsey, Alderney, Herm and Sark through a project that will run over four years. This will result in the production of a robust dataset, which will increase knowledge and understanding of bat distribution and activity across the Bailiwick of

Guernsey. Based around 500 x 500-m squares, this project aims to provide a detailed description of the islands' bat fauna. Whilst the focus of this work is on bats, results for small terrestrial mammals, bush-crickets and audible moths which are recorded as 'by-catch' during bat surveys are also returned. A full report on the first season of the project has already been published (Newson *et al*. 2022; www.bto.org/bailiwick-2021), but some of the findings from this work are useful to highlight here.

During 2021, 613 different locations were surveyed for bats, with all recordings uploaded and processed through the BTO Acoustic Pipeline. Out of 360 500-m x 500-m survey squares originally identified, recording took place in 85% of them. Collectively across all these sites, 2,221 complete nights of recording effort was conducted. The recording effort spanned 234 different nights and 11 months.

During this project, a total of 8,228 small mammal recordings were returned, which were assigned to five species (Table 3). There were a small number of mammal recordings (17 recordings) that we could not currently assign to species. Our thinking is that these could represent unusual calls for the species that we could identify, or other species for which the ultrasonic vocalisations have not yet been described, such as for Ferrets *Mustels furo* which are present on the islands. It is also possible that some of these recordings are of other small terrestrial mammal species for which recordings have not been described, which in the study area includes the Guernsey Vole *Microtus arvalis sarnius*.

By far, the largest number of recordings were for Greater White-toothed Shrew (1,490 recordings) and Brown Rat (6,642 recordings, Table 3). We expect from Section 2.1 that Lesser White-toothed Shrew and Black Rat are likely to be equally detectable, but they only occur on the single island of Sark, so the considerably smaller number of recordings of these species reflects how localised these species are. Based on our findings in Sections 2.1 and 2.2, the small number of Wood Mouse recordings is likely to relate to the detection of this species, where the bat detectors used in the project were deployed at height.

Table 3. Species detected, number of recordings of each species following validation and a summary of the scale of recording.

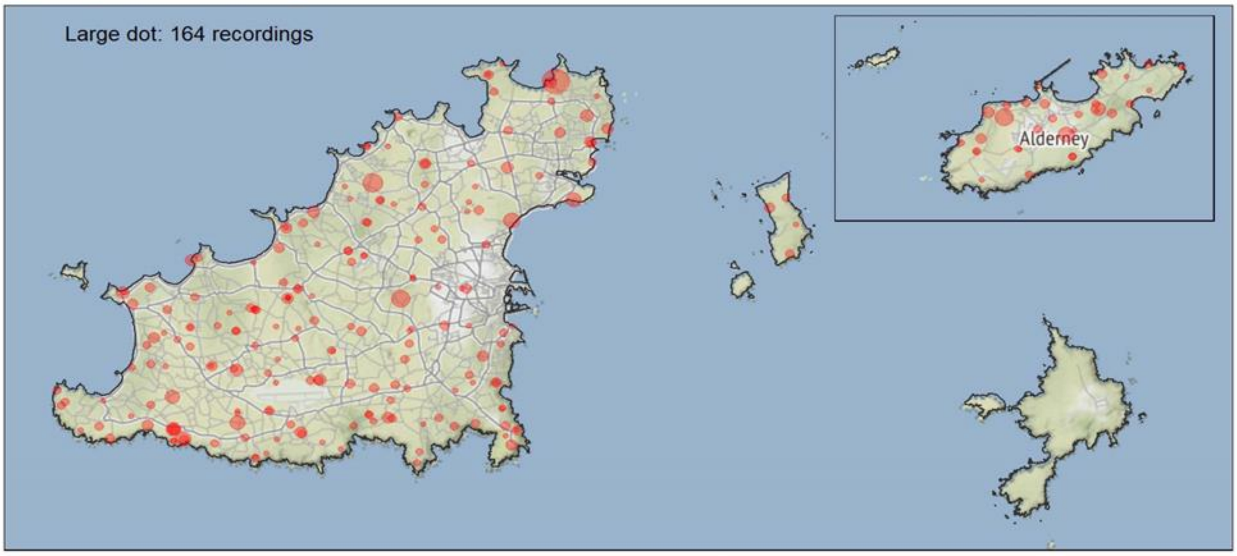
Species	No. of Recordings	No. of different locations (% of total)	No. of nights
Wood Mouse	23	5 (0.8%)	6
Greater White-toothed Shrew	1,490	223 (36.4%)	178
Lesser White-toothed Shrew	5	1 (0.2%)	5
Brown Rat	6,642	172 (28.1%	171
Black Rat	51	12 (2%)	17

Below we share some results from Newson *et al*. (2021) for Greater White-toothed Shrew, Brown Rat and Wood Mouse to illustrate what can be obtained from acoustics.

