BTO RESEARCH REPORT 768

Silvopasture Biodiversity – Beetles and Bats: providing the infrastructure and protocols that farmers can follow to participate in biodiversity monitoring using passive acoustic monitoring

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BTO Birds Science People

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SUMMARY

Background Working with the Devon silvopasture network, a survey and sampling protocol was devised that allowed farmers to deploy static acoustic bat detectors over a 7-month survey season to provide baseline data for bats. This report provides an overview of the survey coverage and main results from 2023, to highlight what can be delivered now using passive acoustic monitoring, whilst providing the next steps and a vision for the future.

Coverage During 2023, 30 different locations across the Elston Farm, farming cluster were surveyed. Recording was undertaken on 94 different nights mainly between April and the end of October, amounting to a total of 199 nights of recording effort across sites. Sound recordings (wav files) were uploaded by farmers 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 end of the survey season, a copy of the recordings was pulled back, and manual auditing of the results / recordings carried out.

Results Overall, 79,375 recordings were collected which, following analyses and validation, were found to include 13,945 bat recordings, and 199 small terrestrial mammal recordings. Over 30,000 recordings of bush-crickets were also recorded as 'by-catch', for which we report species presence on a site and night basis. Following validation, the study confirmed the presence of 15 bat species, 2 small mammal species, and 4 species of bush-crickets. Through the project, we have a better understanding now of the status of all species of bats on the farms surveyed. The report includes a full species-by-species breakdown of spatial, seasonal, and through-the-night patterns of activity. In considering how the data can be exploited for maximising farm productivity and societal gain, we highlight that there remain substantial barriers to real world use of this technology at scale. In a confidential version of this report, we describe how these can be addressed, and present a vision for the future of passive acoustic monitoring.

1. BACKGROUND

We have a good understanding of biodiversity declines at national levels as a result of thousands of hours of recording committed by dedicated citizen scientists every year, but citizen science schemes are intensive to manage and do not always provide insights at fine scales. Many efforts are underway to reverse these declines, but their effectiveness is hampered by a lack of methods to assess and monitor a wide range of taxa efficiently, as each group requires bespoke survey techniques. Recent developments in recording and processing of acoustic data offer the potential to monitor multiple taxa in a cost-effective way, vastly improving our ability to respond to the biodiversity crisis and improve the balance of our natural capital.

Biodiversity monitoring is currently largely restricted to professionals or highly skilled citizen scientists. This limits our capability to gather robust data on biodiversity across a range of spatial scales and for multiple needs - Biodiversity Net Gain, Environmental Land Management, Nature Restoration and National Monitoring, and therefore our ability to optimise decision making. The current disconnect from data collection and results, can also remove those with the greatest power to make a difference, such as farmers and land managers, from the process of nature recovery. We therefore need methods that are easy to deploy, provide fast results, and that work at a range of spatial scales. Recent developments in recording and processing of acoustic data offer the potential to monitor multiple taxa in a cost-effective way.

2. AIMS AND OBJECTIVES

The Silvopasture Biodiversity: Beetles and Bats project comprises of two discrete sub-projects that aim to use technology to enable farmers to self-monitor different components of biodiversity on their land. The first of these sub-projects, led on by Rothamsted Research describes the first steps in automatic monitoring of dung beetles in silvopasture systems, using camera trap technology that farmers can install and use themselves. This work is presented in a separate report by Jowett *et al*. (2024).

The second sub-project, which is the focus of this report, is to provide the infrastructure and protocols that farmers can follow to participate in biodiversity monitoring using passive acoustic monitoring to collect bat distribution and activity data. These were trialled and refined through survey work carried out by the Devon silvopasture network between mid-April and the end of October 2023.

In addition to talking to and working with farmers to identify what they would want to get from passive acoustic monitoring, an important part of this project was to look beyond what is possible now, to where we would like to get to in the future. This includes identifying where there are remaining barriers to real-world use of acoustic monitoring at scale, and in considering how these barriers could be addressed.

Whilst the focus of this work is bats, results for small terrestrial mammals, bush-crickets which are recorded as 'by-catch' during bat surveys were also returned (Newson *et al*., 2017b; Newson *et al*., 2021; Middleton *et al*., 2024).

In addition to the aims above, this sub-project has the following specific objectives, where Objectives 1 and 2 relate to the fieldwork carried out 2023. Objective 3 goes across both sub-projects (beetles and bats), to consider how the data that can be obtained using these technologies can be exploited for maximising farm productivity and societal gain. As considered in the discussion section of this report, for passive acoustic monitoring, there remain substantial barriers to real world use of this technology at scale that need to be addressed first. In a confidential version of this report, we describe solutions to these, and present a vision for the future of passive acoustic monitoring.

Objective 1. Monitoring functional biodiversity in silvopasture systems

- Survey bats during the third year of establishment of silvopasture treatment on commercial farms and adjacent locations that are not managed for silvopasture.
- Provide a baseline of species occurrence from silvopasture systems and paired data from control sites.

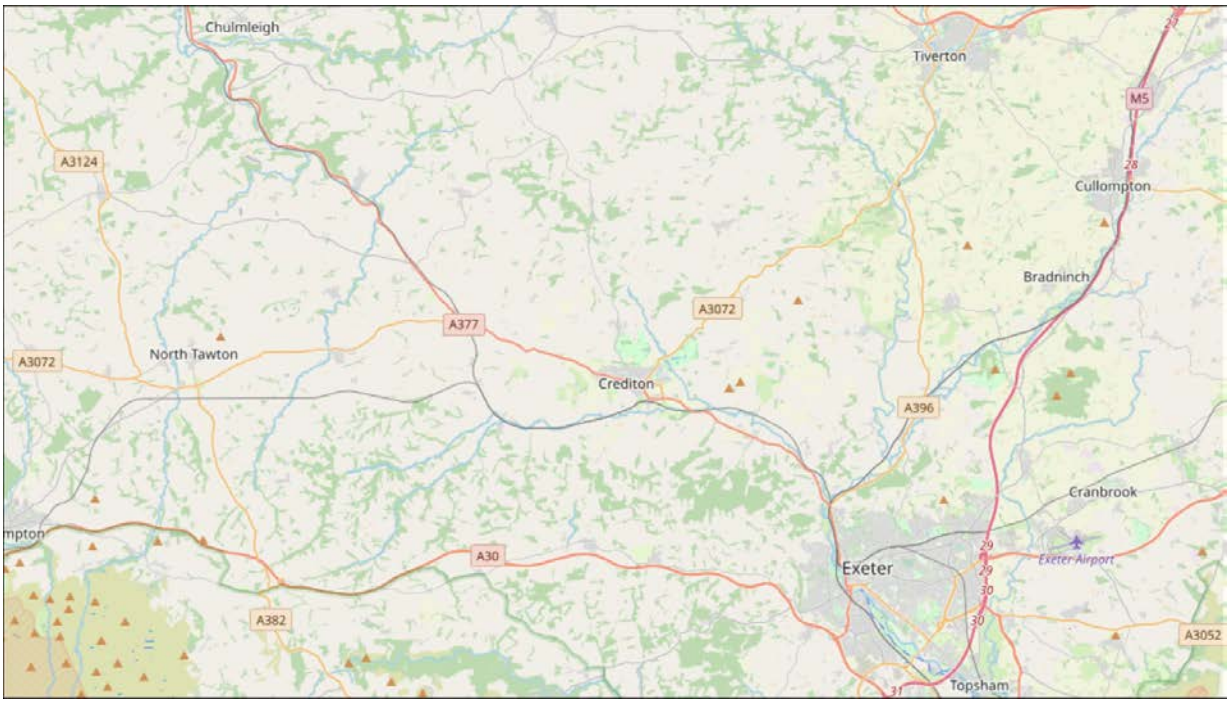
Objective 2. Development of methods for farm self-monitoring

- Develop a sampling protocol and survey instructions that farmers can follow to deploy bat detectors and to upload sound recordings to the BTO Acoustic Pipeline.
- Develop guidance for farmers on how to use and interpret bat acoustic results.

Objective 3. Exploit use of monitoring data for farm productivity and societal gain

- Demonstrate the potential to provide information useful to farmers on functional biodiversity in silvopasture as the systems mature.
- Communicate developed protocols to farmers across the UK and inspire farmers to monitor biodiversity for environmentally healthy and productive systems, adaptive management and societal goods.
- Develop collaborations and data pathways to allow for analysis of silvopasture data beyond project timescales, and feed into an increased knowledge base in silvopasture system development over time.
- Produce data translatable to biodiversity offsetting markets and consumer choice marketing (e.g. LEAF). Identify potential policy requirements for Environmental Land Management schemes results-based payments.

Map of the survey area covered by the Devon silvopasture network.



All maps in this report use the maptiles R package (Giraud 2023) with data copyright OpenStreetMap contributors.

3. METHODS

3.1 Static detector protocol

Our survey approach is based on the Norfolk Bat Survey and Southern Scotland Bat Survey (Newson *et al.*, 2015; Newson *et al.*, 2017a) which was set up to assess the season-wide status of bat species throughout large regions. Our protocol enabled farmers in the Devon Silvopasture Cluster group to have access to passive real-time bat detectors which they left 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 consecutive nights at each location. The recommendation of a minimum 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 10 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 30 minutes before sunset until 30 minutes after sunrise the following day. The microphone was mounted on 2-m poles to avoid ground noise and reduce recordings of reflected calls. Guidance was provided to volunteers on the placement of microphones should 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 the beginning of April to the end of October, but with a small amount of recording outside this period. A long survey season covers the main period of bat activity, and maximises use of the equipment during the year. Having two recording windows between mid-April and mid-July, and then between mid-July and the end of October broadly captures the breeding and post-breeding periods between which the distribution and habitat use by bats is likely to be most different.

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), along with associated information on where the recording was carried out were uploaded by the volunteer to the BTO's Acoustic Pipeline http://bto.org/pipeline for processing. With this, the volunteer had their own online user account, and desktop software through which they could 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 bat 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 bats and small mammals where we were interested in producing a measure of activity, we manually checked all the recordings of a species. With the exception of the most common species, Common Pipistrelle *Pipistrellus pipistrellus* and Soprano pipistrelle *Pipistrellus pygmeaus*, we checked a random sample of 1,000 recordings to quantify the error rate in the dataset. For bushcrickets and audible moths where there can be a large number of recordings, often of the same individual, we instead focus on producing an inventory of species presence instead, where the three recordings with the highest probability for each site and night were selected for auditing.

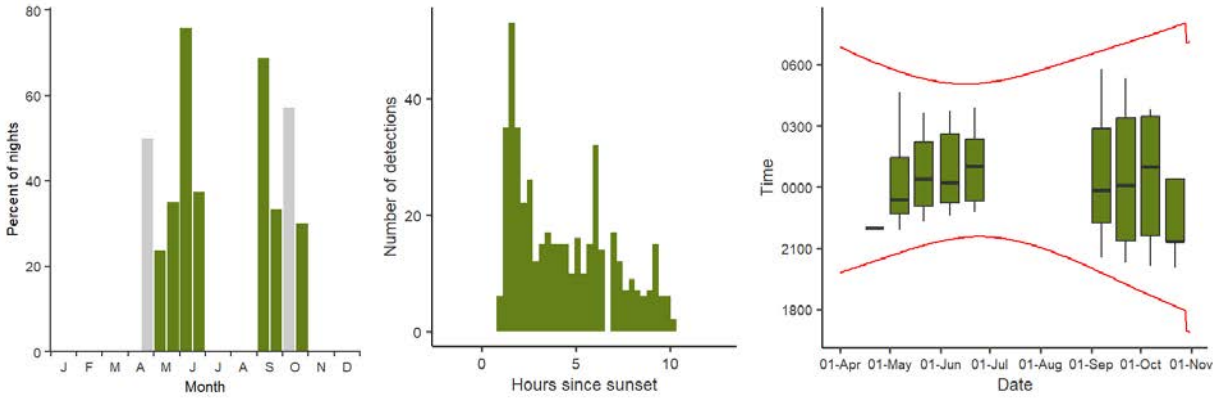
Verification of species identification was carried out through the manual checking of spectrograms using software SonoBat (http://sonobat.com/) which was used as an independent check of the original species identities assigned by pipeline. The spectrograms shown in this report, were also produced using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

It is important to note that the criteria for distinguishing Whiskered Bat *Myotis mystacinus* and Brandt's Bat *Myotis brandtii* are very subtle and poorly defined. For this reason, until further ground-truthing of the identification can be carried out, we treat these two species as a species pair.

3.4 Seasonal and nightly patterns of activity

Important for improving our understanding of the species present, we examine how bat 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 bat species was detected. Activity through the night was analysed by first converting all bat pass 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 passes 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 Natterer's Bat. 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 extend to 1.5 times the interquartile range, and small dots show outliers.



3.5 Spatial patterns of activity and distribution

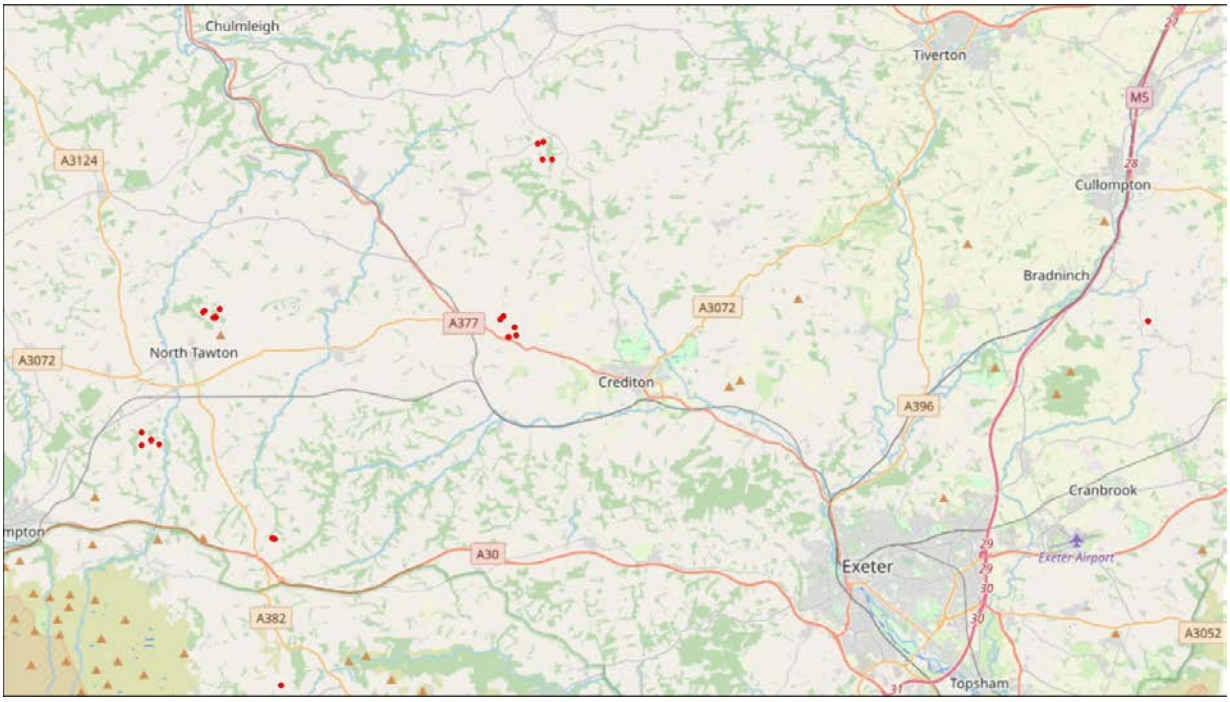
We produce maps of bat and small mammal activity. With these, dots are scaled according to the total number of recordings of this species at each location. Activity here represents usage of an area, which will be a combination of species abundance, and time spent in the area. For bush-crickets, the results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

4. RESULTS

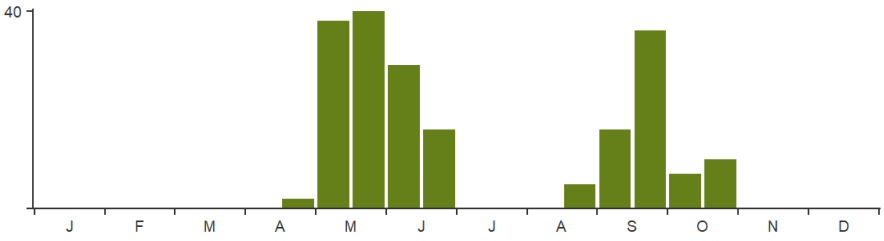
4.1 Survey coverage

During 2023, 30 different locations were surveyed for bats by the Devon Silvopasture Cluster group. The distribution of these locations is shown below. Collectively across all these sites, 199 complete nights of recording effort was conducted. The recording effort spanned 94 different nights and 6 months. The seasonal pattern of recording effort is shown in the bottom figure. Manual checking of recordings was carried out for all species and recordings, except for Common Pipistrelle and Soprano Pipistrelle for which 1000 randomly selected recordings were checked. For Common Pipistrelle 7 (0.5%) recordings and for Soprano Pipistrelle 5 (0.5%) recordings were assigned to the wrong species.

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



Number of locations surveyed.



4.2 General results

Overall, 79,375 recordings were collected which, following analyses and validation, were found to include 13,945 bat recordings, and 199 small terrestrial mammal recordings. In addition, four bush-cricket species were recorded (see table below). Following validation, the presence of at least 15 bat species, 2 small mammal species, and 4 bush-

cricket species can be confirmed.

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

Bats

Species (/call type)	No. of recordings following validation	No. of different locations (% of total)
Barbastelle, Barbastella barbastellus	58	14 (46.7%)
Serotine, Eptesicus serotinus	83	13 (43.3%)
Bechstein's Bat, Myotis bechsteinii	4	2 (6.7%)
Daubenton's Bat, Myotis daubentonii	70	13 (43.3%)
Whiskered or Brandt's Bat, Myotis mystacinus or M. brandtii	31	12 (40%)
Natterer's Bat, Myotis nattereri	457	20 (66.7%)
Leisler's Bat, Nyctalus leisleri	102	17 (56.7%)
Common Noctule, Nyctalus noctula	3981	27 (90%)
Nathusius' Pipistrelle, Pipistrellus nathusii	4	3 (10%)
Common Pipistrelle, Pipistrellus pipistrellus	6394	24 (80%)
Soprano Pipistrelle, Pipistrellus pygmaeus	2253	25 (83.3%)
Brown Long-eared Bat, Plecotus auritus	501	25 (83.3%)
Grey Long-eared Bat, Plecotus austriacus	5	3 (10%)
Greater Horseshoe Bat, Rhinolophus ferrumequinum	1	1 (3.3%)
Lesser Horseshoe Bat, Rhinolophus hipposideros	1	1 (3.3%)

Small mammals

Species	No. of recordings following validation	No. of different locations (% of total)
Common Shrew, Sorex araneus	146	11 (36.7%)
Eurasian Pygmy Shrew, Sorex minutus	53	6 (20%)

Bush-crickets

Species	No. of different locations (% of total)
Long-winged Conehead, Conocephalus fuscus	6 (20%)
Speckled Bush-cricket, Leptophyes punctatissima	4 (13.3%)
Dark Bush-cricket, Pholidoptera griseoaptera	2 (6.7%)
Roesel's Bush-cricket, Roeseliana roeselii	1 (3.3%)

4.3 Species and call-type results

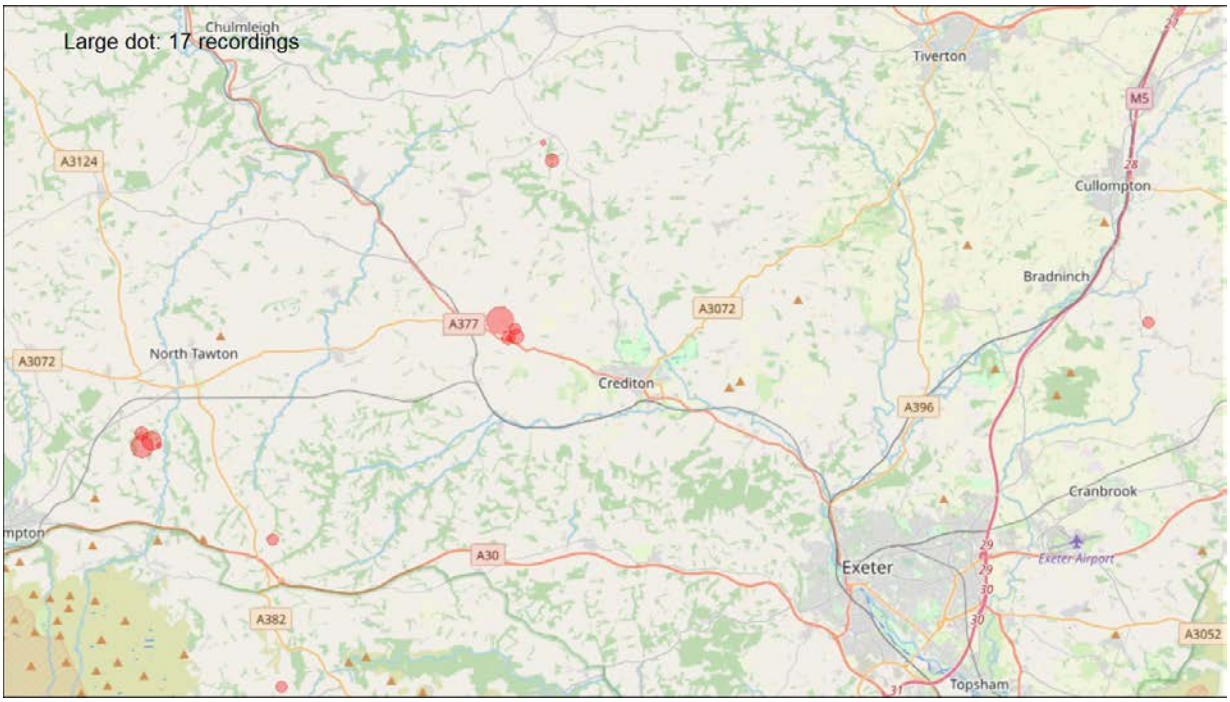
The following sections provide results for each species and/or call type.

4.3.1 Bat species

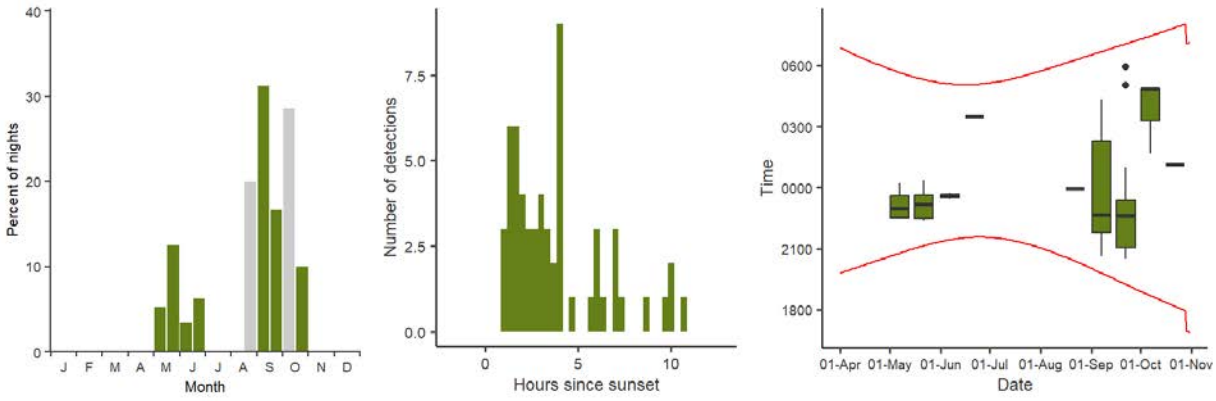
Barbastelle

Barbastelle *Barbastella barbastellus* was recorded on 22 nights, from 14 locations, giving a total of 58 recordings.

Spatial pattern of activity



Seasonal and nightly activity

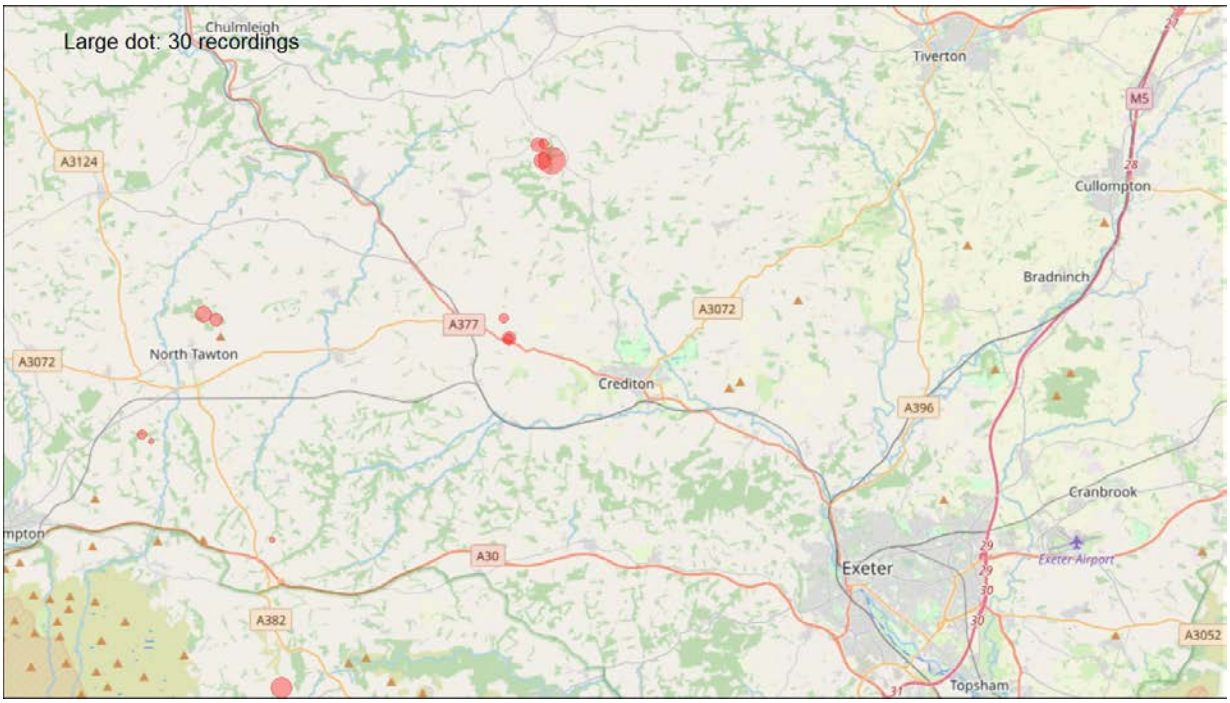


Barbastelle was recorded in single figures across a number of farms in the study, but with a maximum of 13 recordings on the 22nd September from a bat detector deployed by Andy Gray.

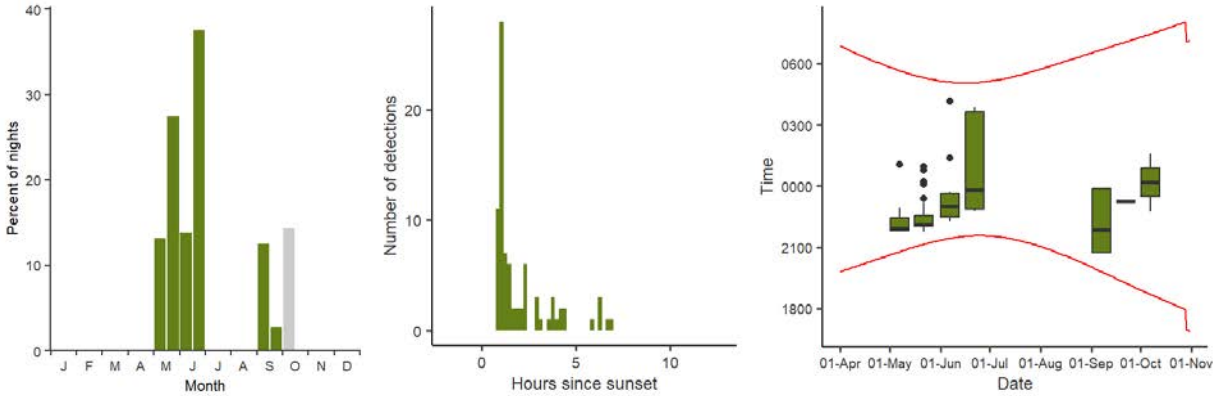
Serotine

Serotine *Eptesicus serotinus* was recorded on 24 nights, from 13 locations, giving a total of 83 recordings.

Spatial pattern of activity



Seasonal and nightly activity



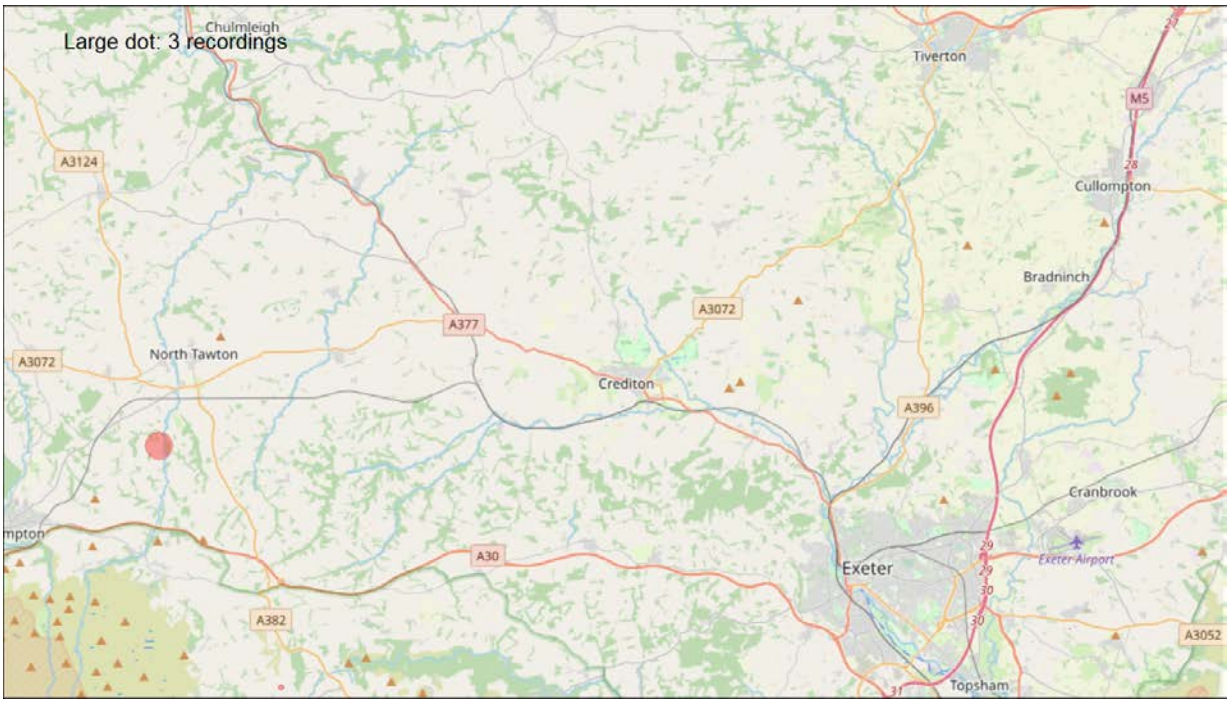
Serotine was widely recorded across farms, with single figures of recordings from most nights, but with a maximum of 16 recordings from a one night from a bat deployed by Henrietta Curtis close to Black Dog on the 16th May.

Acoustically, it is normally straightforward to distinguish Serotine from *Nyctalus* species, of which Common Noctule and Leisler's Bat are the most likely confusion species here. In contrast to Serotine, *Nyctalus* species often show strong alternating frequencies in the calls within a sequence. Leisler's Bat often shows sharp frequency changes within a sequence of over 2 kHz, where such changes would be unusual for Serotine. One situation where it can be more difficult to distinguish Serotine/*Nyctalus* is in high clutter, but *Nyctalus* normally do not stay long in high clutter, so it would be exceptional to find consecutive steep calls of these species.

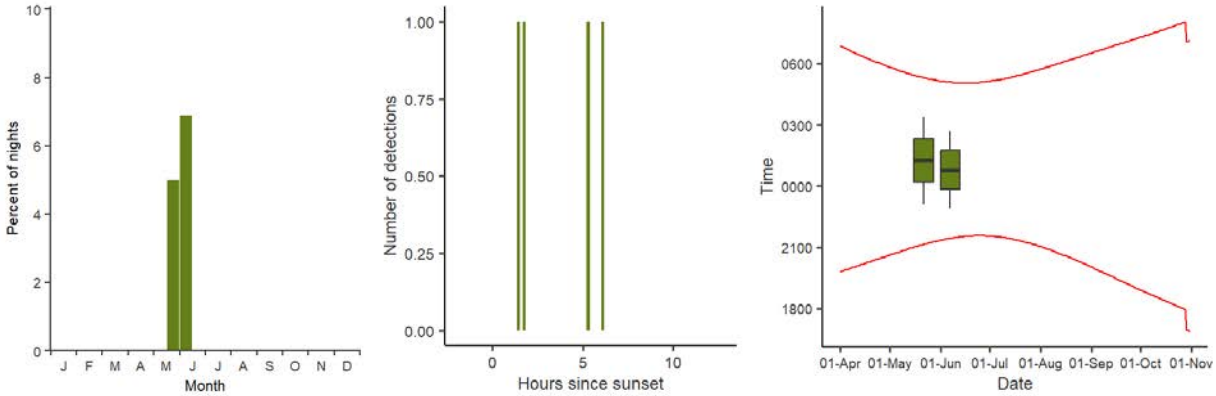
Bechstein's Bat

Bechstein's Bat *Myotis bechsteinii* was recorded on four nights, from two locations, giving a total of 4 recordings.

Spatial pattern of activity



Seasonal and nightly activity

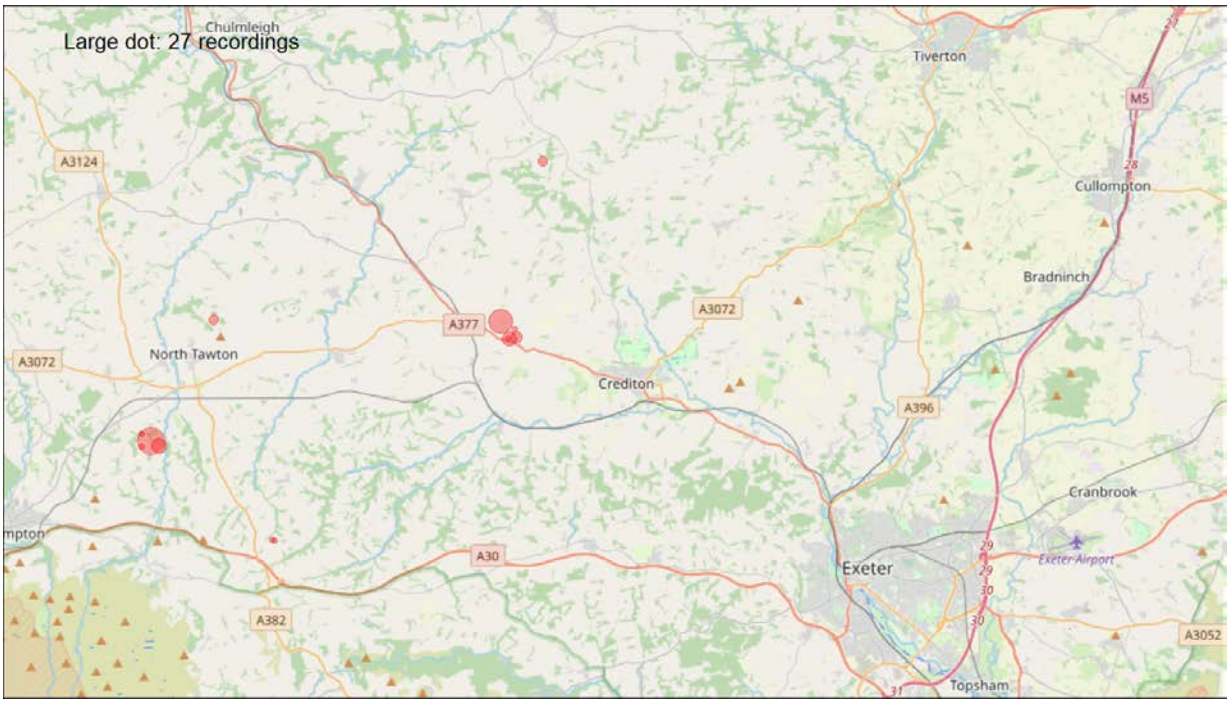


Bechstein's Bat was recorded by Sam Bullingham and by Seb Powell from two locations and with just four recordings in total.

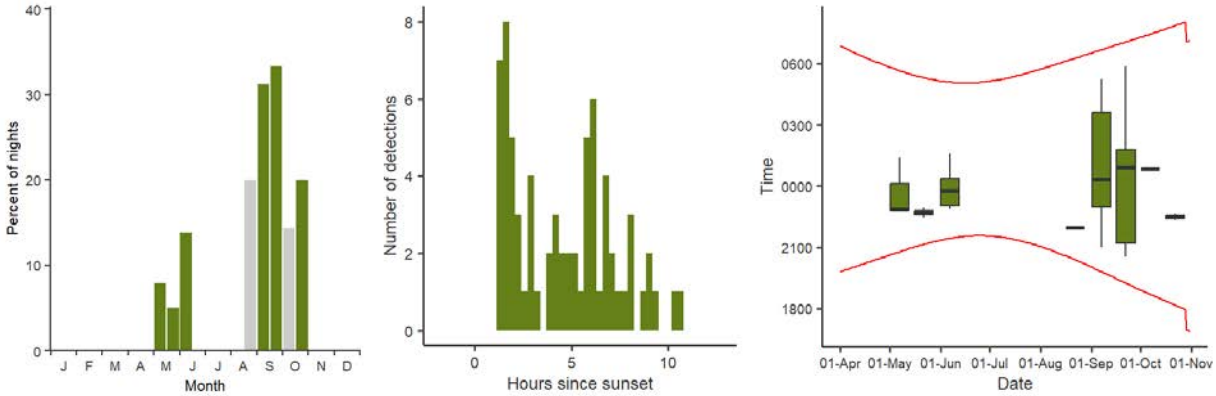
Daubenton's Bat

Daubenton's Bat *Myotis daubentonii* was recorded on 25 nights, from 13 locations, giving a total of 70 recordings.

Spatial pattern of activity



Seasonal and nightly activity

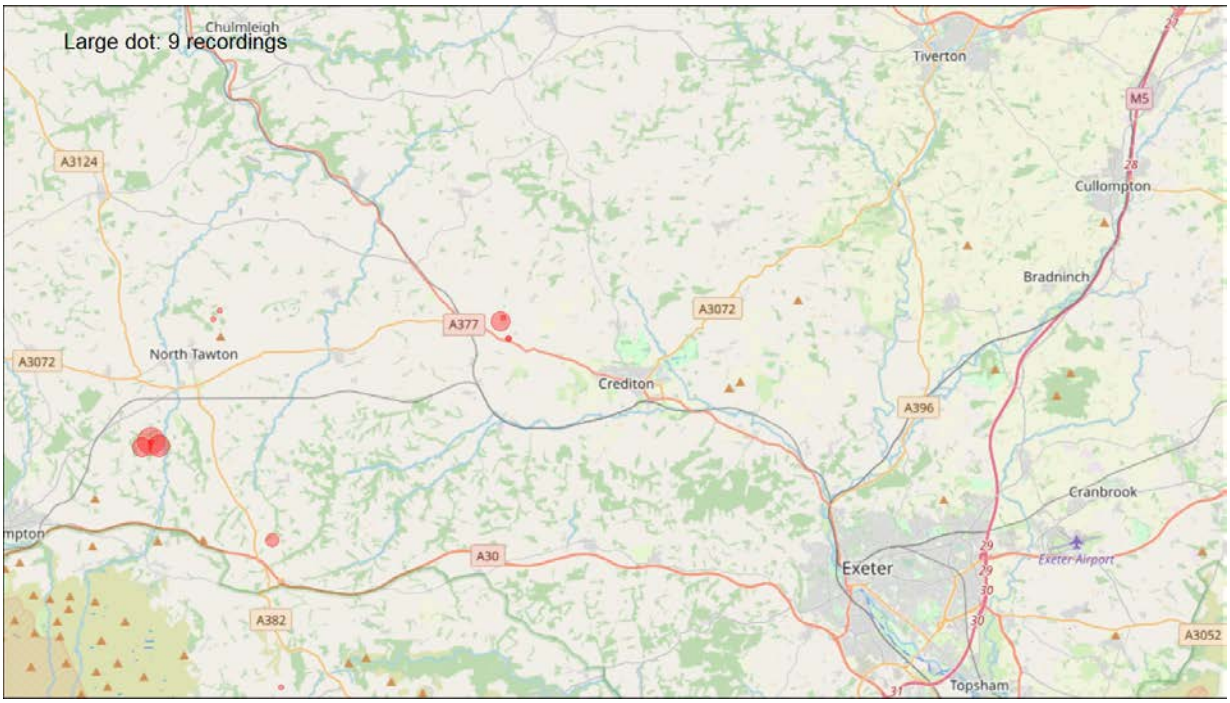


Daubenton's Bat was widely recorded on most farms in 2023, but with the highest activity, 17 recordings on the 25th September, recorded by Andy Gray. See Identification appendix 1 for further information on the sound identification of Daubenton's Bat in comparison to Natterer's Bat.

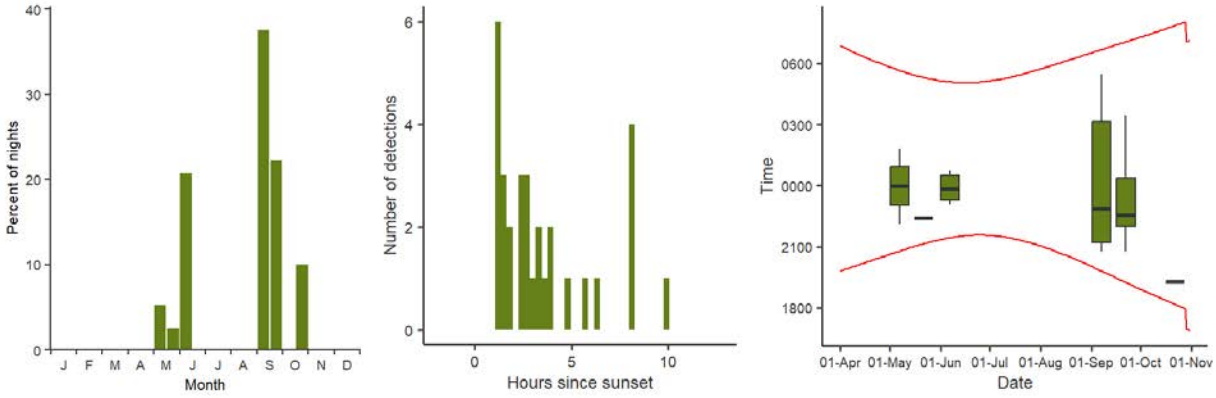
Whiskered or Brandt's Bat

Whiskered or Brandt's Bat *Myotis mystacinus or M. brandtii* was recorded on 20 nights, from 12 locations, giving a total of 31 recordings.

Spatial pattern of activity



Seasonal and nightly activity

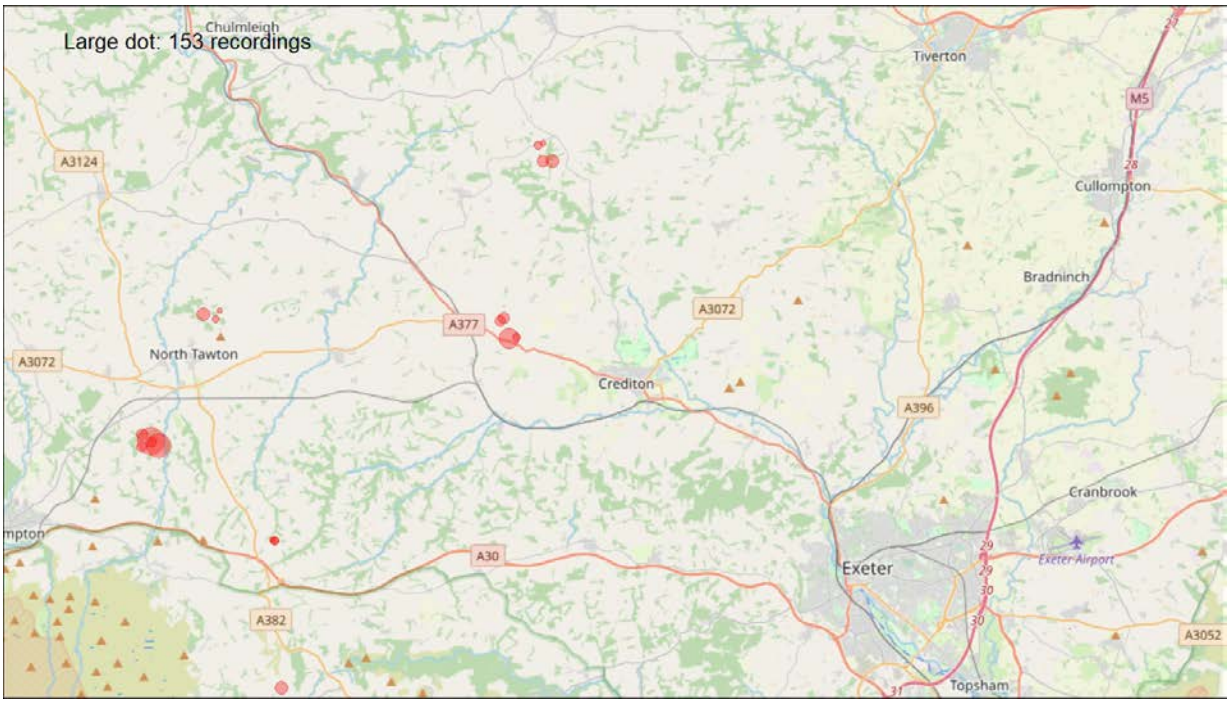


Whiskered or Brandt's Bat were very widely recorded across farms, but with only a handful of recordings a night at any single location. A maximum of three recordings was made by Sam Bullingham on the 13th September. At the current time, there are no good clear criteria for distinguishing Whiskered and Brandt's Bat acoustically with confidence. Looking across recordings there is an indication from the call measurements and social calls that Brandt's Bat is likely to be the most common and widespread of the two species, but this would need to be proven by some other means (e.g. DNA evidence or trapping). For further discussion on our approach to the sound identification of *Myotis* see Identification appendix 2.