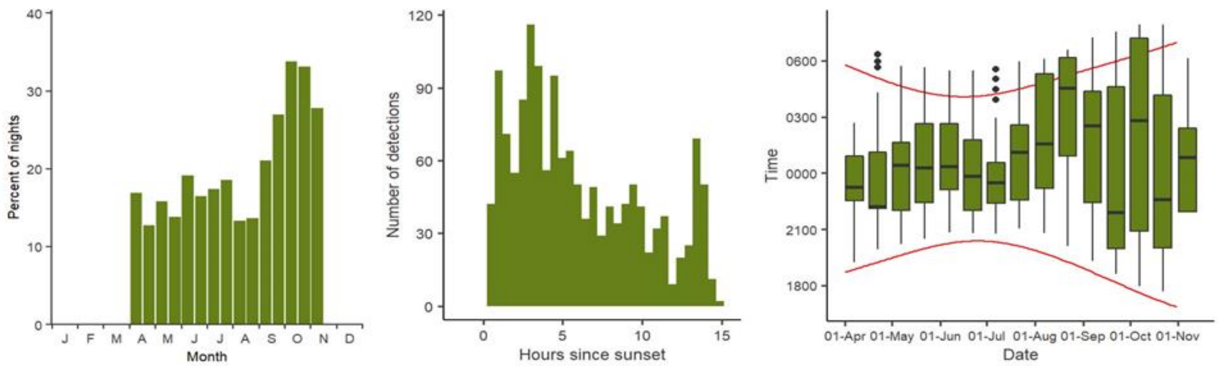
Greater White-toothed Shrew

Greater White-toothed Shrew *Crocidura russula* was recorded on 178 nights, from 223 locations, giving a total of 1,490 recordings.

Spatial pattern of activity



Seasonal and nightly activity



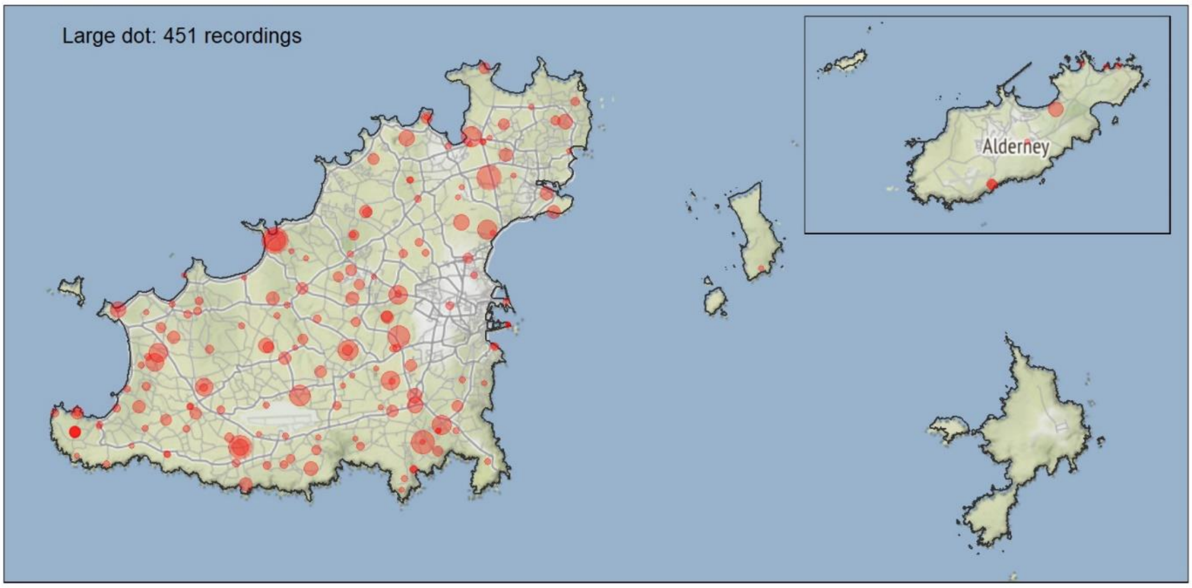
Greater White-toothed Shrew was recorded on Guernsey, Alderney and Herm. Greater White-toothed Shrew is the only shrew species that is believed to be present on these islands. The sound identification of Greater White-toothed Shrew has not previously been described anywhere before and this is the first time a Bailiwick distribution map for the species has been produced. They were extremely widespread and were present on three islands – Guernsey, Alderney and Herm. More analysis needs to be done but they seemed to be associated with farmlands and gardens. The reporting rate increased from 15-20% of nights from April to August to c. 35% in September and October. Numbers would have increased then as there will be large numbers of juveniles in autumn, but it might also signify a change in vocalisation behaviour at this time.