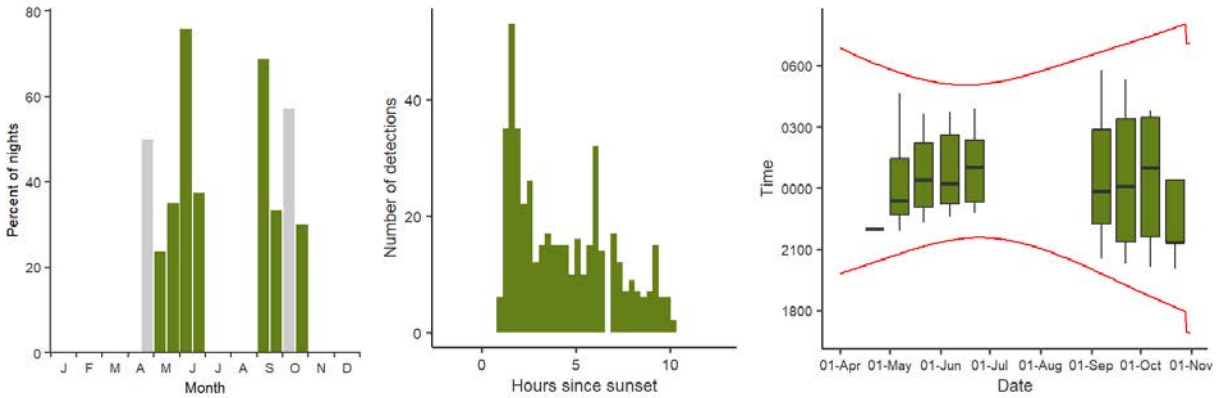
Natterer's Bat

Natterer's Bat *Myotis nattereri* was recorded on 57 nights, from 20 locations, giving a total of 457 recordings.

Spatial pattern of activity



Seasonal and nightly activity

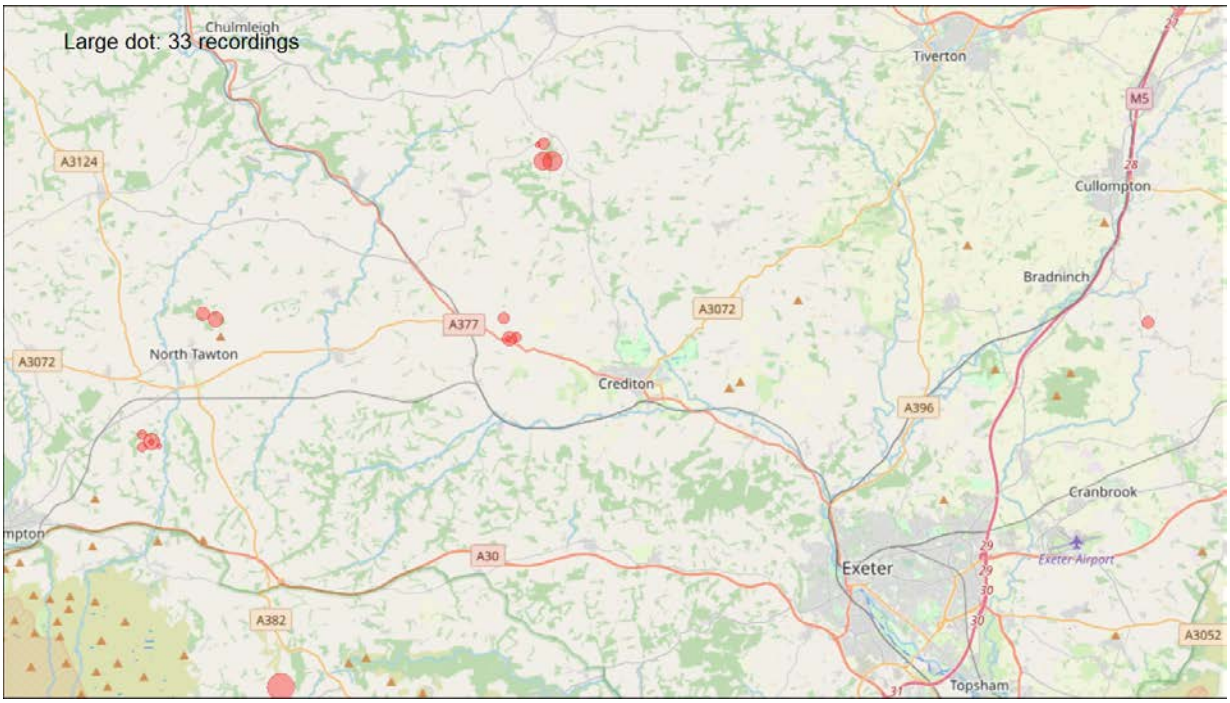


Natterer's Bat was widely recorded in 2023. Of particular note were three locations where there were double figures of recordings a night, two of which were recorded by Sam Bullingham (in June and September) and the third location was from Andy Gray in September. As with Whiskered and Brandt's Bat above, the first consideration when looking at recordings is the quality of the recording, to consider whether the quality is good enough to try and assign the recording to species. See Identification appendix 3 for further information on the sound identification of Natterer's Bat.

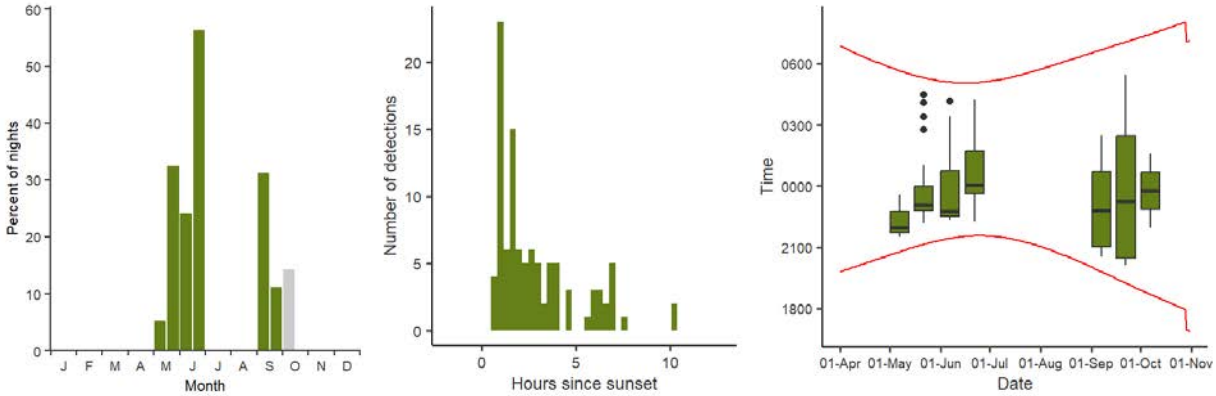
Leisler's Bat

Leisler's Bat *Nyctalus leisleri* was recorded on 31 nights, from 17 locations, giving a total of 102 recordings.

Spatial pattern of activity



Seasonal and nightly activity

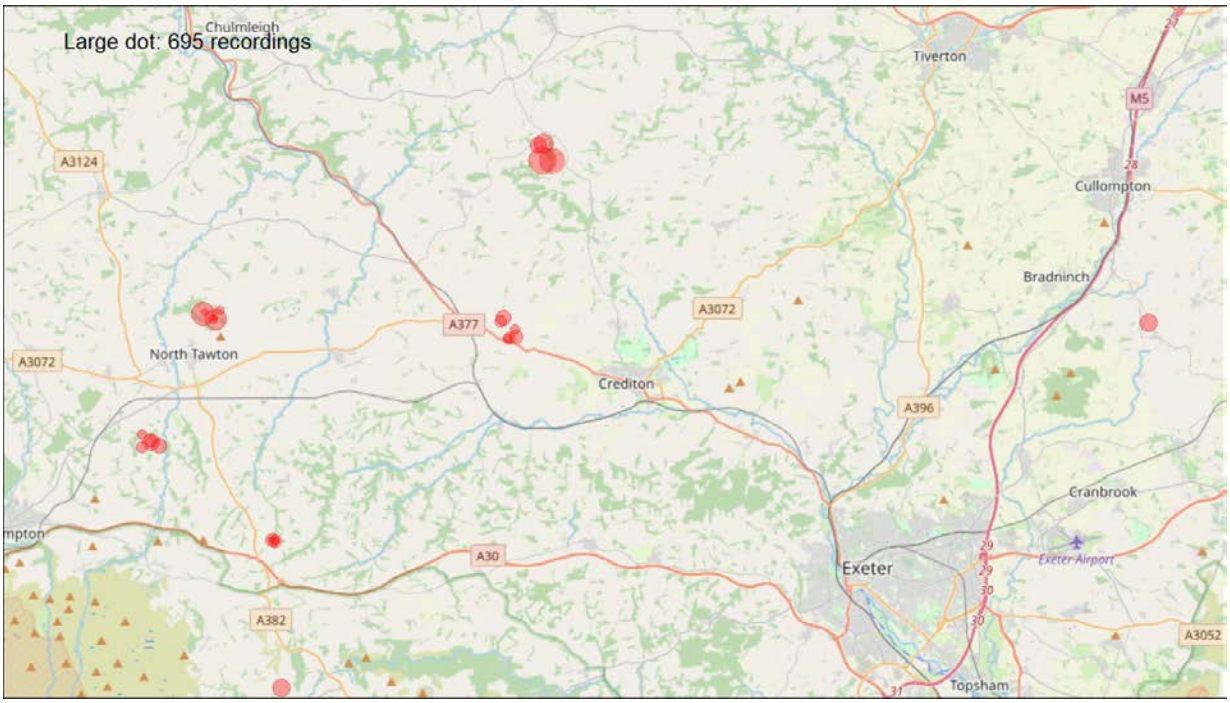


Leisler's Bat a few recordings of this species were collected across most farms, but particularly notable was 20 recordings made by Seb Powell from one location on the 13th May. In these recordings, there are alternating call frequencies, which is typical for *Nyctalus*. Narrowing down the identification further, given the call durations in the presumed Leisler's Bat recordings, it is clear the frequency of the calls, is higher than would be expected for Noctule given the flat call shape. See Identification appendix 4 for further information on the sound identification of Leisler's bat and Noctule.

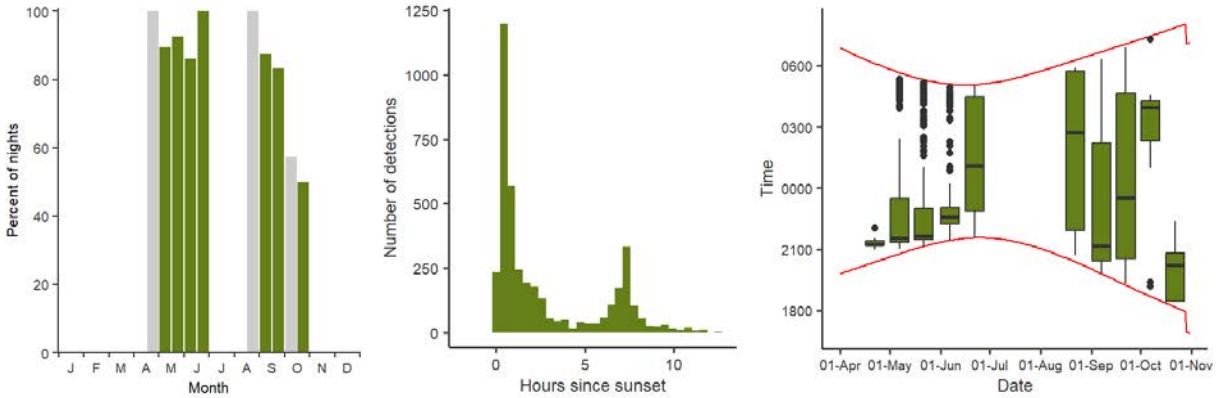
Common Noctule

Common Noctule *Nyctalus noctula* was recorded on 87 nights, from 27 locations, giving a total of 3,981 recordings.

Spatial pattern of activity



Seasonal and nightly activity

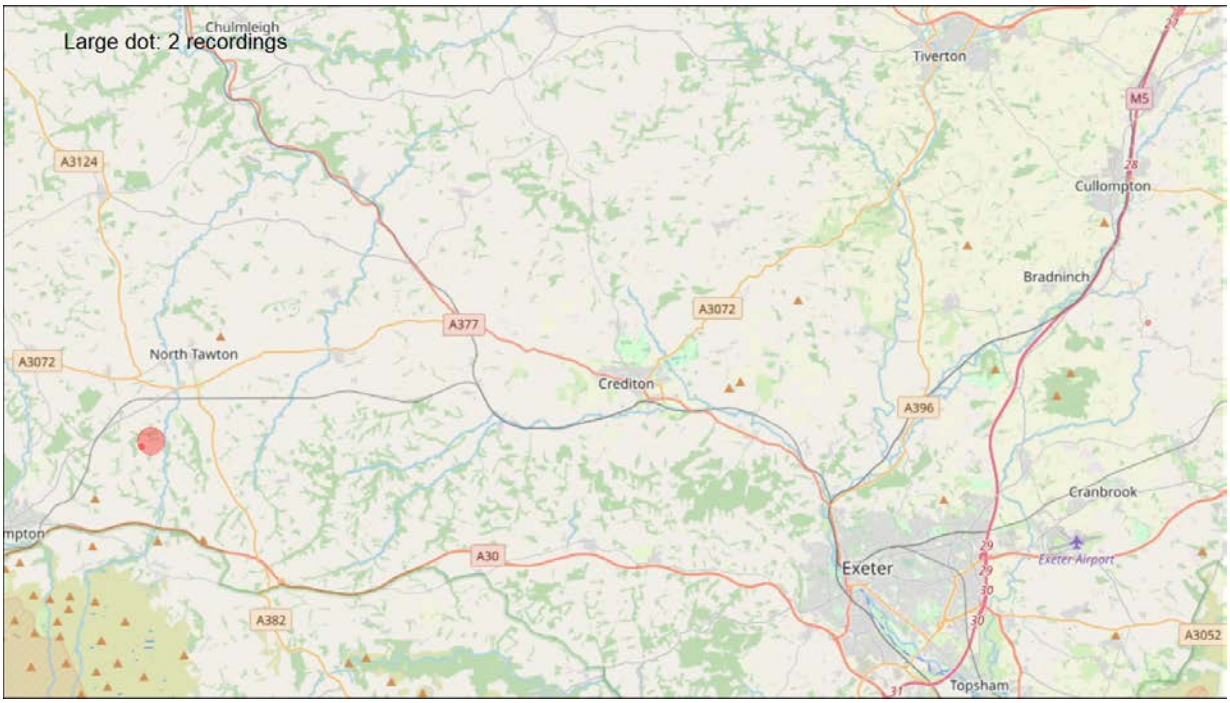


Common Noctule was the most widely recorded bat species (recorded at 90% of locations), and was the second most commonly recorded species (number of recordings) after Common Pipistrelle. The maximum number of recordings of Noctule from a night was 205 recordings made by Henrietta Curtis on the 17th May. See Identification appendix 5 for further information on the sound identification of Noctule and how it compares with the closely related Leisler's Bat.

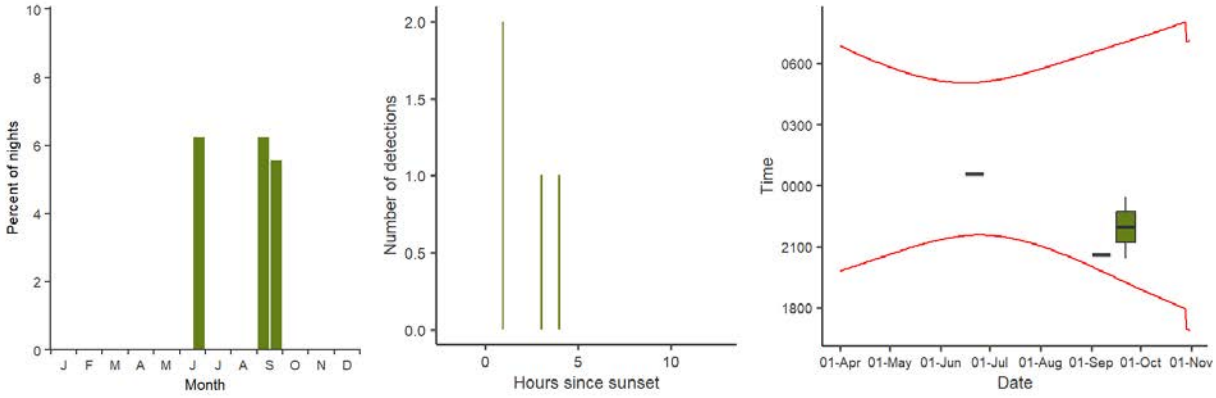
Nathusius' Pipistrelle

Nathusius' Pipistrelle *Pipistrellus nathusii* was recorded on three nights, from three locations, giving a total of 4 recordings.

Spatial pattern of activity



Seasonal and nightly activity

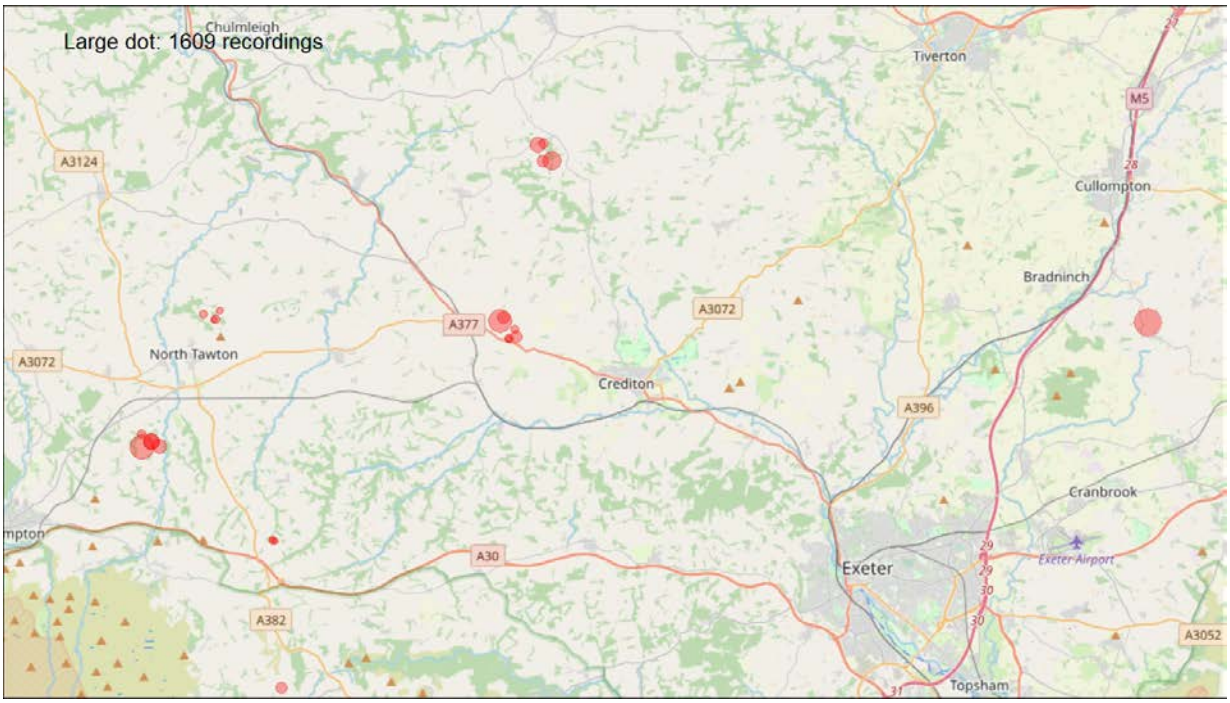


Nathusius' Pipistrelle was recorded from three locations, but with a maximum of only two recordings from one location. One of these recording from 26th June was made by Andy Gray, with the remaining recordings all made by Sam Bullingham in September.

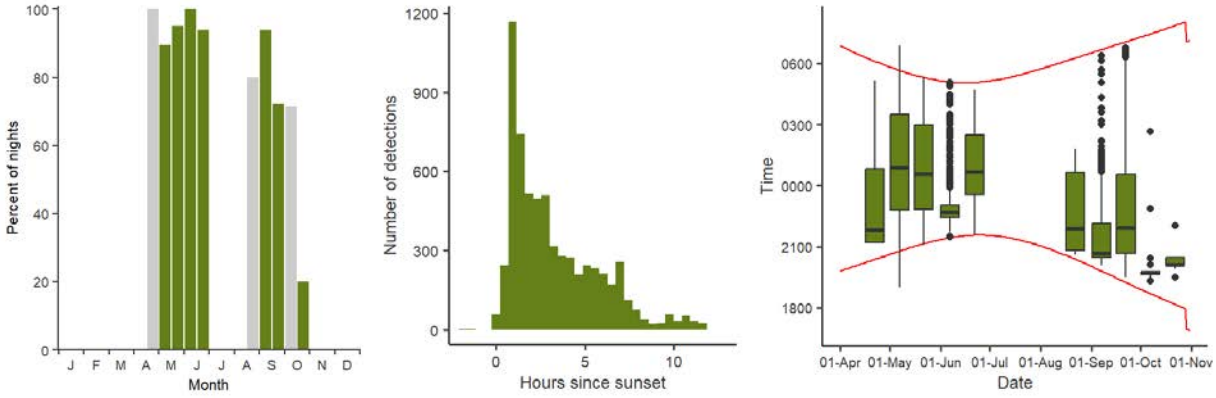
Common Pipistrelle

Common Pipistrelle *Pipistrellus pipistrellus* was recorded on 84 nights, from 24 locations, giving a total of 6,394 recordings.

Spatial pattern of activity



Seasonal and nightly activity

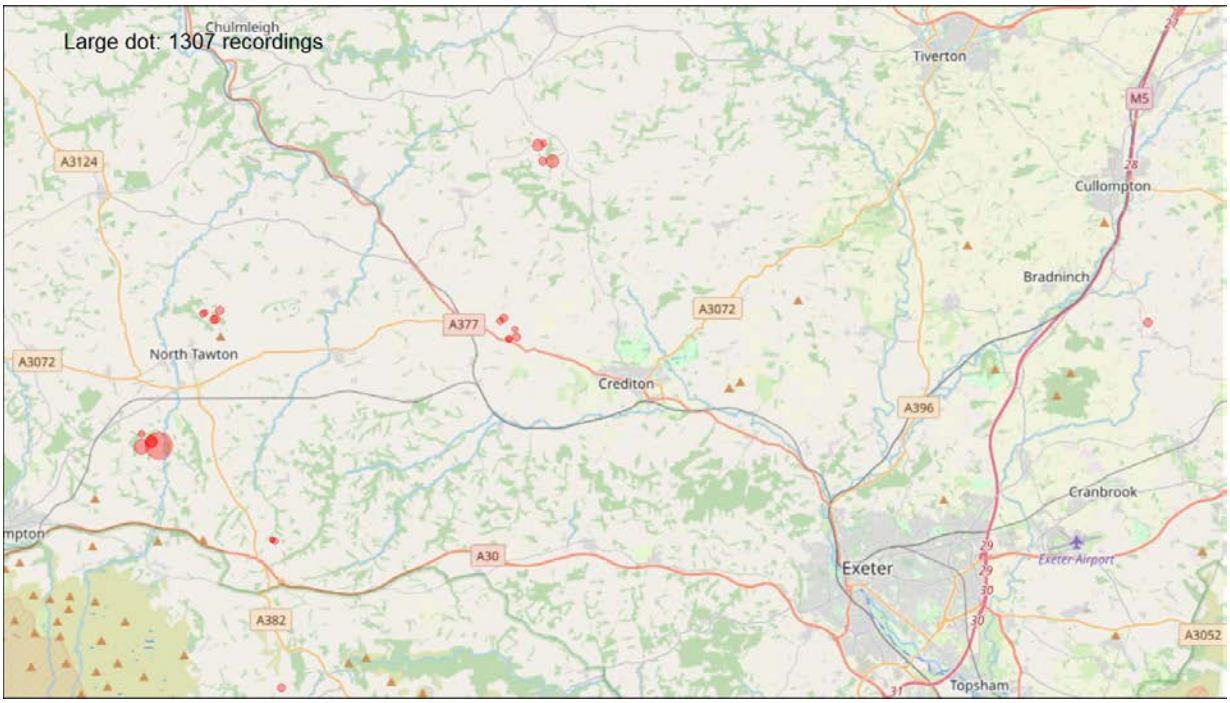


Common Pipistrelle was recorded from 80% of locations from whih it was the most commonly recorded bat species, with 6,394 recordings from 24 different locations. The maximum number of recordings from a night, was 1,396 recorded by Andy Gray on the 26th June. Common Pipistrelle is normally straightforward 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.

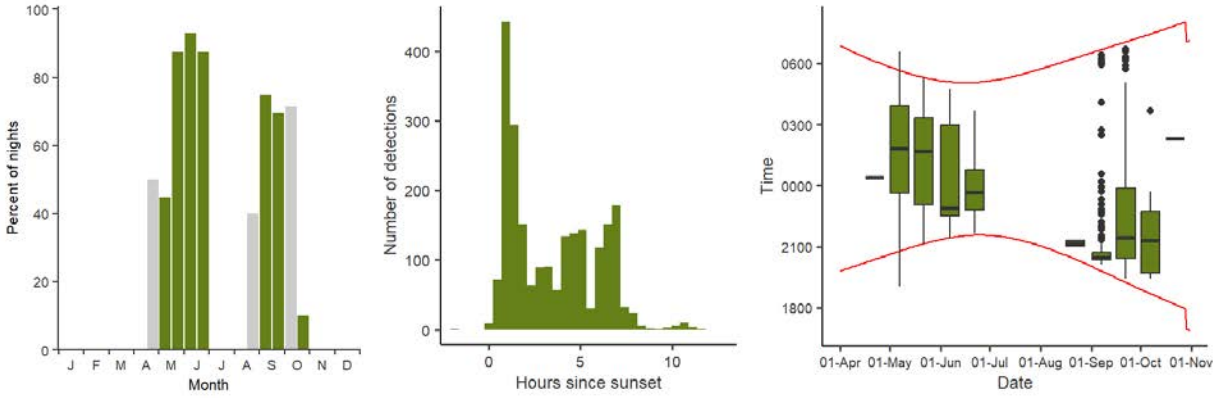
Soprano Pipistrelle

Soprano Pipistrelle *Pipistrellus pygmaeus* was recorded on 77 nights, from 25 locations, giving a total of 2,253 recordings.

Spatial pattern of activity



Seasonal and nightly activity

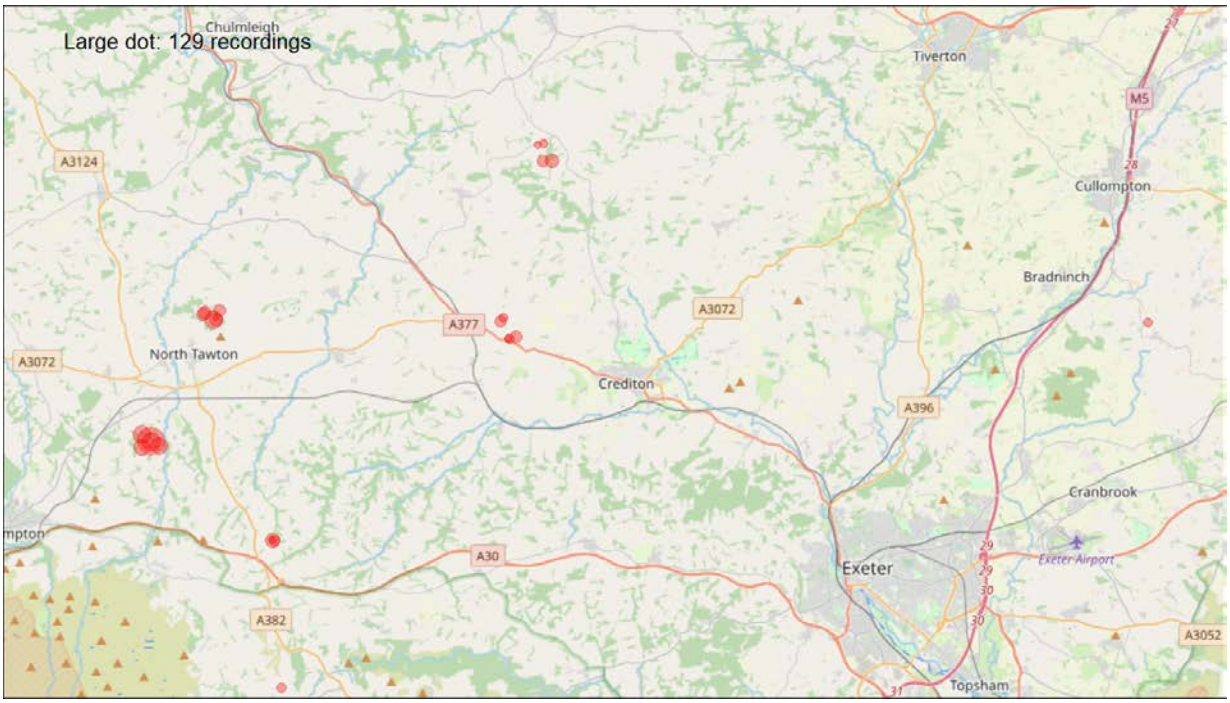


Soprano Pipistrelle was the third most common and widely recorded bat species, with 2,253 recordings from 25 different locations (over 83% of survey locations), but compared with Common Pipistrelle highest activity was more localised. A maximum of 415 recordings of Soprano Pipistrelle were recorded by Sam Bullingham on the night of the 28th May.

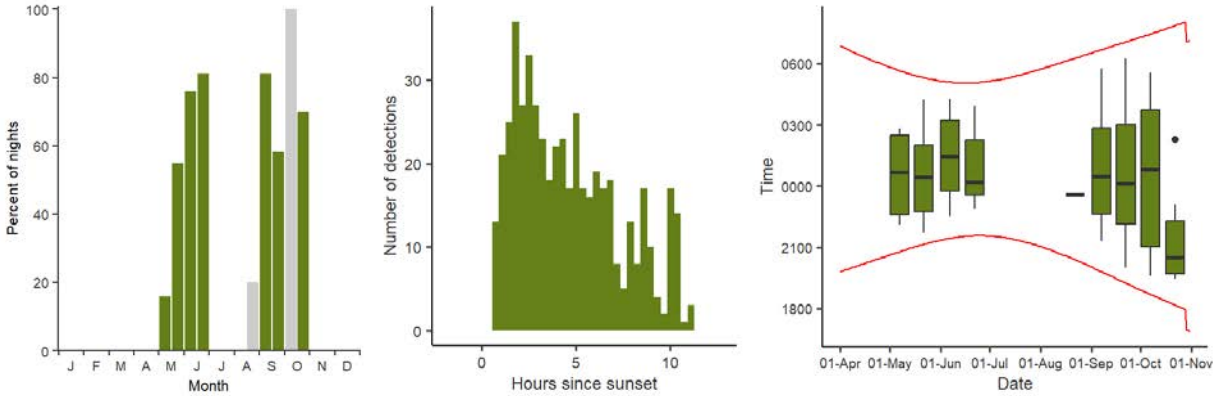
Brown Long-eared Bat

Brown Long-eared Bat *Plecotus auritus* was recorded on 68 nights, from 25 locations, giving a total of 501 recordings.

Spatial pattern of activity



Seasonal and nightly activity

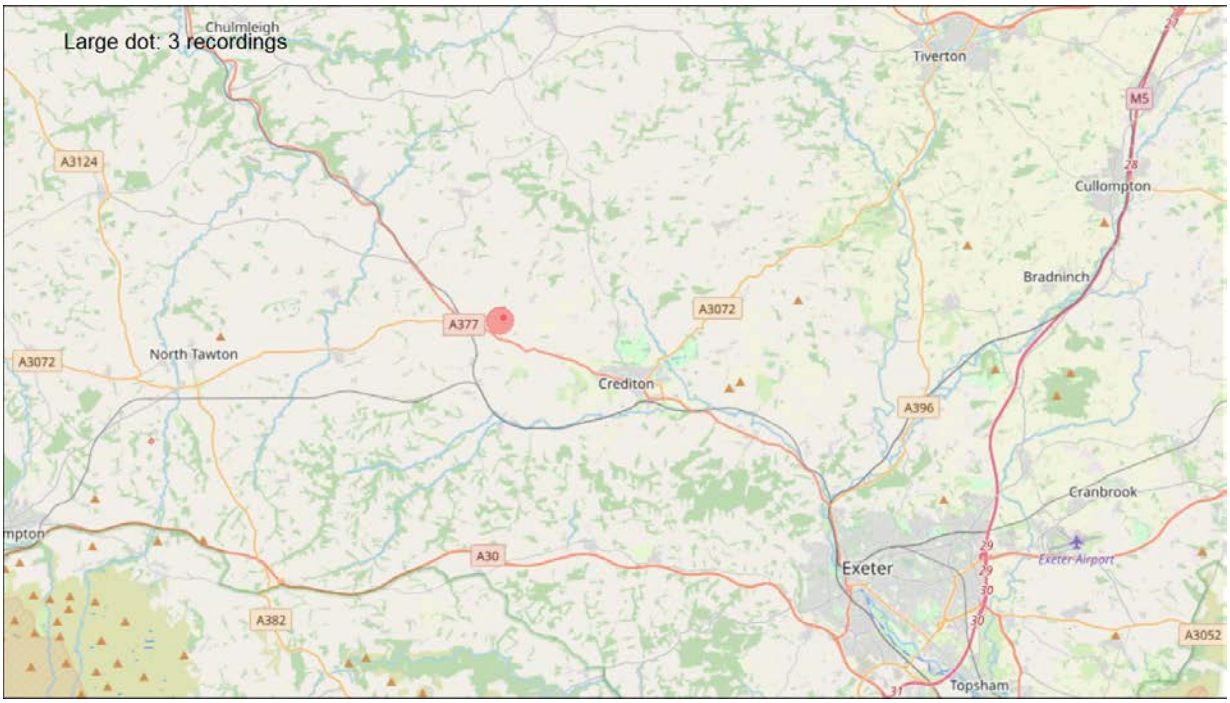


Brown Long-eared Bat was widely recorded across the survey area. The maximum number of recordings a night was 35, from a bat detector deployed by Sam Bullingham on the 17th September. For a visual comparison of the calls of Brown Long-eared Bat and Grey Long-eared Bat of the same call duration (i.e. comparing like with like) see Identification appendix 5.

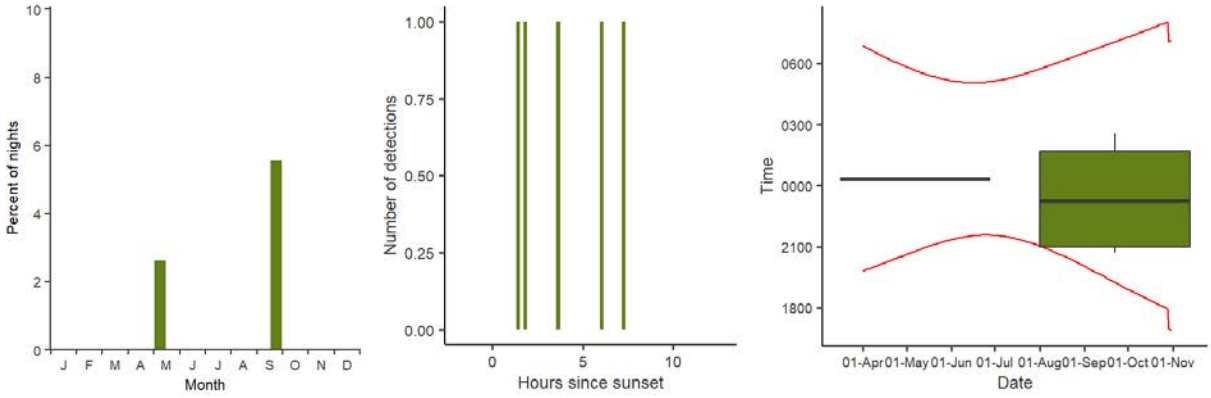
Grey Long-eared Bat

Grey Long-eared Bat *Plecotus austriacus* was recorded on two nights, from three locations, giving a total of 5 recordings.

Spatial pattern of activity



Seasonal and nightly activity

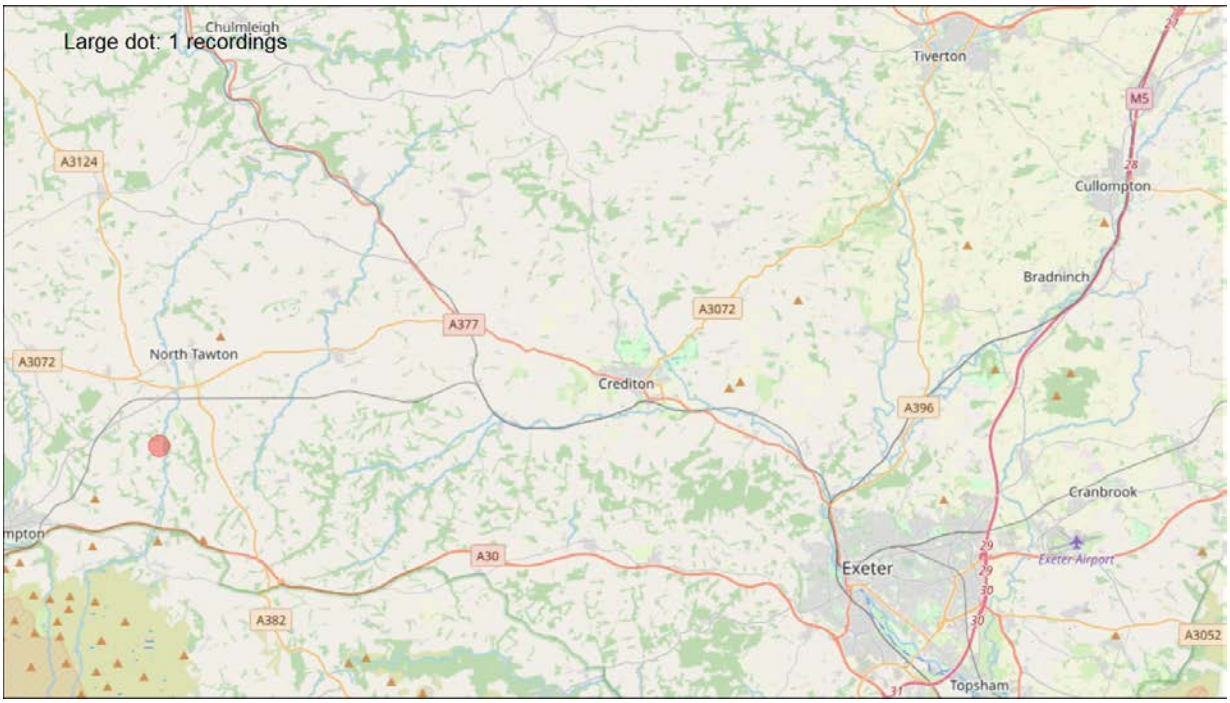


Grey Long-eared Bat was recorded from three locations, of which two locations surveyed by Andy Gray in May and September were close to one another. The third location, comprised just a single recording was recorded by Sam Bullingham. For a visual comparison of the calls of Brown Long-eared Bat and Grey Long-eared Bat of the same call duration (i.e. comparing like with like) see Identification appendix 5.

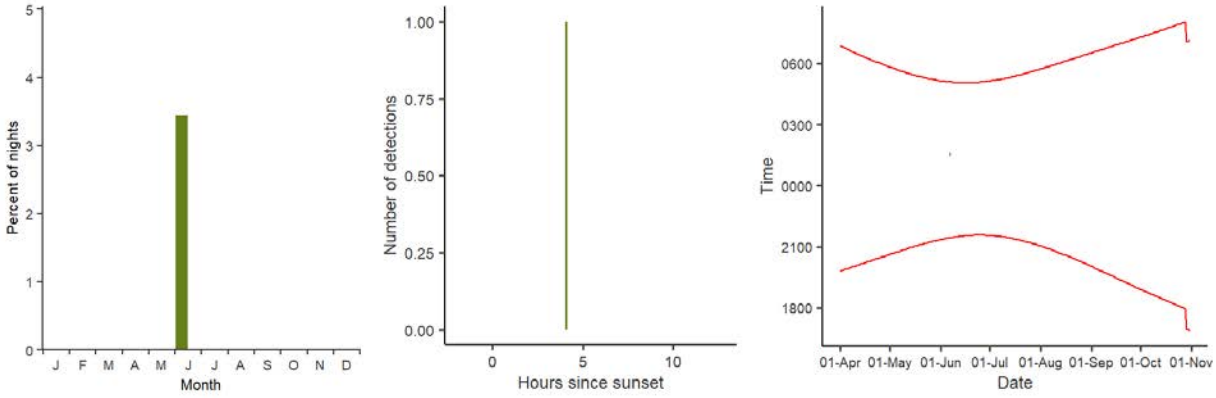
Greater Horseshoe Bat

Greater Horseshoe Bat *Rhinolophus ferrumequinum* was recorded on one night, from one location, giving a total of 1 recordings.

Spatial pattern of activity



Seasonal and nightly activity

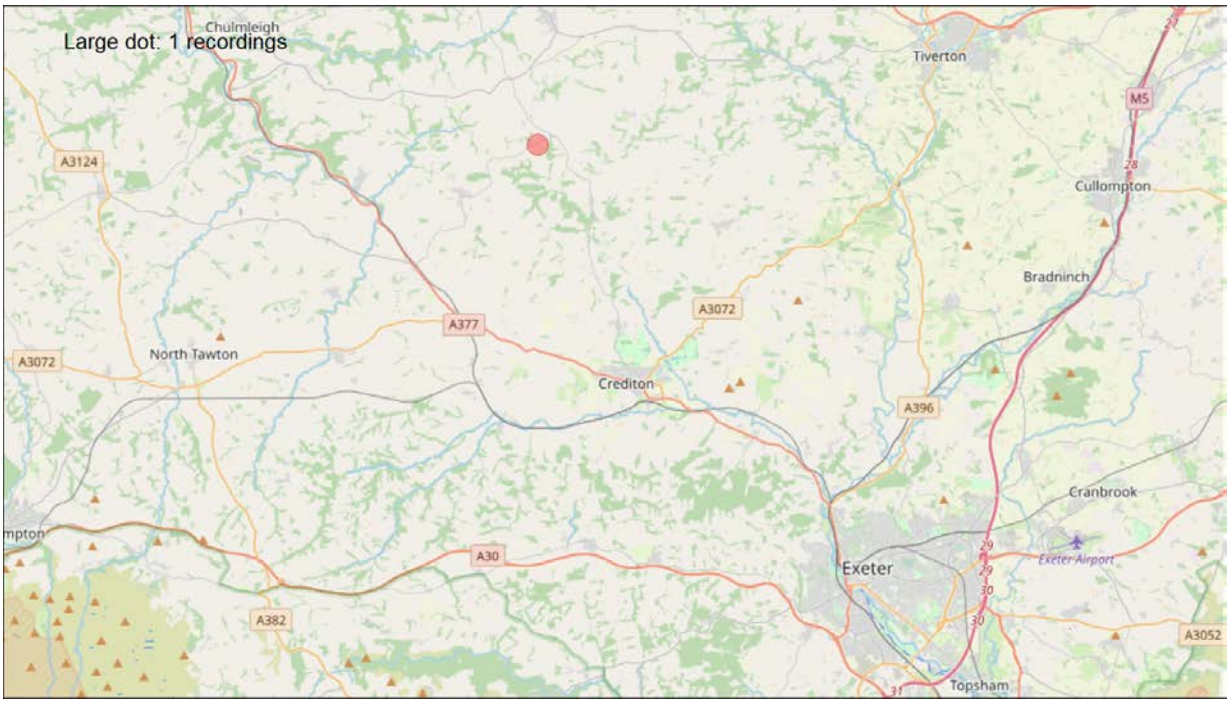


Greater Horseshoe Bat. This is an iconic bat species where there just a single recording made by Sam Bullingham for the project on the 7th June.

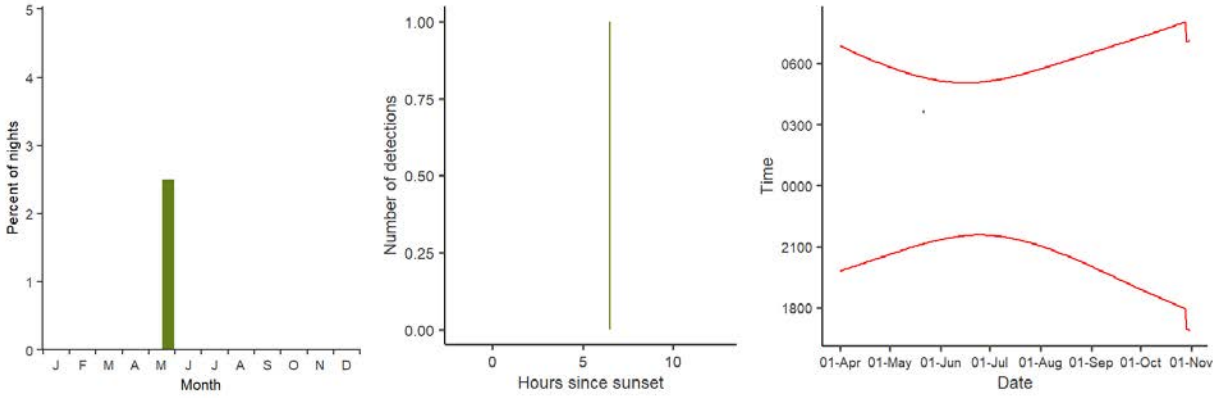
Lesser Horseshoe Bat

Lesser Horseshoe Bat *Rhinolophus hipposideros* was recorded on one night, from one location, giving a total of 1 recordings.

Spatial pattern of activity



Seasonal and nightly activity



Lesser Horseshoe Bat was only recorded from one location (1 recording) by Henrietta Curtis on the 23rd May. This species produces echolocation calls where the maximum (peak) energy is in the range of 107-114 kHz. The only likely confusion species is Greater Horseshoe Bat, but this produces calls with maximum energy in the range of 77-84 kHz.