The calls sound quite different from those of Common Shrew *Sorex araneus*, Pygmy Shrew *Sorex minutus* and Water Shrew *Neomys fodiens* found on mainland UK and described in Newson *et al*., (2021). In particular, the calls are shorter in duration, which makes the calls sound more abrupt.

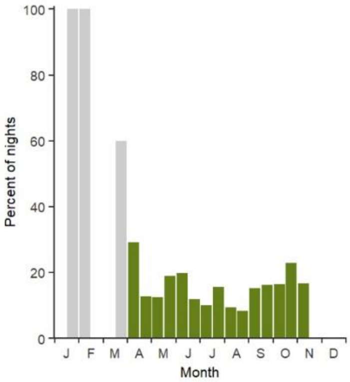
Brown Rat

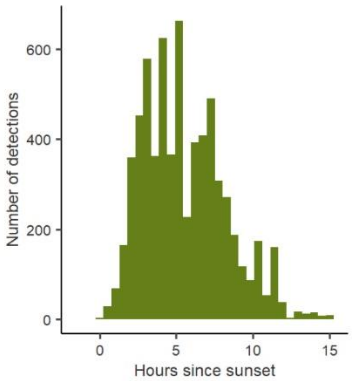
Brown Rat *Rattus norvegicus* was recorded on 171 nights, from 172 locations, giving a total of 6,642 recordings.