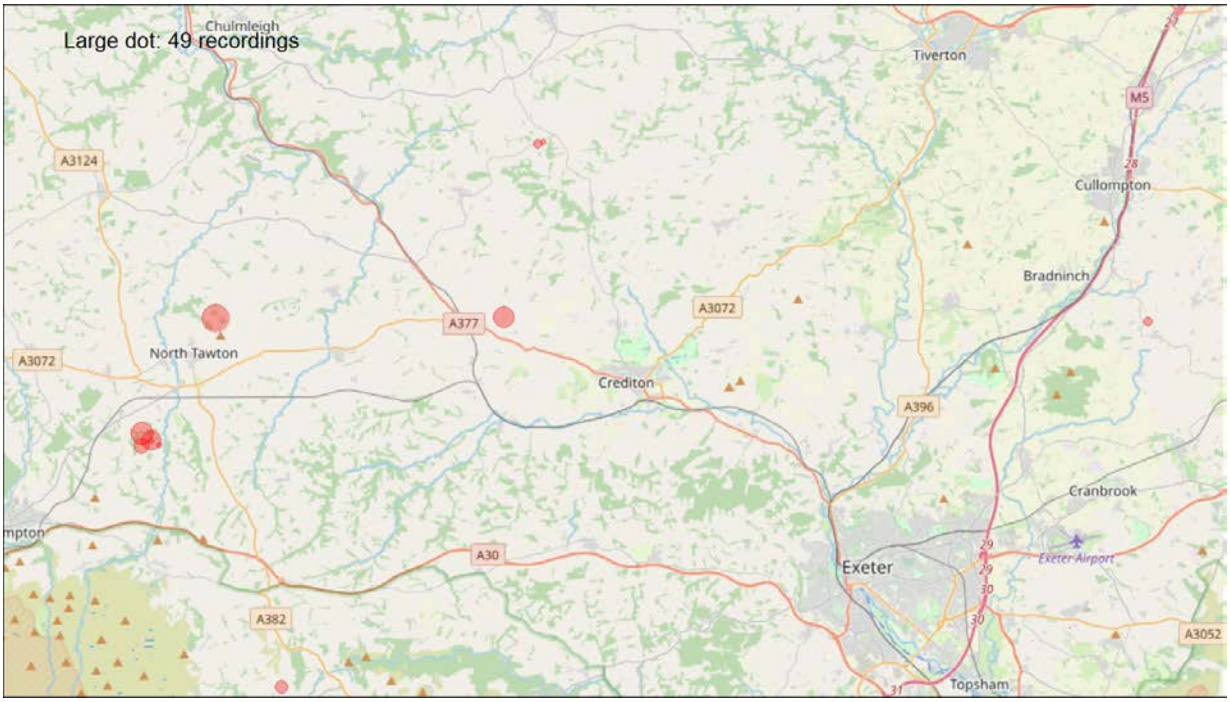
4.3.2 Small terrestrial mammal species

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

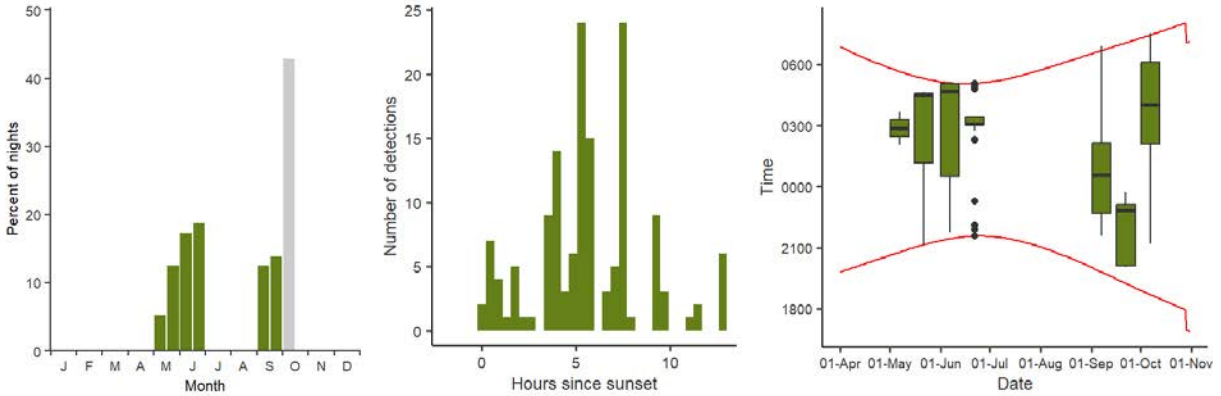
Common Shrew

Common Shrew *Sorex araneus* was recorded on 25 nights, from 11 locations, giving a total of 146 recordings.

Spatial pattern of activity



Seasonal and nightly activity

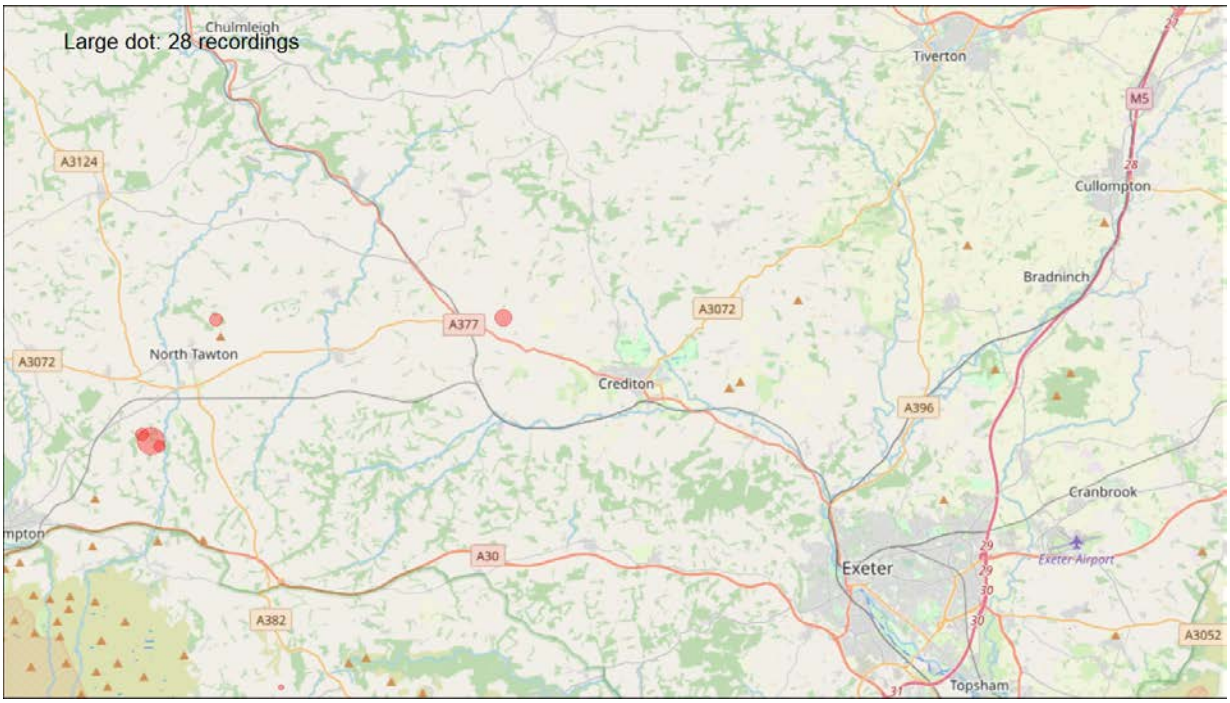


Common Shrew was recorded quite widely across farms taking part in the project in 2023. Common and Pygmy Shrew produce calls that are notably different from those of Rodents in having multiple harmonics that when played slowed down, produces a warbling sound. In most cases it is possible to separate Common Shrew and Pygmy Shrew, the former producing quite simple calls with much less variability in frequency and call structure than the latter. In the case of Common Shrew, the first harmonic (i.e. the fundamental) of the call (if present) ends at around 10 kHz, while the often stronger second harmonic ends at double the frequency to the first (i.e. about 20 kHz). Up to three further harmonics may be recorded, depending on how close the shrew is to the microphone. The complex calls of the Pygmy Shrew, in contrast, 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) and Middleton *et al.*, (2024).

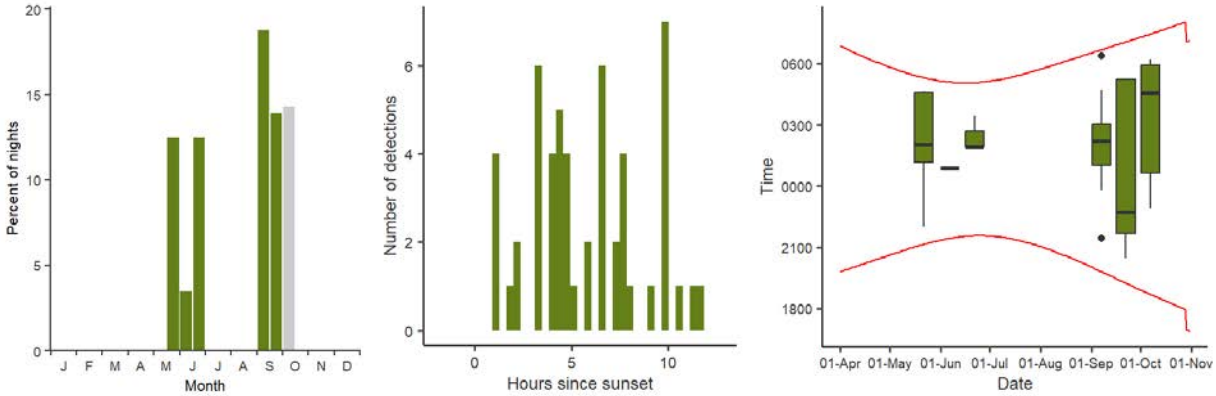
Eurasian Pygmy Shrew

Eurasian Pygmy Shrew *Sorex minutus* was recorded on 17 nights, from six locations, giving a total of 53 recordings.

Spatial pattern of activity



Seasonal and nightly activity



Pygmy Shrew was recorded quite widely during the project, but notable is one location of Sam Bullingham's where this species was recorded most nights that detector was deployed in September, with up a maximum of 9 recordings on one night. As discussed in the previous section (and see Newson *et al*., 2021; Middleton *et al*. 2024), it is normally straightforward to distinguish this species acoustically from Common Shrew.

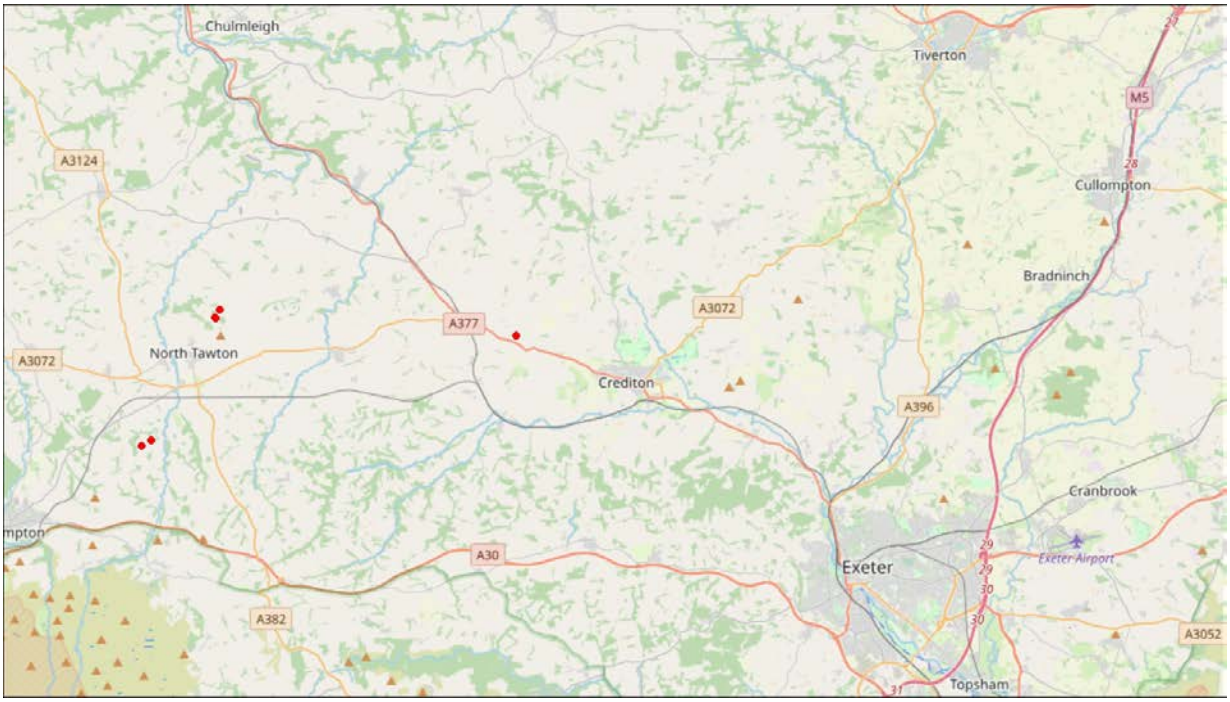
4.3.3 Bush-crickets

Being stationary, and calling for long periods, the number of recordings is not an informative measure of abundance. For this reason, bush-cricket data are shown as presence information rather than activity information.

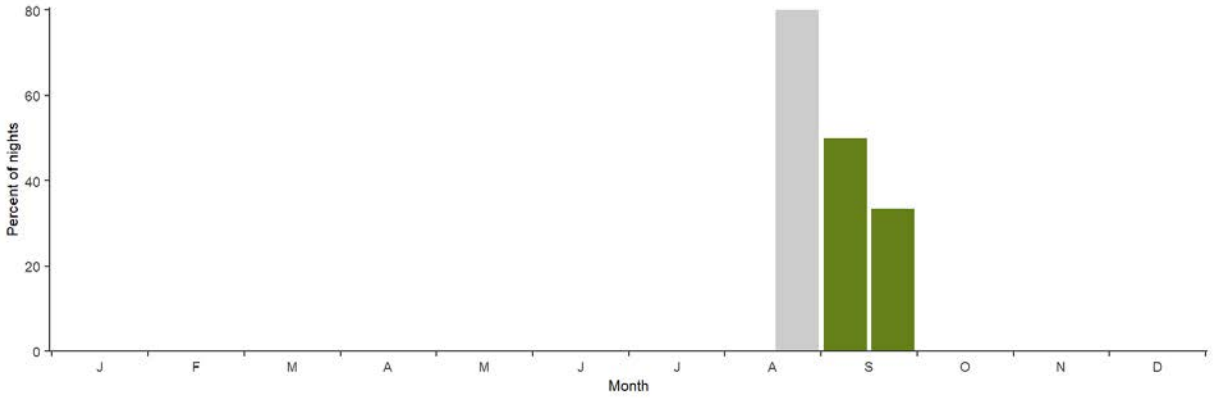
Long-winged Conehead

Long-winged Conehead *Conocephalus fuscus* was recorded on 18 nights, from six locations.

Spatial pattern of detections



Seasonality

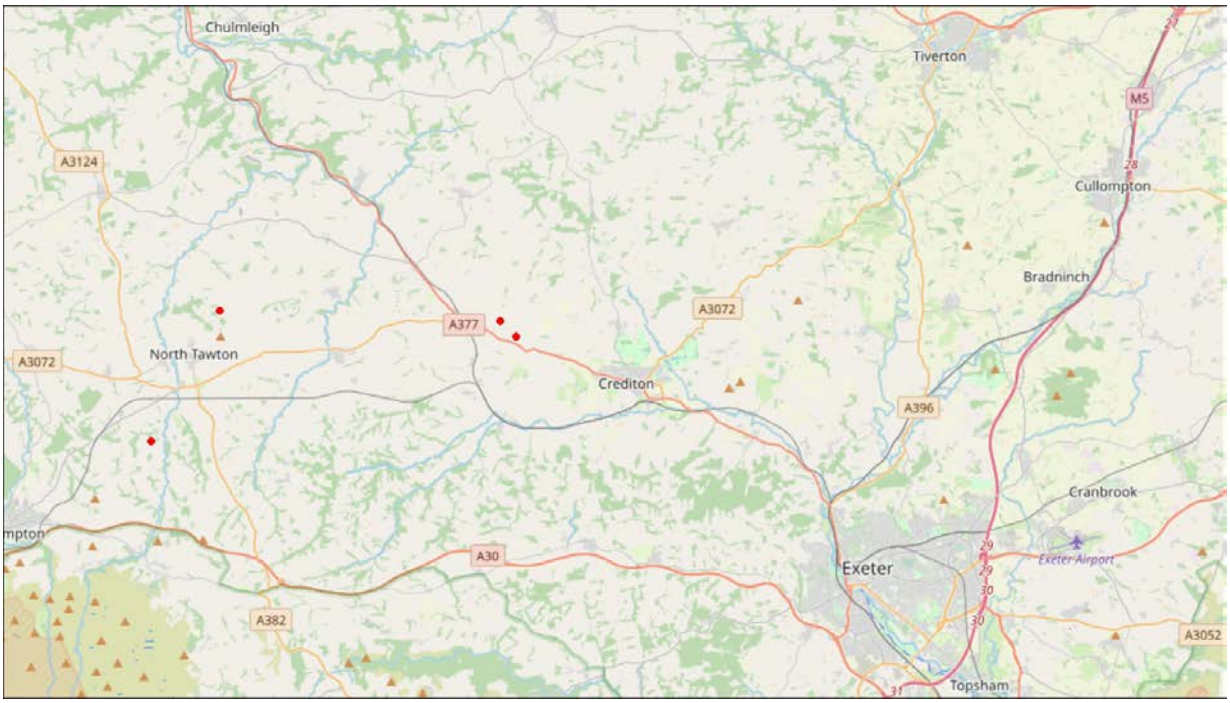


Long-winged Conehead was recorded from a number of farms between between late August and late-September. Long-winged Conehead produces 'calls' with a peak frequency about 26 kHz. It is most similar acoustically to Short-winged Conehead (Middleton 2020), which was not recorded during the project, but Long-winged Conehead produces three-syllable calls (two short calls, pause, followed by one longer duration call).

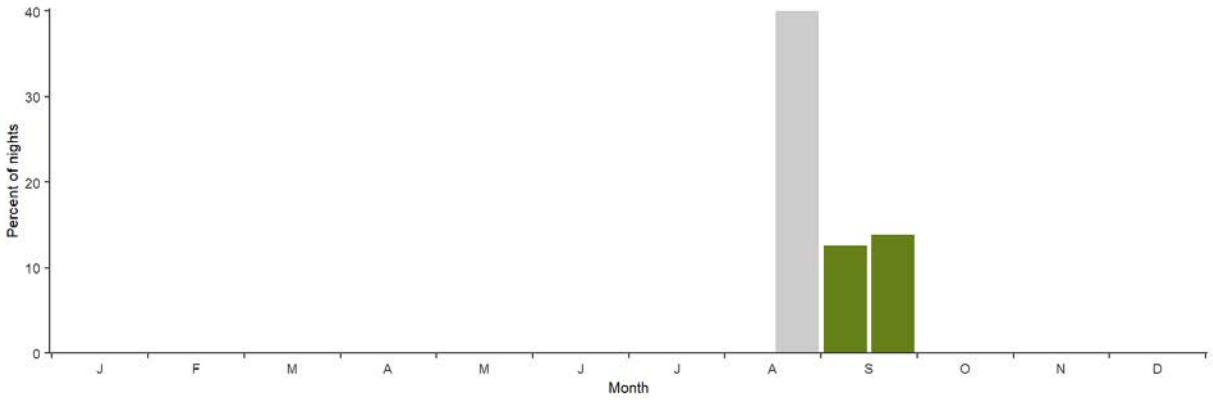
Speckled Bush-cricket

Speckled Bush-cricket *Leptophyes punctatissima* was recorded on nine nights, from four locations.

Spatial pattern of detections



Seasonality

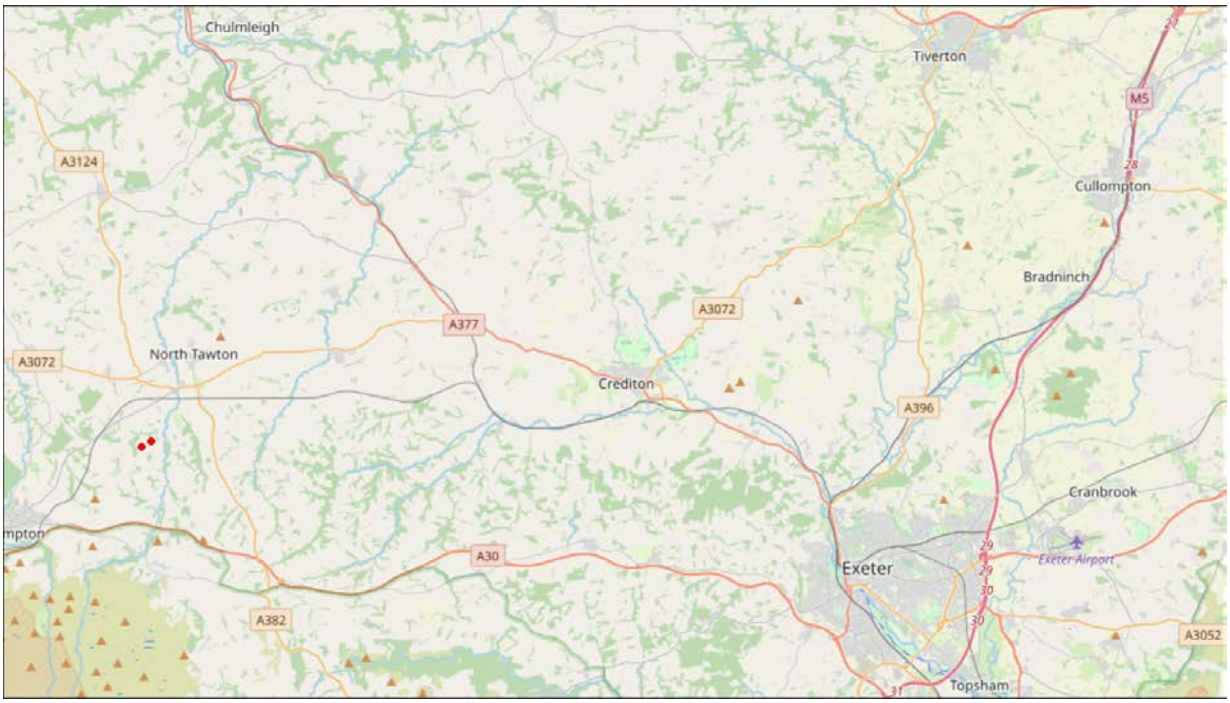


Speckled Bush-cricket were recorded from four locations between the mid-August and late-September. Speckled Bush-cricket produces distinctive multiple syllable calls. There are normally at least five of these, which are isolated, short and are at high frequency, 30-40 kHz. In this species, the female also calls in response to the male, but the calls normally comprise a shorter call sequence.

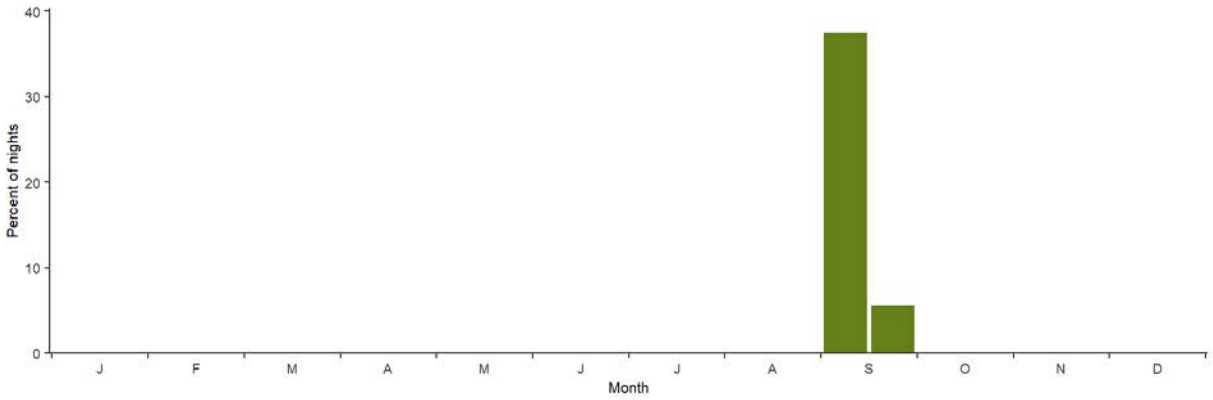
Dark Bush-cricket

Dark Bush-cricket *Pholidoptera griseoaptera* was recorded on five nights, from two locations.

Spatial pattern of detections



Seasonality

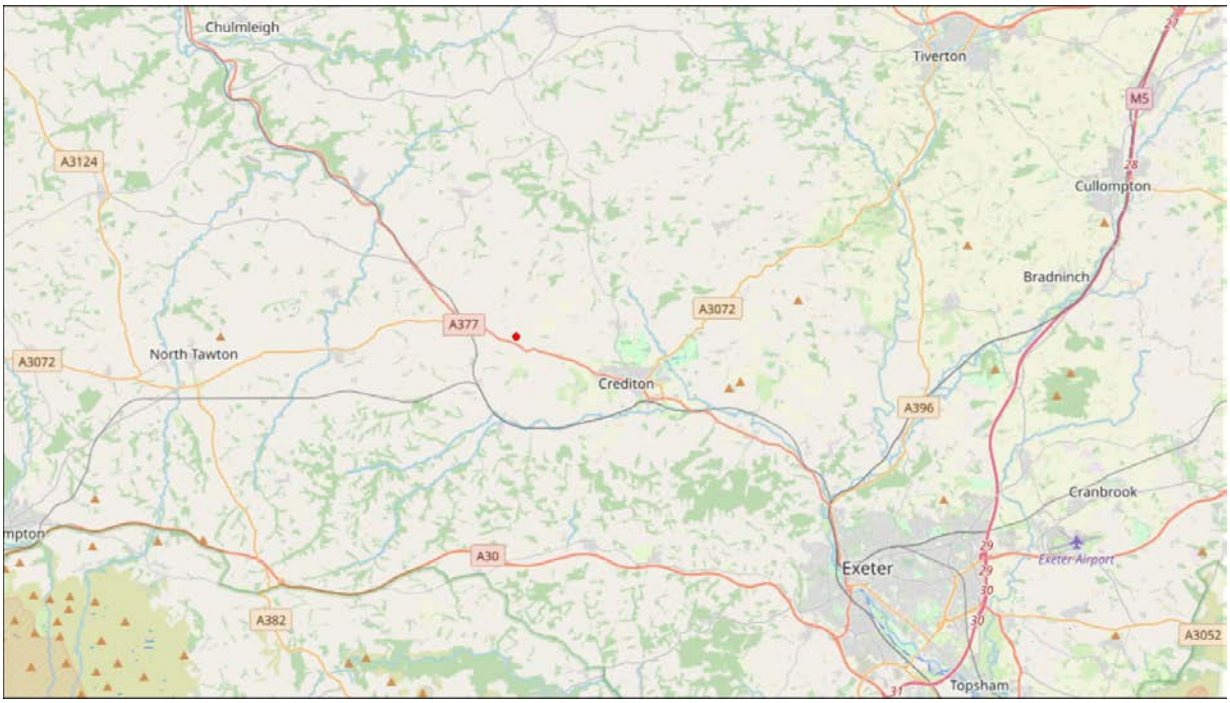


Dark Bush-cricket were recorded from two locations in September. Dark Bush-cricket produces isolated call of 3 syllables (sometimes the first syllable is faint or missing), with a peak frequency of about 12 kHz. This species is typically active during the evening and through the night.

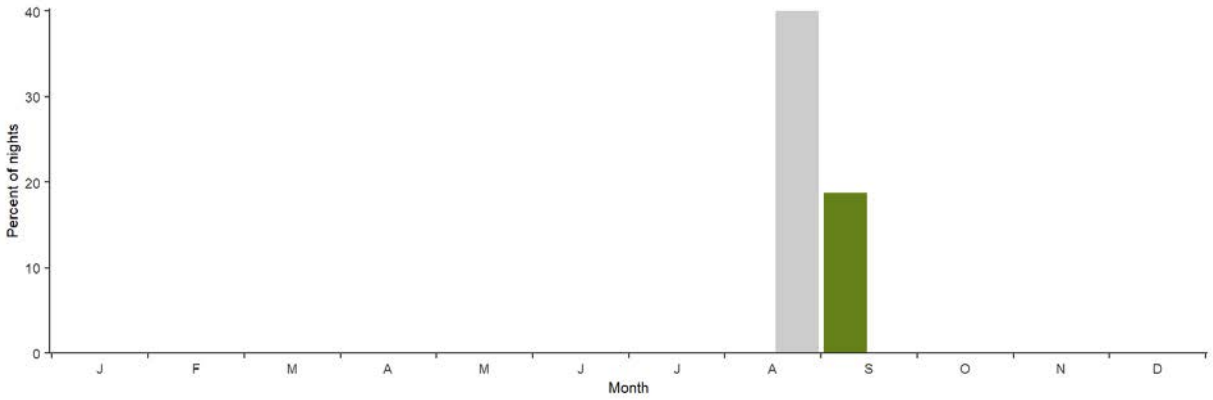
Roesel's Bush-cricket

Roesel's Bush-cricket *Roeseliana roeselii* was recorded on five nights, from one location.

Spatial pattern of detections



Seasonality



Roesel's Bush-cricket were recorded by Andy Gray from one location over five nights in late August and into September. Roesel's Bush-cricket produces 'calls' with a peak frequency about 20 kHz. This species is distinctive in producing simple continuous / regular 'calls'. This species most commonly 'calls' between midday and mid-afternoon, but as here, it can be recorded during the evening and sometimes later in the night.

5. DISCUSSION

5.1 General discussion

Acoustic monitoring has developed as a promising approach for surveying biodiversity and quantifying change (e.g. biodiversity credits), due its potential for low-cost, and scalable data collection (Berger-Tal & Lahoz-Monfort 2018; Gibb *et al*. 2019; Mcloughlin *et al*. 2019; Sugai *et al*. 2019). This has been driven by the development of better hardware which autonomously collects high-quality data, and machine-learning classifiers that allow for rapid identification of acoustic data (Browning *et al*. 2017).

Through this project we demonstrate the possibilities that acoustics using the BTO Acoustic Pipeline (AP) can offer for farmers to self-monitor bats, small mammals and bush-crickets on their land. At the local level, the current dataset of 13,945 bat recordings from a total of 79,375 recordings, has been very valuable in adding to our understanding of patterns of occurrence and activity of bats across farms taking part in the project, but it also adds to our understanding of some other species groups that were recorded as 'by-catch' during bat surveys. This includes three small terrestrial mammal species, comprising 64 recordings of Common Shrew, 56 recordings of Pygmy Shrew and 15 recordings of Brown Rat. For further information on the sound identification of terrestrial small mammals in Britain see Newson *et al*. (2020) and Middleton *et al*. (2024). Four species of bush-crickets - Long-winged Conehead, Roesel's Bush-cricket, Speckled Bush-cricket and Dark Bush-cricket were also recorded.

During the project, results were returned to farmers in the form of csv results file, but we will be adding some new functionality to the BTO Acoustic Pipeline shortly, that will provide various visualisations of the results, which will go some way towards making it easier for farmers to interpret their results.

However, despite the successes of the project, it also highlighted that there remain some substantial barriers to real-world use of acoustic monitoring at scale, due to the lack of accessible tools to aid in survey design, data processing, management and outputs, especially across multiple species groups (August *et al*. 2022). At the moment, validation of records is a necessary, but time-consuming, and specialist process (Barre *et al*. 2019). This adds substantial costs to the conducting acoustic monitoring surveys for specialists, and means non-specialist users lack the resources to choose appropriate machine-learning classifiers and interpret their outputs.

These barriers ultimately mean that users that could benefit most from the advantages of acoustic monitoring (e.g. farmers and other land managers, citizen scientists, developers and NGOs) still need substantial expert input to carry-out projects, negating the cost-saving and accessibility benefits of acoustic monitoring over traditional surveys, such as point counts or roost surveys. Furthermore, lack of standardisation of data processing and outputs from acoustic data means that valuable data cannot feed directly into national monitoring and record schemes without substantial and resource-intensive validation (August *et al*. 2022).

In another confidential / commercially sensitive version of this report, we look in detail at how these can be addressed, and in doing so, we propose a major step-change in acoustic monitoring.

6. ACKNOWLEDGEMENTS

We would like to thank the Devon silvopasture network who took part in Silvopasture Biodiversity project in 2023. We would also like to thank Adham Ashton-Butt, Simon Gillings and Phil Atkinson at the BTO for their input which has helped shape the vision section of the discussion. Lastly we would like to thank Paul Unwin at Innovate UK for managing and supporting us throughout the project, and to the Innovate UK Farming Innovation Programme for funding the project.

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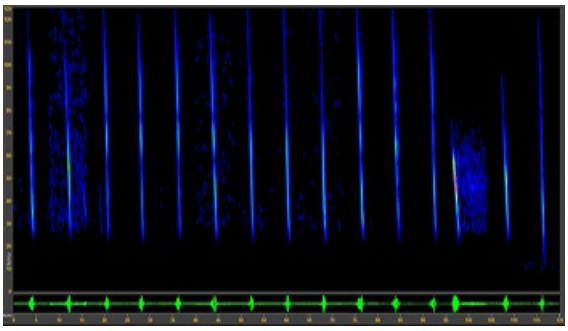
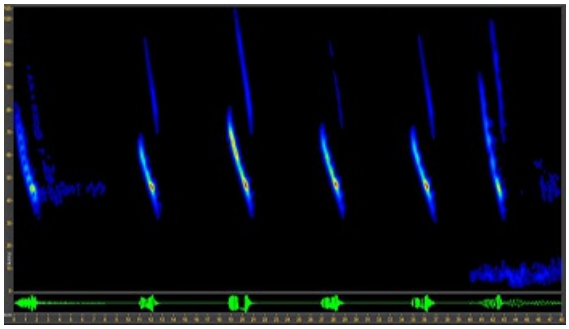
Identification appendix 1: Daubenton's Bat *Myotis daubentonii* and Natterer's Bat *Myotis nattereri*

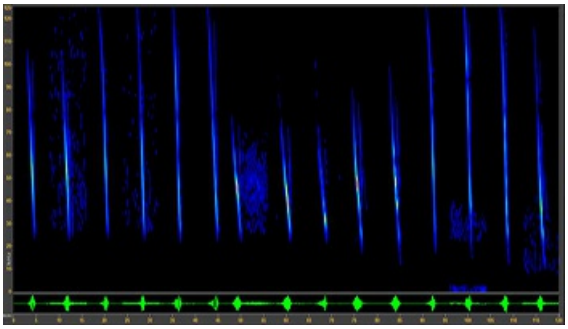
Daubenton's Bat - call duration up to 1.4 ms no examples



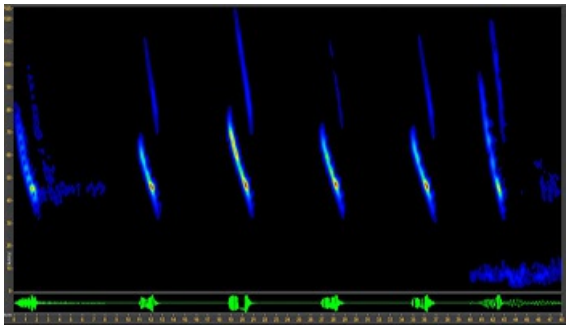
Natterer's Bat - call duration up to 1.4 ms



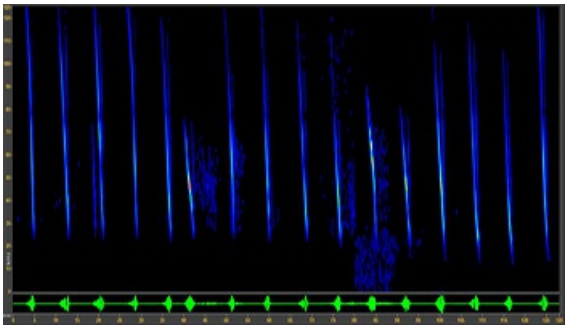
Daubenton's Bat - call duration 1.5-2.0 ms



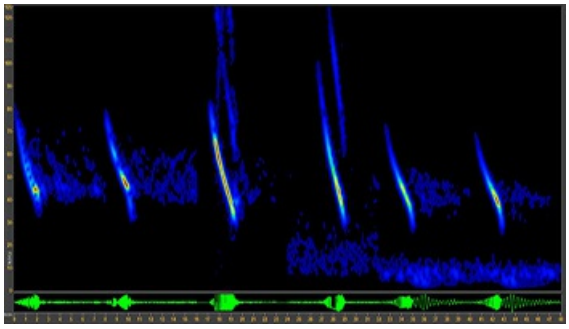
Natterer's Bat - call duration 1.5-2.0 ms



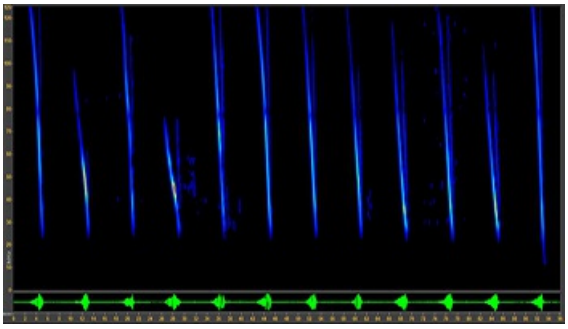
Daubenton's Bat - call duration 2.1-2.3 ms



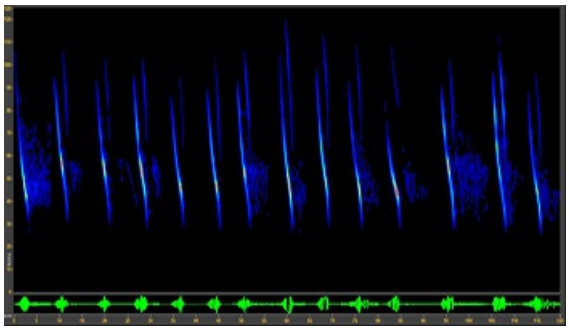
Natterer's Bat - call duration 2.1-2.3 ms



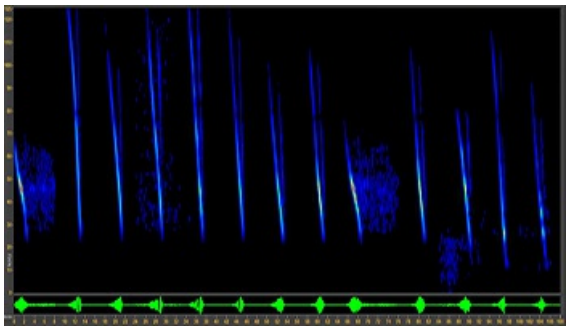
Daubenton's Bat - call duration 2.4-2.5 ms



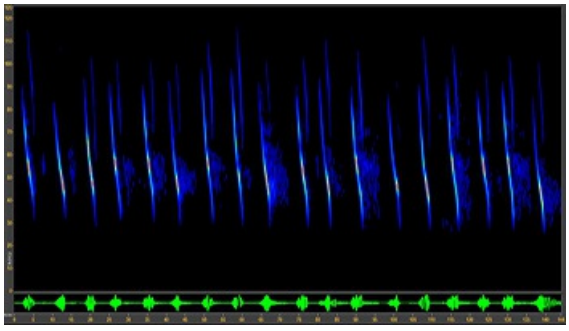
Natterer's Bat - call duration 2.4-2.5 ms



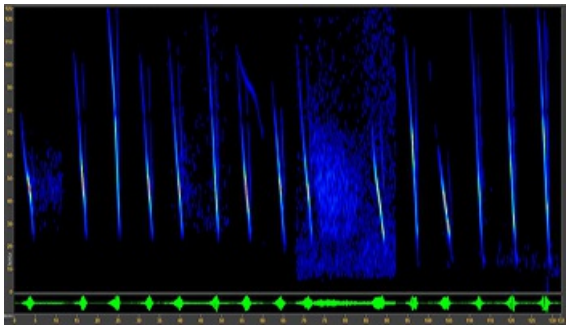
Daubenton's Bat - call duration 2.6-2.7 ms



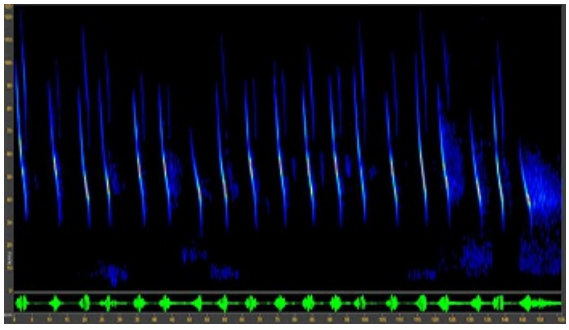
Natterer's Bat - call duration 2.6-2.7 ms



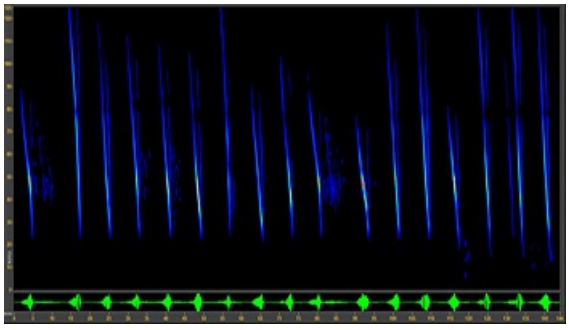
Daubenton's Bat - call duration 2.8-2.9 ms



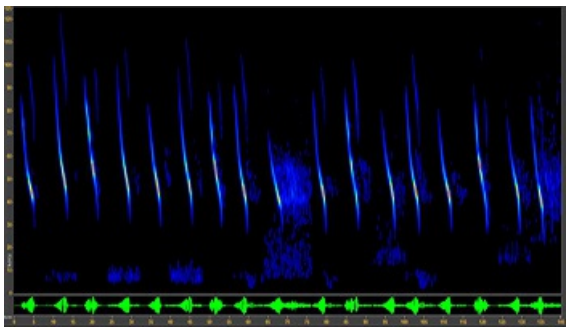
Natterer's Bat - call duration 2.8-2.9 ms



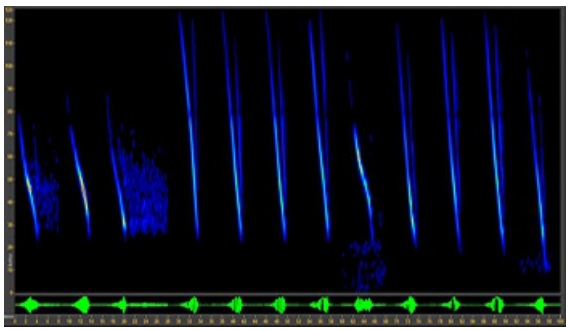
Daubenton's Bat - call duration 3.0-3.1 ms



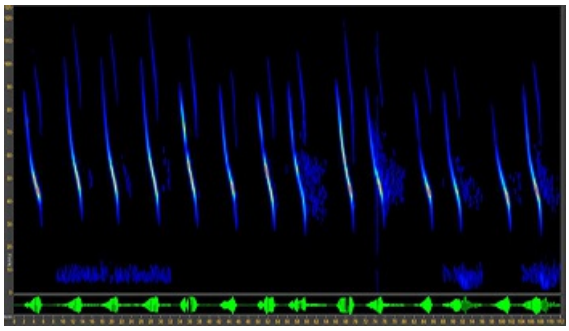
Natterer's Bat - call duration 3.0-3.1 ms



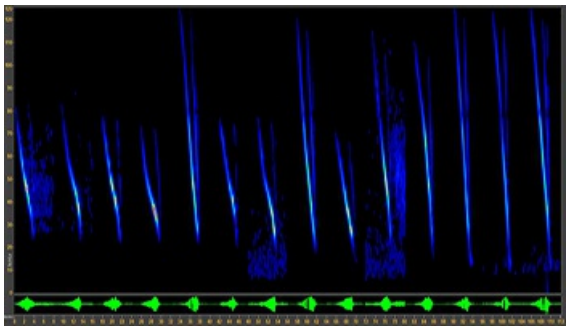
Daubenton's Bat - call duration 3.2-3.3 ms



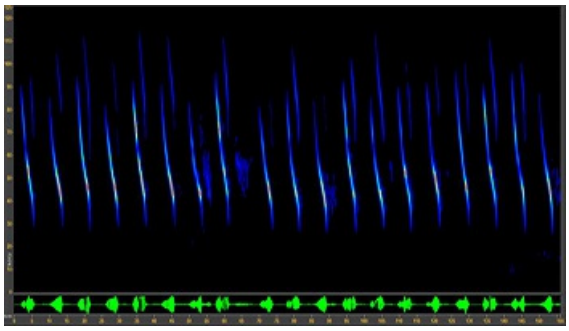
Natterer's Bat - call duration 3.2-3.3 ms



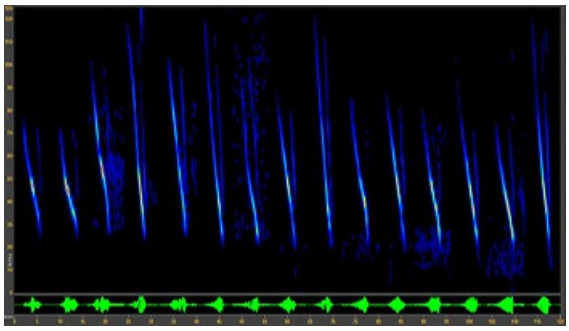
Daubenton's Bat - call duration 3.4-3.5 ms



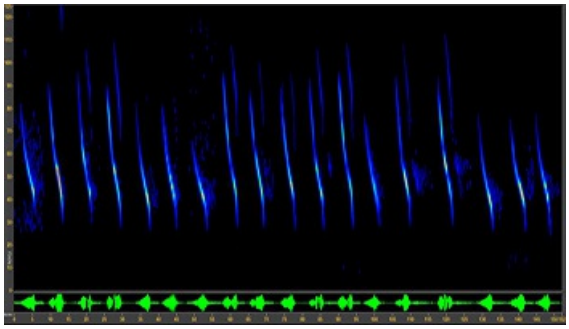
Natterer's Bat - call duration 3.4-3.5 ms