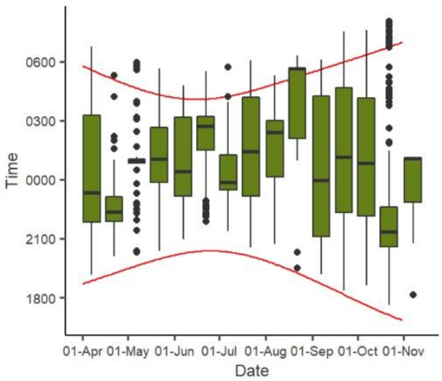
Spatial pattern of activity



Seasonal and nightly activity



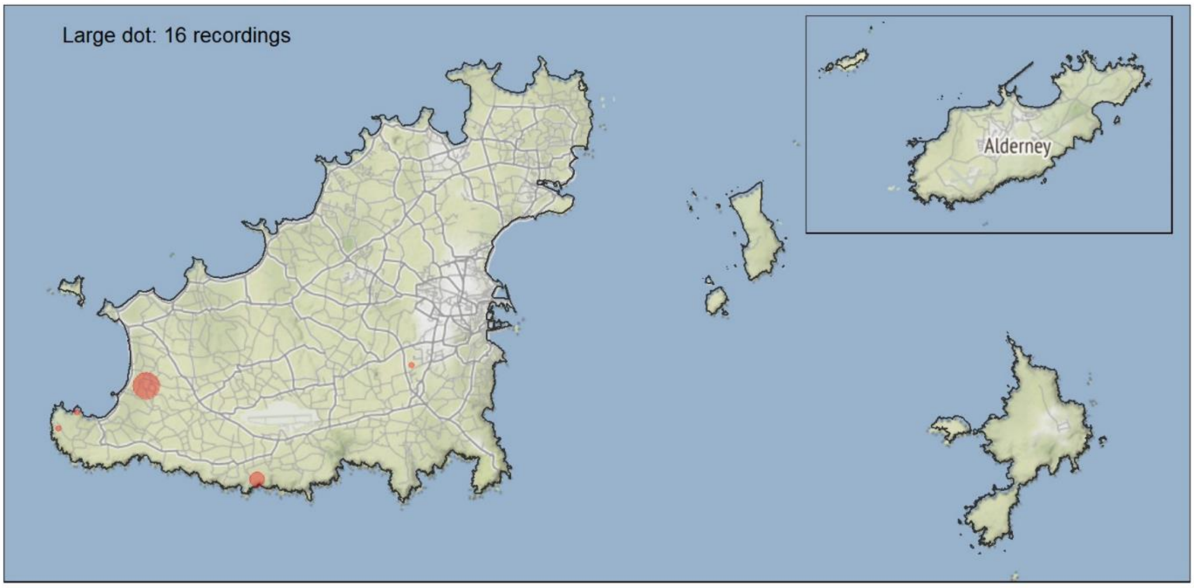




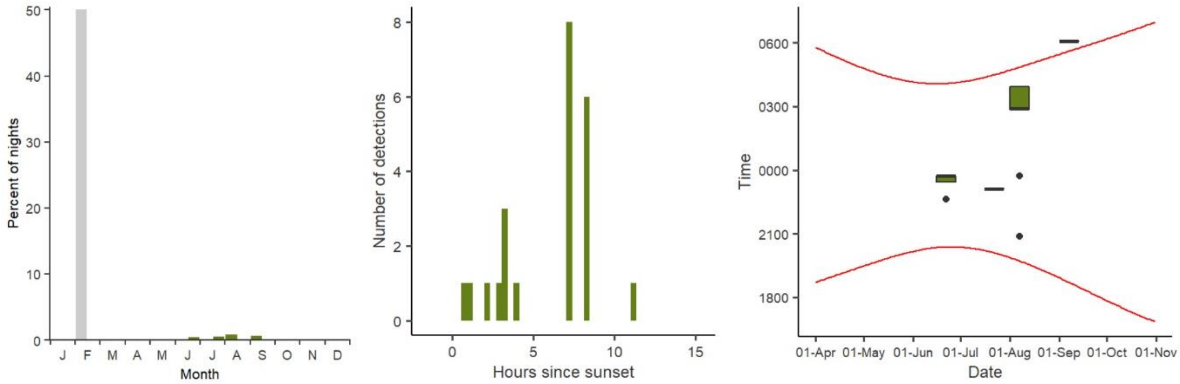
Wood Mouse

Wood Mouse *Apodemus sylvaticus* was recorded on six nights, from five locations, giving a total of 23 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. For more information on the sound identification of Wood Mouse see Newson *et al.*, (2021)

3.3 BTO Acoustic Pipeline

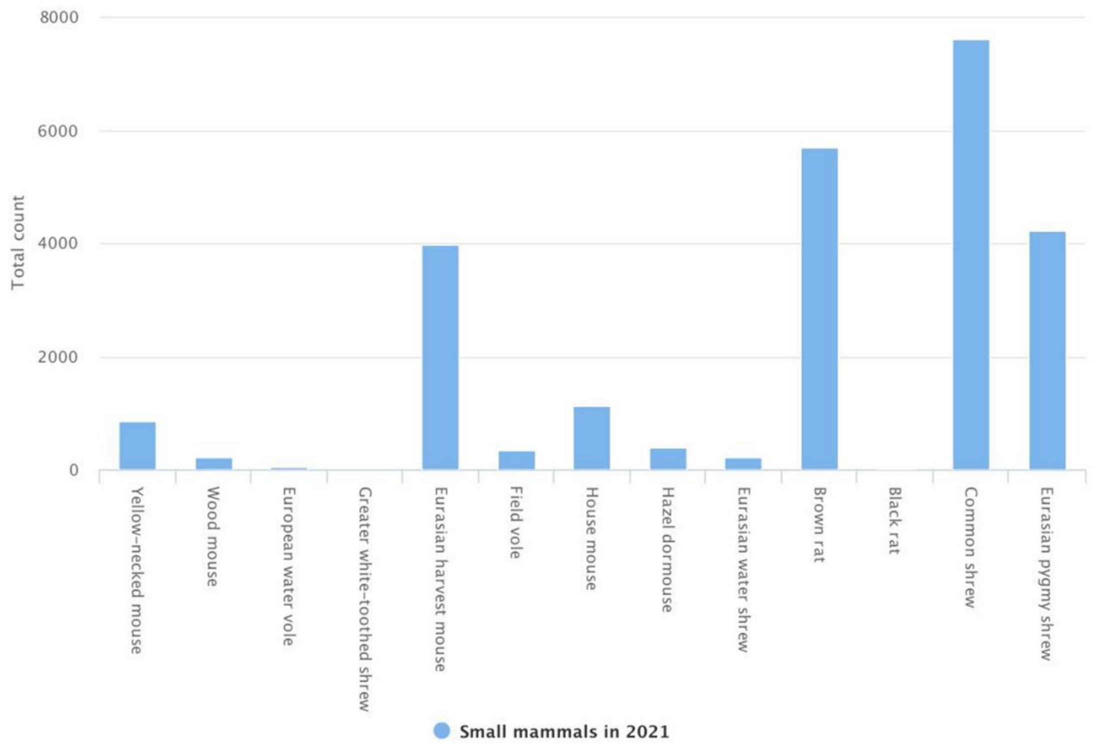
One of the challenges presented by the use of passive bat detectors left in situ is the very large volumes of recordings collected. For bat workers, not all of the recordings will be bat calls; the files may contain the calls of small terrestrial mammals, bush-crickets and human-made sounds. The incorporation of bat social and echolocation calls, together with the calls of small terrestrial mammals and bush-crickets all in the same classifier helps to improve identification of any bat calls, and the elimination of the non-bat call 'by-catch'. Conversely, if the interest is in small mammals, including non-bat calls and bat social calls in the classifier is very important, since the latter could be confused with small mammal calls.