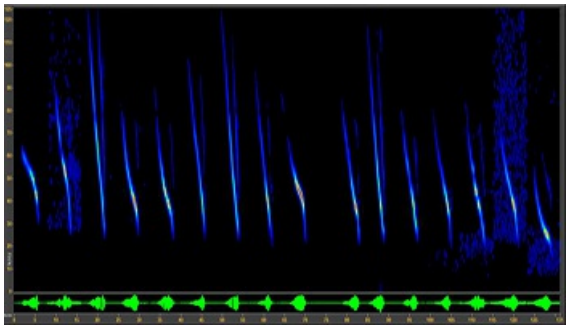
Daubenton's Bat - call duration 3.6-3.7 ms



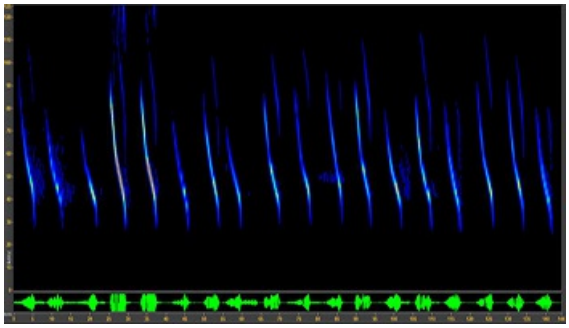
Natterer's Bat - call duration 3.6-3.7 ms



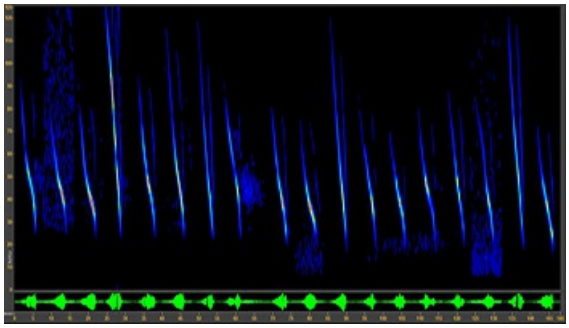
Daubenton's Bat - call duration 3.8-3.9 ms



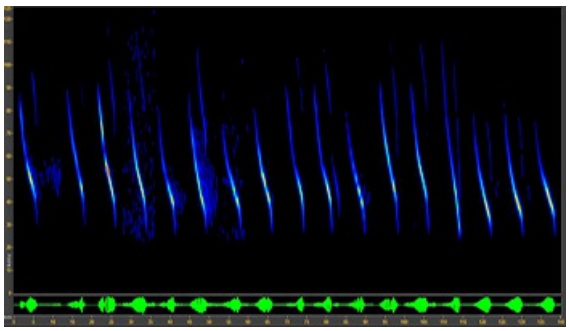
Natterer's Bat - call duration 3.8-3.9 ms



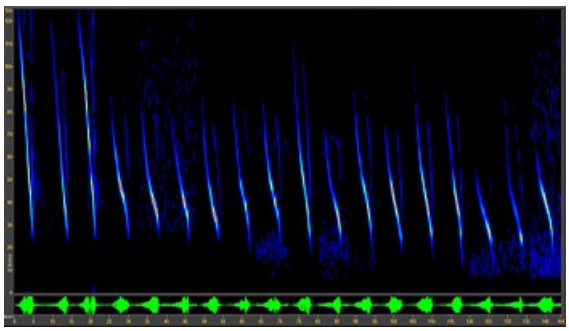
Daubenton's Bat - call duration 4.0-4.1 ms



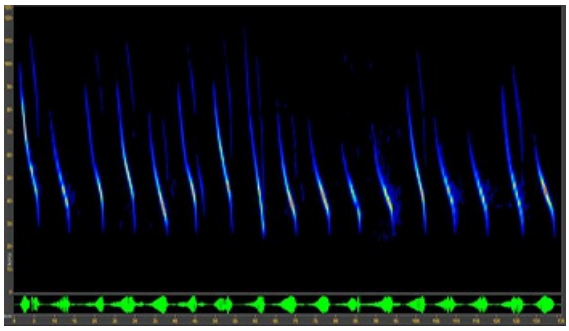
Natterer's Bat - call duration 4.0-4.1 ms



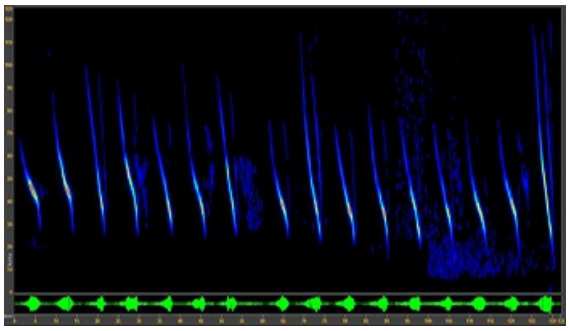
Daubenton's Bat - call duration 4.2-4.3 ms



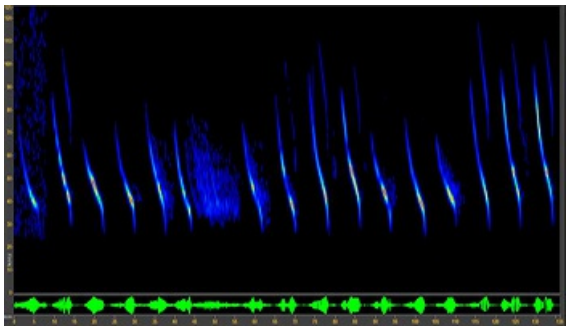
Natterer's Bat - call duration 4.2-4.3 ms



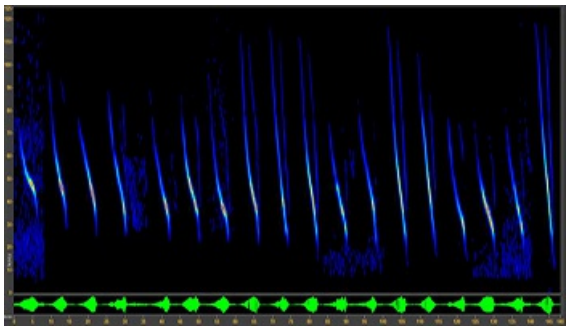
Daubenton's Bat - call duration 4.4-4.5 ms



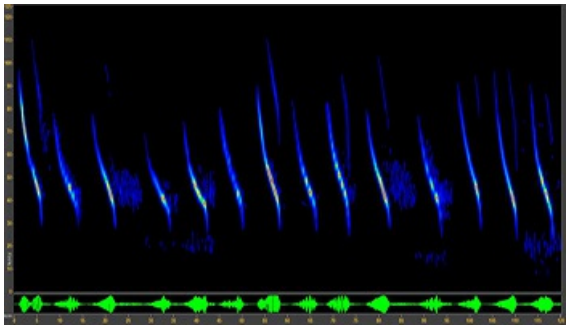
Natterer's Bat - call duration 4.4-4.5 ms



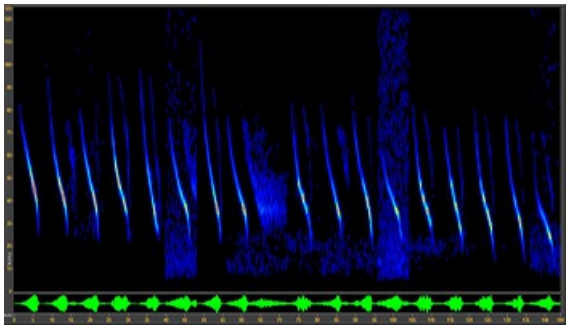
Daubenton's Bat - call duration 4.6-4.7 ms



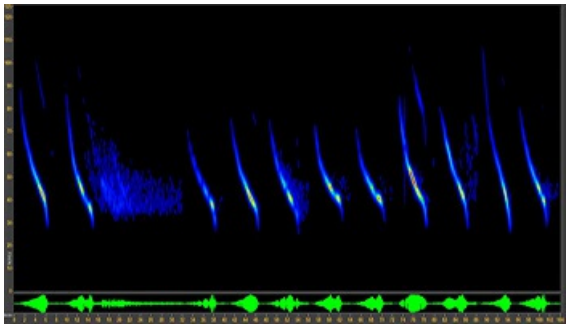
Natterer's Bat - call duration 4.6-4.7 ms



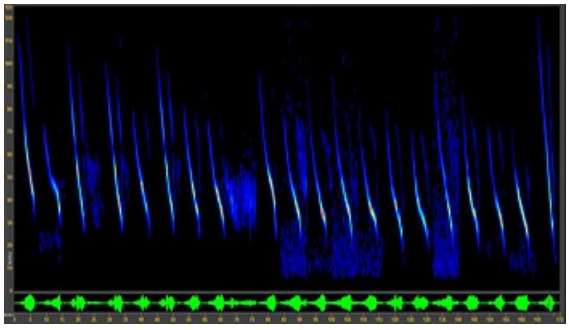
Daubenton's Bat - call duration 4.8-4.9 ms



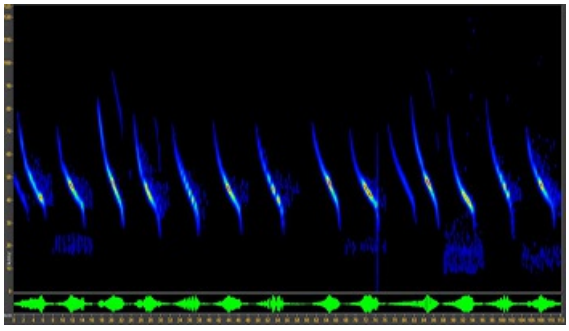
Natterer's Bat - call duration 4.8-4.9 ms



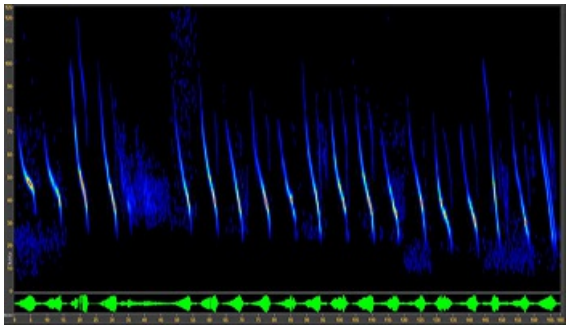
Daubenton's Bat - call duration 5.0-5.1 ms



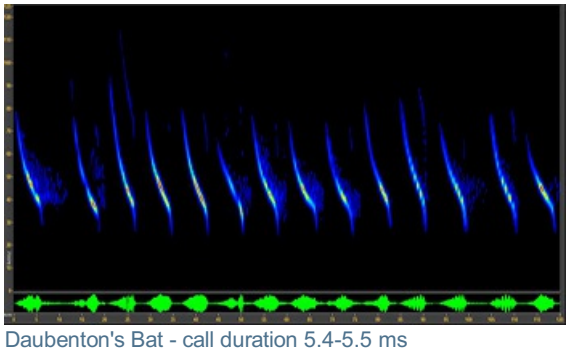
Natterer's Bat - call duration 5.0-5.1 ms



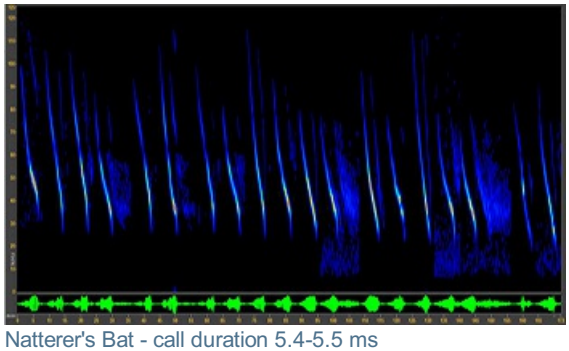
Daubenton's Bat - call duration 5.2-5.3 ms



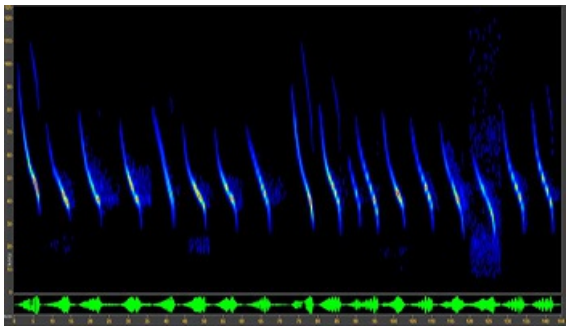
Natterer's Bat - call duration 5.2-5.3 ms



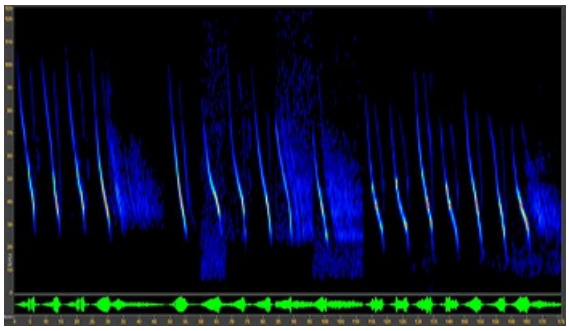
Daubenton's Bat - call duration 5.4-5.5 ms



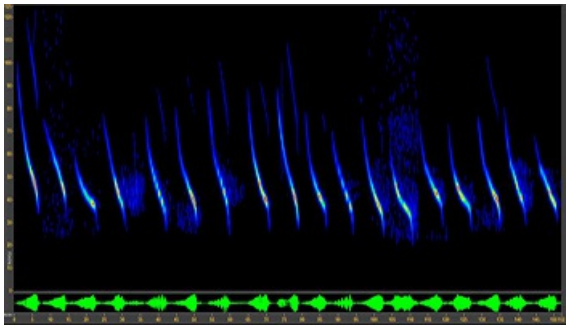
Natterer's Bat - call duration 5.4-5.5 ms



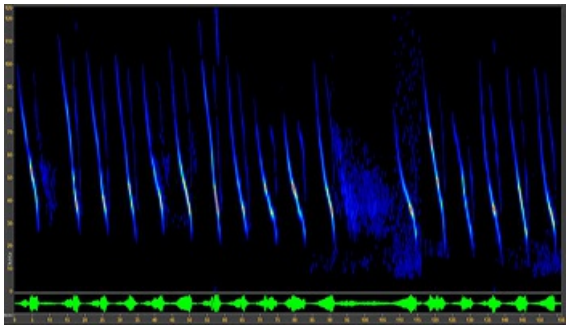
Daubenton's Bat - call duration 5.6-5.7 ms



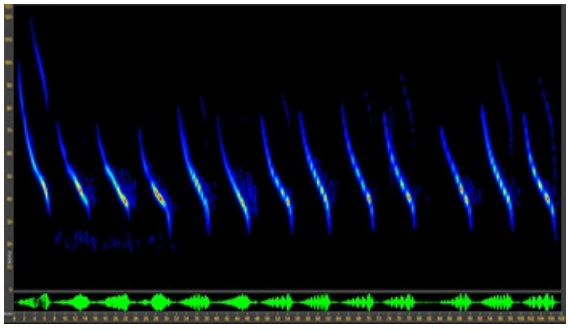
Natterer's Bat - call duration 5.6-5.7 ms



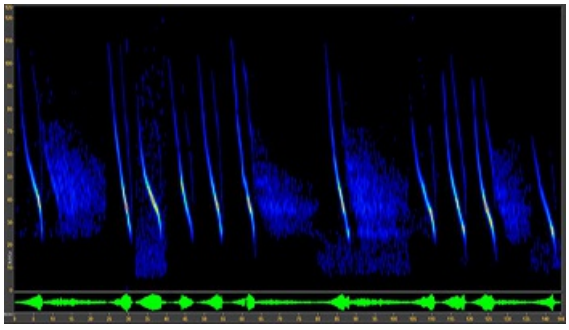
Daubenton's Bat - call duration 5.8-5.9 ms



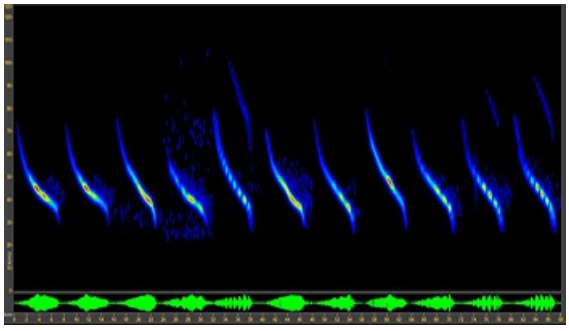
Natterer's Bat - call duration 5.8-5.9 ms



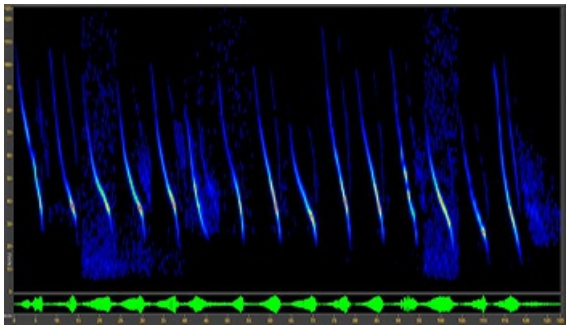
Daubenton's Bat - call duration 6.0-6.1 ms



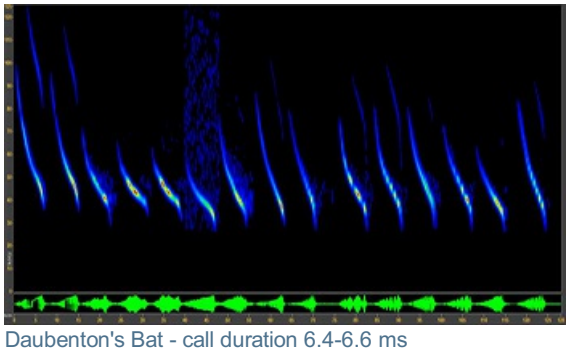
Natterer's Bat - call duration 6.0-6.1 ms



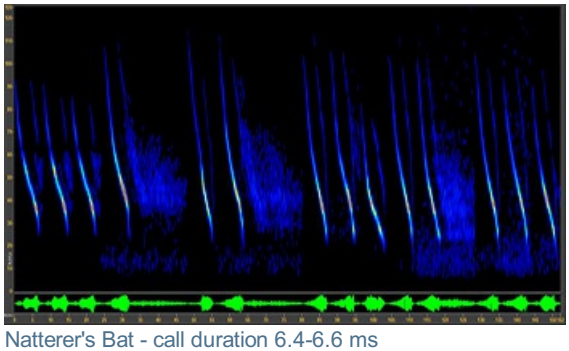
Daubenton's Bat - call duration 6.2-6.3 ms



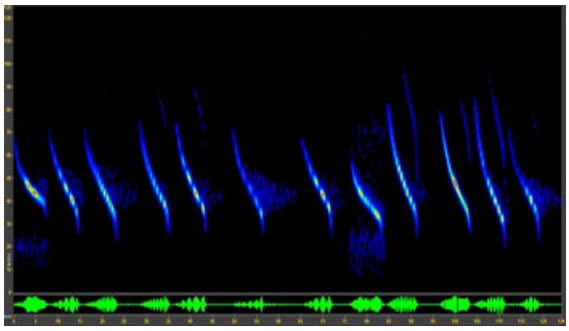
Natterer's Bat - call duration 6.2-6.3 ms



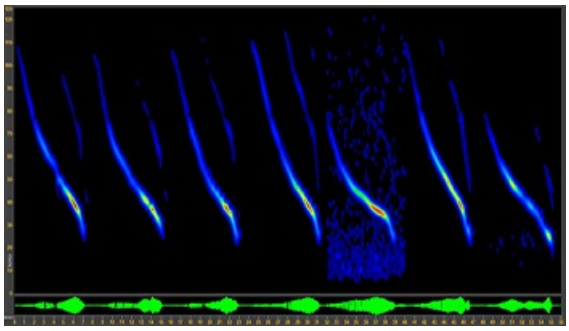
Daubenton's Bat - call duration 6.4-6.6 ms



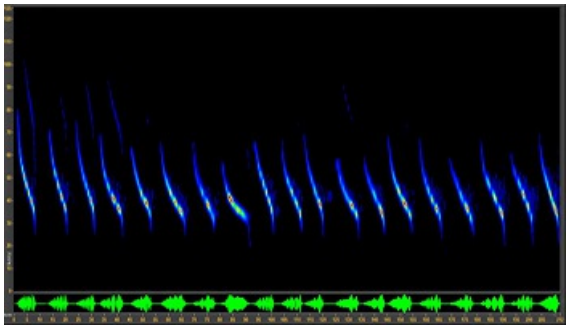
Natterer's Bat - call duration 6.4-6.6 ms



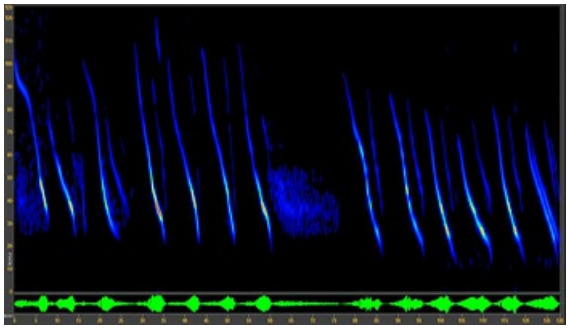
Daubenton's Bat - call duration 6.7-6.8 ms



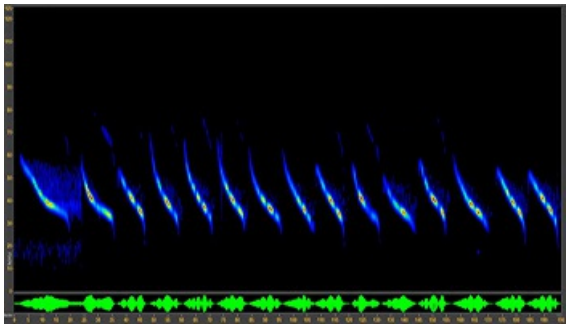
Natterer's Bat - call duration 6.7-6.8 ms



Daubenton's Bat - call duration 6.9-9.5 ms



Natterer's Bat - call duration 6.9-9.5 ms



Daubenton's Bat - call duration 9.6-17.3 ms

Natterer's Bat - call duration 9.6-17.3 ms no examples

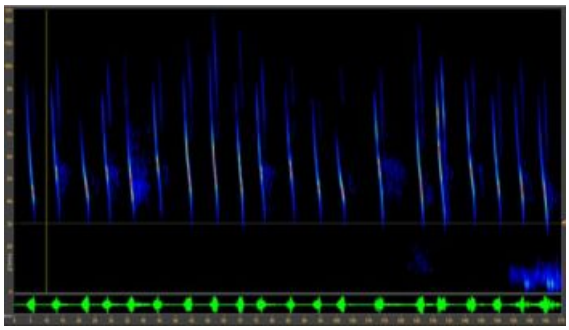
Identification appendix 2: Whiskered/Brandt's Bat *Myotis mystacinus/brandtii*

When it comes to the sound identification of bats in the genus *Myotis*, there is a common view that it is not possible to assign recordings to species, even among experienced bat workers. In the following, we would like to explain, with a recording of Whiskered Bat or Brandt's Bat, some of our thinking on how we approach an identification.