This is the approach adopted by BTO's Acoustic Pipeline (www.bto.org/pipeline), which enables users to upload recordings from full-spectrum detectors to a cloud-based processing and reporting application. The pipeline enables users to manage and (if applicable) share their recordings; it also provides functionality for project management, for example enabling multiple volunteers to submit recordings that will come together for a particular project. Importantly, the system also encourages users to share their data so that the data are used more widely; it does this through a discounted payment structure. Where data cannot be shared for commercial reasons, users can opt for the peace of mind of confidential processing and secure storage if required.

The Pipeline provides a robust and easy to use system for both commercial clients and citizen scientists. Since the Pipeline was launched in March 2021, 810 users have uploaded over 28.2 million recordings, resulting in 17.3 million species identifications. Use of the pipeline comes with free initial credits, enabling potential users to test its effectiveness for their needs. By taking this approach, the BTO Acoustic Pipeline has been able to cover its costs in cloud processing and storage in 2021, which makes this sustainable for the future.

The Pipeline does not currently have an in-built system for supporting the verification of results, which is something that we would like to develop in the future. For our own projects like the Bailiwick Bat Survey, we have pulled back a copy of the uploaded recordings at the end of the survey season, on which we carry out a process of manual auditing of the recordings and results before the data are used. Whilst the classifiers for the sound identification of small mammals are continuing to get better every time they are updated, they can make mistakes, so a robust process for verification is important. Whilst these identifications are unverified, it is helpful to look at the number of recordings with small mammal identifications.

Users of the Pipeline have uploaded over 8.4 million recordings to the ‘Citizen Science’ project alone since the launch in March 2021. The number of recordings that will be assigned to small mammal species following verification will be less than this, but pre-verification this contains about 23,000 small mammal recordings from 13 species. As expected from the findings above, Common Shrew, Pygmy Shrew and Brown Rat comprise a significant proportion of the recordings uploaded to the Pipeline. In Figure 7 we provide some examples of some of the functionality that is currently in development for the Pipeline for exploring the results from projects.


8000
6000
4000
2000
0
Total count
Yellow-necked mouse
Wood mouse
European water vole
Greater white-toothed shrew
Eurasian harvest mouse
Field vole
House mouse
Hazel dormouse
Eurasian water shrew
Brown rat
Black rat
Common shrew
Eurasian pygmy shrew
Small mammals in 2021


Long Term Patterns
Zoom 1m 6m 1y All
From Apr 14, 2021 To Nov 16, 2021
1.25
1
0.75
0.5
0.25
0
Average Count
May '21
Jun '21
Jul '21
Aug '21
Sep '21
Oct '21
Nov '21
2016
2018
2020
Common shrew

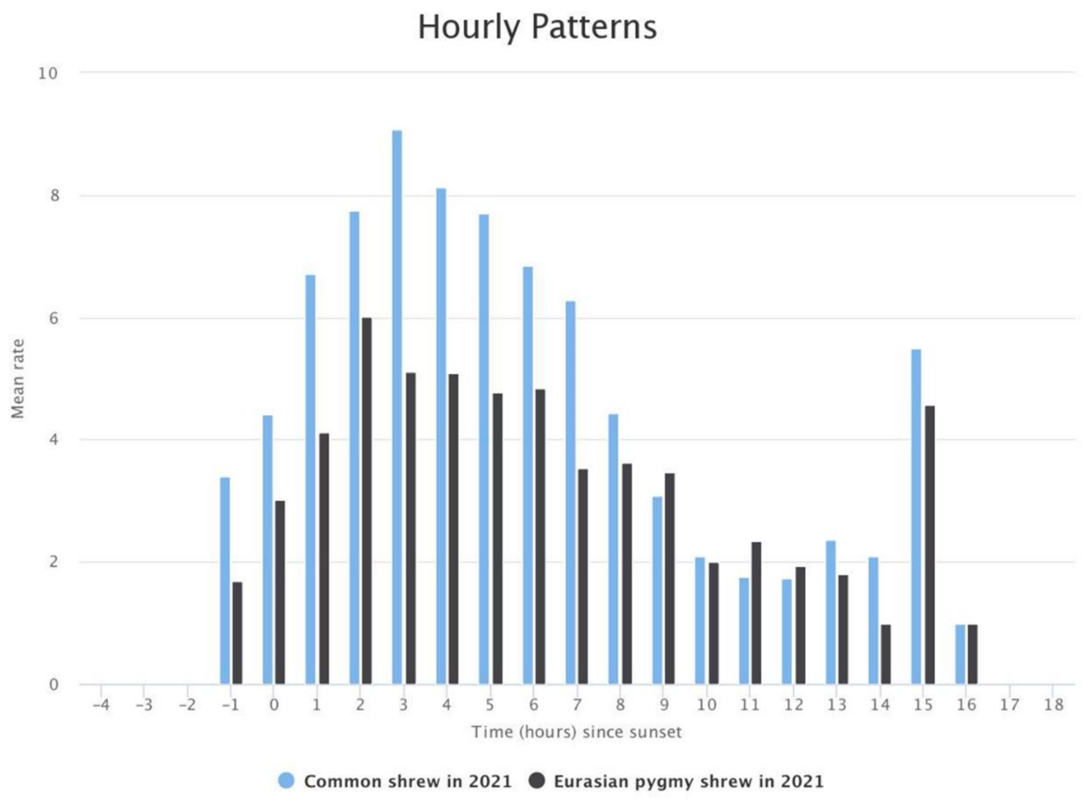


Figure 7. Examples of project-level visualisations of data produced by the BTO Acoustic Pipeline.

4 Discussion

4.1 How can acoustics contribute to an operational monitoring programme for small mammals?

Acoustic studies offer a number of benefits over other survey approaches for small mammals: they can be carried out without directly impacting on an animal's behaviour, and the techniques can be deployed by many surveyors across much larger areas than would be possible under more invasive methods, such as live-trapping.

For shrews there are additional benefits. Because the calls of shrews can be detected at over five metres away from a bat detector, valuable acoustic data on shrews is straightforward to collect, including as incidental data during static bat detector surveys. This may be particularly important for shrews, where the risks of mortality during live-trapping could be avoided if Longworth traps fitted with shrew holes are used, which catch most small mammal species, but allow shrews to escape. The potential for acoustics for recording shrews is perhaps best illustrated on page 13 for Greater White-toothed Shrew, where incidental data collected during bat surveys led to the production of the first distribution map of Greater White-toothed Shrew for the Bailiwick of Guernsey.

If using traps with shrew holes, it may also be possible to reduce the survey effort needed to check traps as regularly as you would if catching shrews, and with a reduction in treadle sensitivity applied, traps should not be triggered by shrews and thus the trap rate for other target species would increase. Together, this may make small mammal trapping easier, and more appealing for volunteers since advanced training required for a shrew licence would not be necessary, offering more opportunities for volunteer participation/citizen science projects.

There are likely to be benefits for other licenced or priority species that could be monitored more easily, including possibilities for monitoring climbing and arboreal species such as Harvest Mouse and Hazel Dormouse that are difficult to monitor by live-trapping and/or where conventional surveys can only be carried out by licenced personnel. The use of acoustics is also likely to be valuable for collecting small mammal data from remote areas or habitats that are difficult to survey using traditional methods.

Brown Rats are very poorly monitored, considering how common they are. However, they are easy to record and identify using acoustics. This is illustrated on page 14, where incidental recordings collected during bat surveys have resulted in large-scale data on Brown Rat for the Bailiwick of Guernsey. Acoustics may be particularly valuable for detecting the presence of Brown Rats (or Black Rats) on seabird islands, where acoustics would offer a valuable and cost-effective approach for detecting the presence of Brown Rats alongside eradication efforts.

Similarly, Greater White-toothed Shrew is an invasive species to the Republic of Ireland and, based on evidence of high detection rates observed during the Bailiwick Bat Survey, it is plausible that acoustic methods could be used to track the distribution and spread of this species, and accordingly inform the need for species control measures, where localised populations are likely to have an adverse impact on native Pygmy Shrew populations.

Our studies to date have found that the acoustic detection of *Apodemus* species and voles is typically low and influenced by the height of the detector and period of survey. It is hoped that further studies may in the future inform more effective methods for applying acoustic surveys for monitoring these species.

4.2 What is the role of structured and unstructured recording?

An important consideration is the amount of survey effort that is needed to record small mammals. In this report, we have used as case studies, data from some of the largest volunteer-based acoustic projects that have been carried out in the UK. Unlike bats, small mammals do not call most of the time as they move around their environment, and so acoustics does not produce the same volume of records. This is illustrated in Section 3.1 with our LandSpAES project, where from 4,366,304 triggered recordings, there were 431,887 bat recordings, but only 1,051 small mammal recordings.

There is a question as to whether national bat monitoring could collect useful data for small mammals alongside bat recording. We think that there are opportunities, but there are some big challenges and potentially the need for compromise over what might be ideal for recording bats to make this work, which is probably not acceptable. Firstly, national bat monitoring using full spectrum static detectors would need to be scaled up to an unprecedented level to produce sufficient data to produce trends for even the most common detectable species. It is also likely that greater survey effort and targeted survey work in particular parts of the country and habitats would be needed to produce useful data for several species of small mammals. To cover the broadest suite of small mammals possible, it may also be important to position a bat detector closer to the ground than would be ideal for recording bats and/or for the recording schedule to be extended beyond what would be typical for bat surveys. Lastly to be able to process the recordings, a pipeline would need to be in place to identify small mammals, which at the current time would require processing to be carried out by the BTO Acoustic Pipeline.

Other possibilities could be to combine the collection of unstructured data, which is already being collected at a large-scale through the BTO Acoustic Pipeline, with acoustic surveys that are better designed to target the species of interest. As we demonstrate in Section 2.3, a lot can be learnt from captive individuals for informing survey design.

4.3 What questions need to be addressed?

There are several species in the UK, where more work to collect reference recordings would be extremely valuable. Through Newson *et al*. (2021) we have made a good start in describing the sound identification of small mammals, but there are some species that we have done more work on and understand better than others. We are continuing to work on some species, but any progress this year will be made accessible to others in 2023, through the publication of a book by Neil Middleton, Stuart Newson and Huma Pearce on the 'Sound Identification of Terrestrial Mammals in Britain and Ireland' to be published by Pelagic Publishing.

In relation to unstructured data, it would be useful to pull back and manually verify the 23,000 small mammal recordings that have been uploaded to the BTO Acoustic Pipeline. The number of users and the volume of recordings that are being uploaded to the Pipeline is increasing the whole time but accessing the value of these data would be a useful first step in understanding the role that these data can play in small mammal recording.

Lastly, there is a large gap in our understanding of how acoustics compares with more traditional monitoring approaches, whether the call rate can be used to infer changes in relative abundance of small mammal populations, and the possibilities for other technologies such trail cameras, and how these could be used potentially in combination with acoustics. In turn, how these relate to the study population on the ground. Recording of captive individuals may provide opportunities for informing our understanding of seasonal and night variation in activity, that may help inform survey design, but would also need to be tested in field situations to assess whether the same patterns of activity apply to wild populations. Understanding these, will allow us to design acoustic surveys that are more likely to provide us with the answers that we need.

5 Author contributions

SEN led on the writing, work on estimating the detection distance of small mammals and interpretation of the analysis. HP designed and carried out the fieldwork in London to compare live-trapping and acoustics, and to record captive Hazel Dormice at the British Wildlife Centre, with subsequent acoustic analysis and manual verification of recordings. Both co-authors helped to shape the ideas, context and analysis of the project and read and commented on draft versions of the manuscript.

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