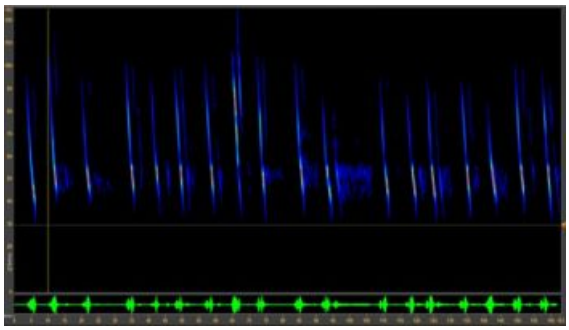
Given a *Myotis* recording, an important first consideration is the quality of the recording. Firstly, to consider whether there is significant overloading across calls that makes it difficult to determine the start and end of the calls. There is a bit of overloading in a few of the recordings of Whiskered or Brandt's Bat recordings shown in the main part of the report, but this is not extreme, and there are some good quality calls still in the sequence.

The next important consideration is to look at the ends of the calls, and to determine whether there is important attenuation of the weaker ends of the calls - in other words, whether you are missing the ends of the calls. Where there is attenuation of the calls, the apparent ends of the calls may appear to be higher in frequency than is really the case, and the start of the calls lower in frequency than is really the case. If there is important attenuation of the calls, it is often necessary to stop at this point and to not go further with an identification.

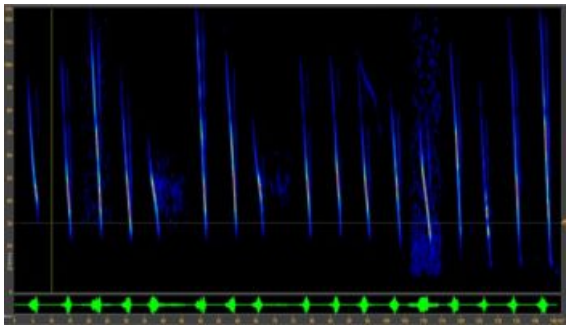
If the quality of the recordings and calls is good, we would normally expect to have a good idea of what species produced it, but it is helpful next to consider what you would expect calls of that species, given that call duration to look like, and to consider how this compares with other similar species. Just to illustrate, in the below I compare one good call from a recording of Whiskered Bat or Brandt's Bat (call shown left of the yellow vertical line in all the spectrograms below), with known calls for other *Myotis* species (compiled recordings made from known species recordings using the Sonobat Reference Compiler). Taking this approach for the recordings above, it is straightforward to see that the recordings above are well outside what you would expect for Natterer's Bat and Alcathoe bat. The difference between short duration calls of Daubenton's Bat and the presumed Whiskered / Brandt's Bat is more subtle. In Whiskered / Brandt's Bat for calls of this duration there tends to be a long and steep neck to calls and kink in the calls towards the bottom. This can be seen in Daubenton's Bat, but it is not so typical for this species, and would be usual for such calls to present across a sequence of calls without some additional clues to the real identification. The chance of seeing atypical calls is less likely again, where there is more than one recording at almost the same time of what is likely to be the same bat as seen here.



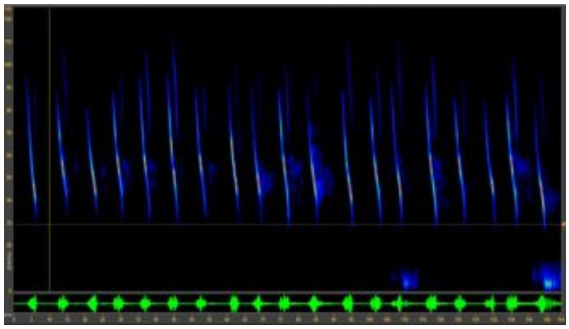
Whiskered or Brandt's Bat call (left), against known Whiskered calls (right)



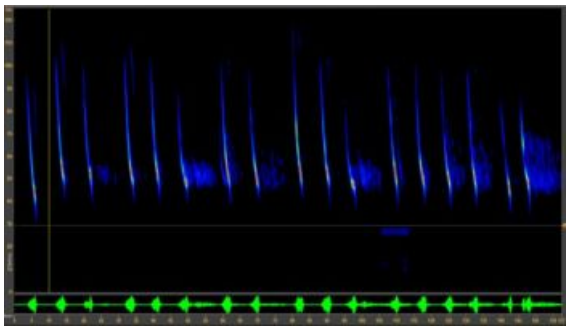
Whiskered or Brandt's Bat call (left), against known Brandt's Bat calls (right)



Whiskered or Brandt's Bat call (left), against Natterer's Bat calls (right)



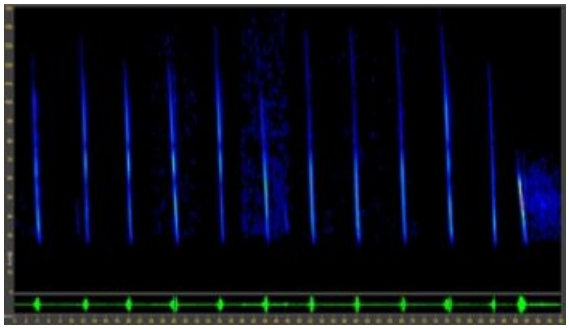
Whiskered or Brandt's Bat call (left), against known Daubenton's Bat calls (right)



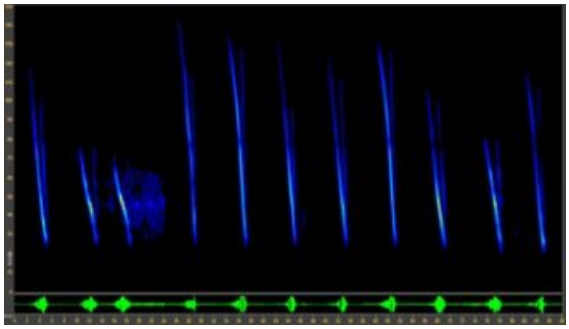
Whiskered or Brandt's Bat call (left), against known Alcathoe Bat calls (right)

Identification appendix 3: Natterer's Bat *Myotis nattereri*

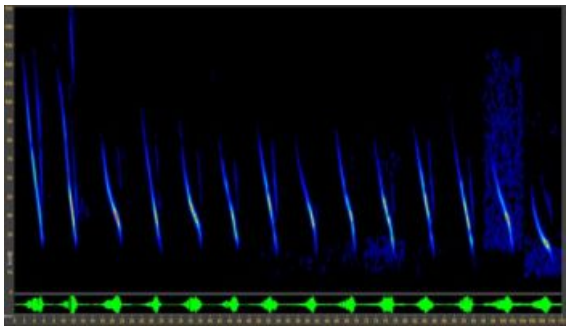
As with Whiskered and Brandt's Bat, the first consideration when looking at recordings is the quality of the recording, to consider whether the quality is good enough to try to assign the recording to species. Given a good recording, Natterer's Bat can occasionally produce atypical calls that could be mistaken for other *Myotis* species. However, such unusual calls rarely continue for long, and careful consideration of these, and in relation to neighbouring recordings where these are present to understand what is going on, should be sufficient in most cases to be able to assign these to species. 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 to long duration calls produced when flying in the open.



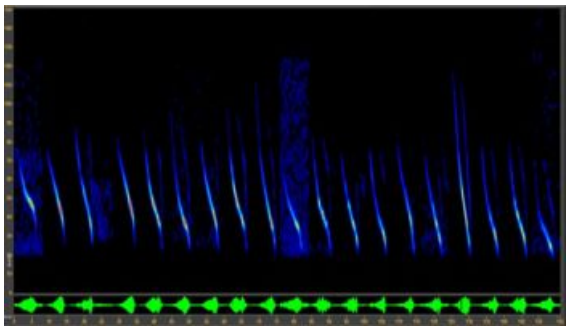
Natterer's Bat - call duration up to 1.2 ms



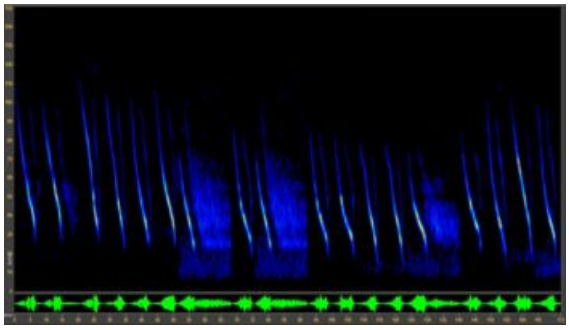
Natterer's Bat - call duration 2.7-2.8 ms



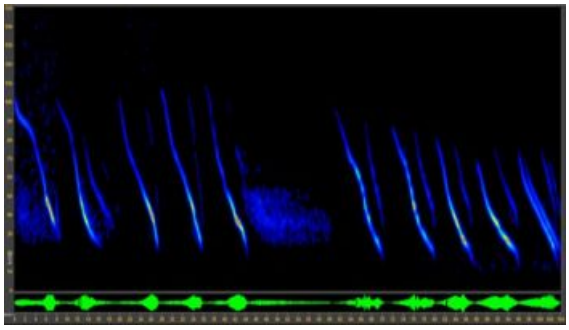
Natterer's Bat - call duration 3.9-4.0 ms



Natterer's Bat - call duration 4.9-5.0 ms

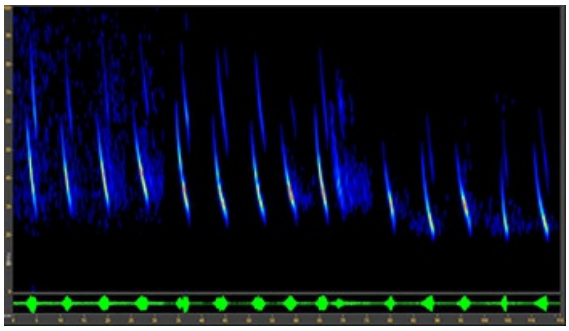


Natterer's Bat - call duration 5.9-6.0 ms

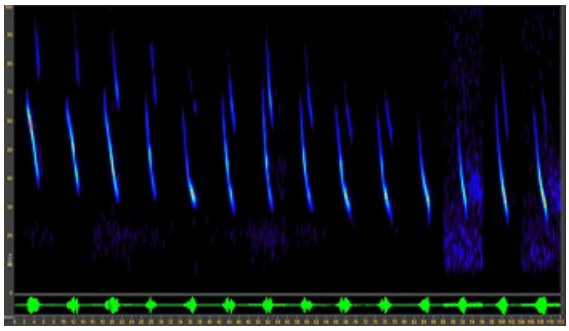


Natterer's Bat - call duration 7.1-9.4 ms

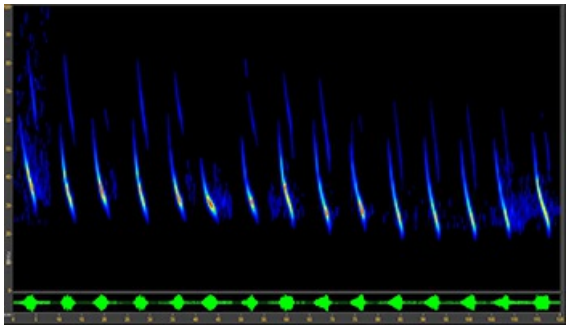
Identification appendix 4: Common Noctule *Nyctalus noctula* and Leisler's Bat *Nyctalus leisleri*



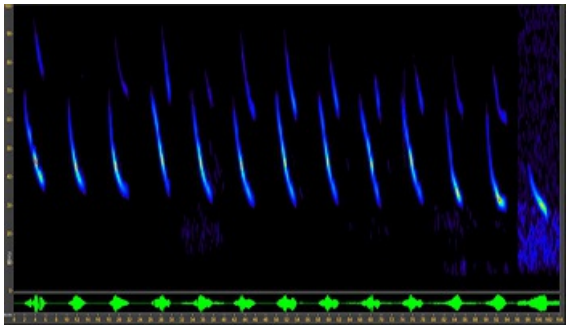
Common Noctule - call duration 1.4-3.0 ms



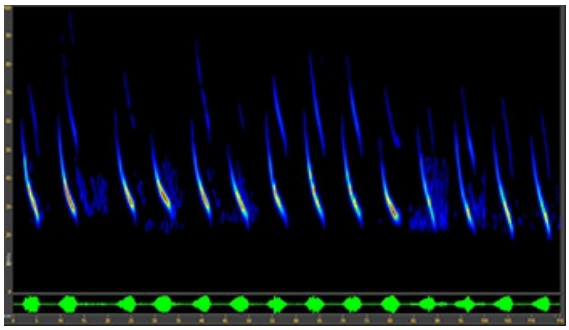
Leisler's Bat - call duration 1.4-3.0 ms



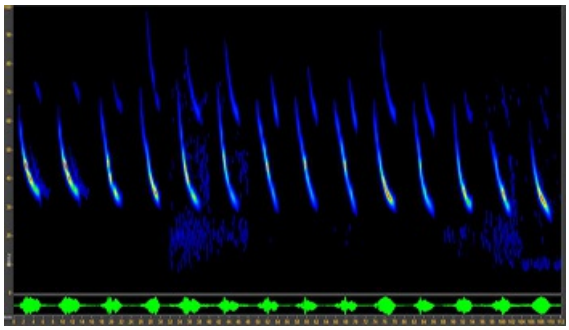
Common Noctule - call duration 3.1-3.7 ms



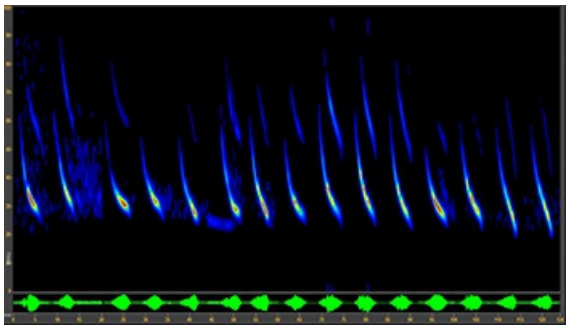
Leisler's Bat - call duration 3.1-3.7 ms



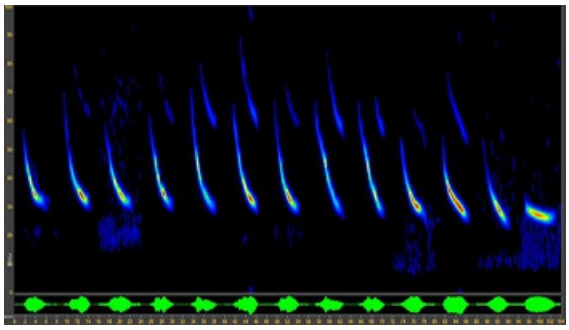
Common Noctule - call duration 3.8-4.3 ms



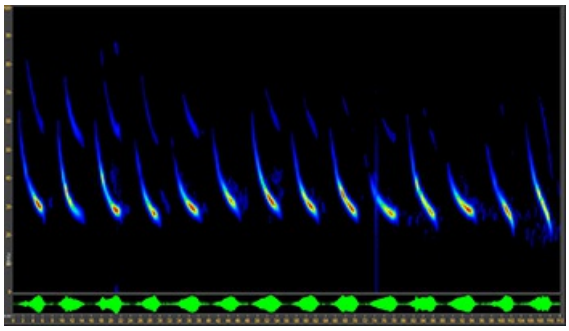
Leisler's Bat - call duration 3.8-4.3 ms



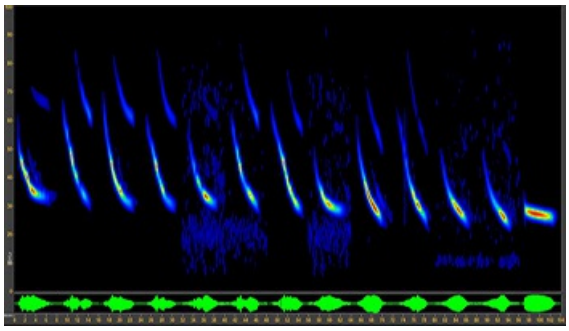
Common Noctule - call duration 4.4-4.9 ms



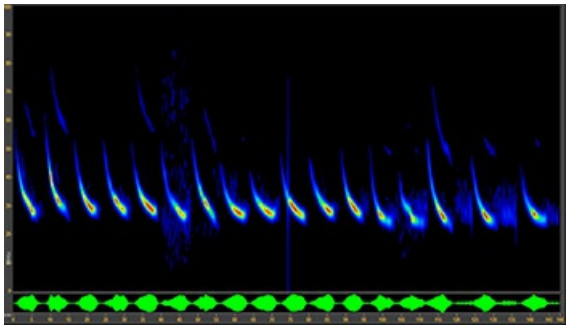
Leisler's Bat - call duration 4.4-4.9 ms



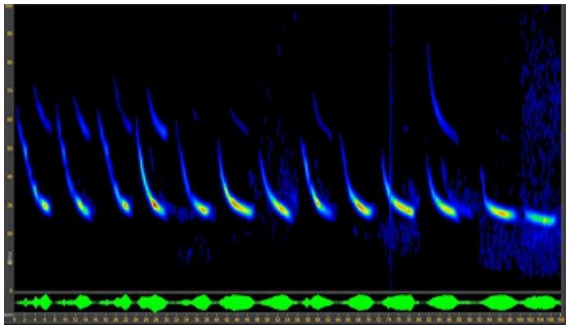
Common Noctule - call duration 5.0-5.9 ms



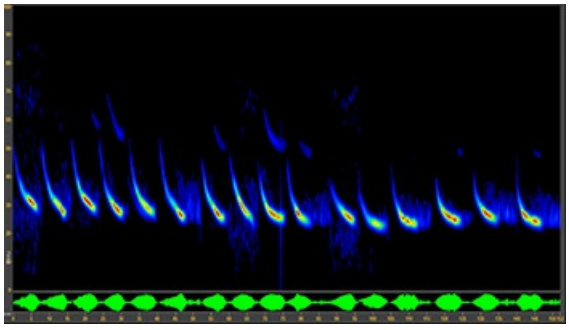
Leisler's Bat - call duration 5.0-5.9 ms



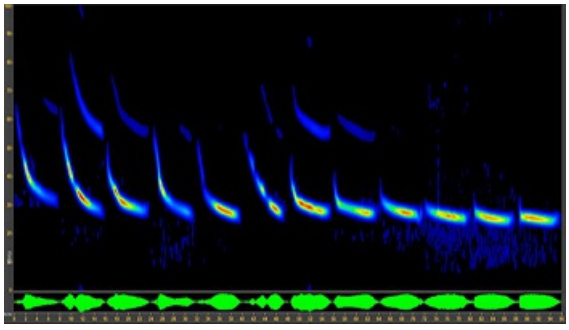
Common Noctule - call duration 6.0-6.8 ms



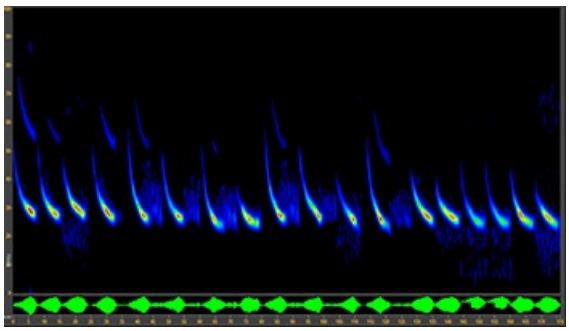
Leisler's Bat - call duration 6.0-6.8 ms



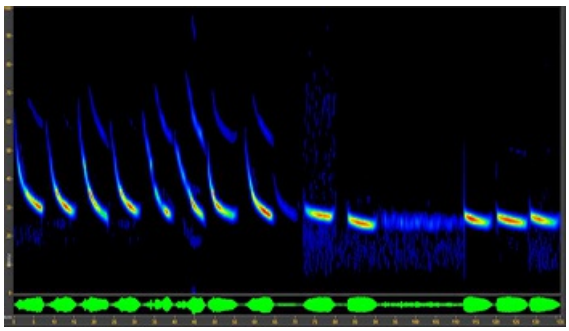
Common Noctule - call duration 6.9-7.2 ms



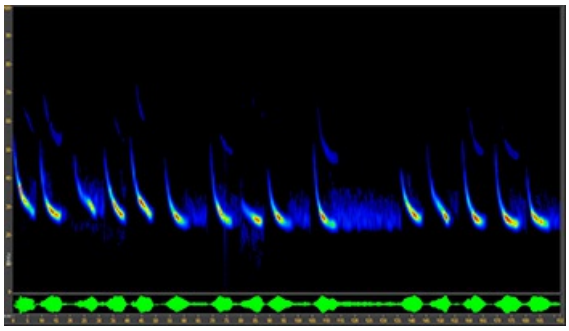
Leisler's Bat - call duration 6.9-7.2 ms



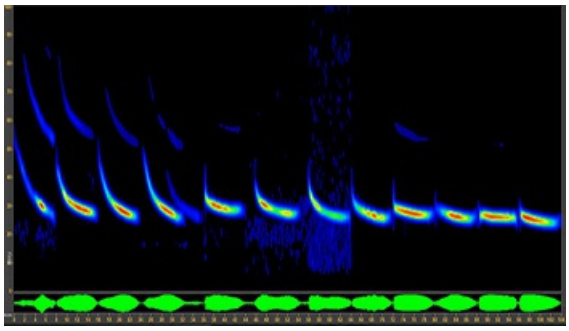
Common Noctule - call duration 7.3-7.6 ms



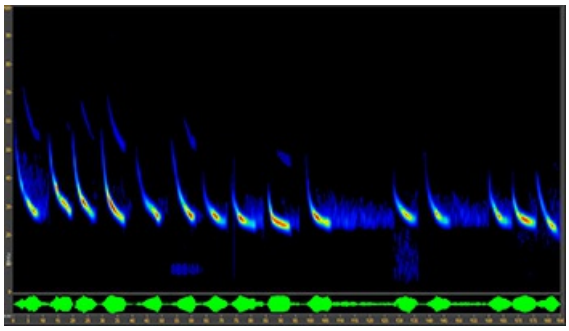
Leisler's Bat - call duration 7.3-7.6 ms



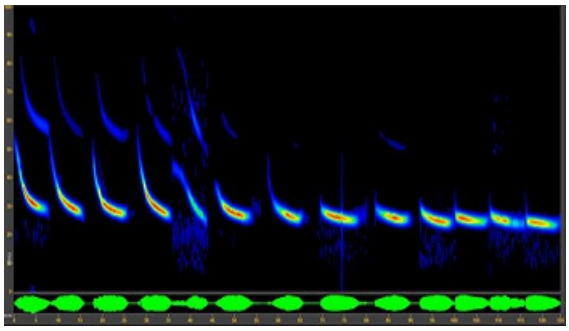
Common Noctule - call duration 7.7-7.8 ms



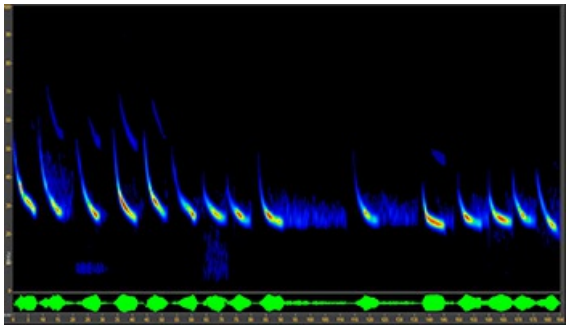
Leisler's Bat - call duration 7.7-7.8 ms



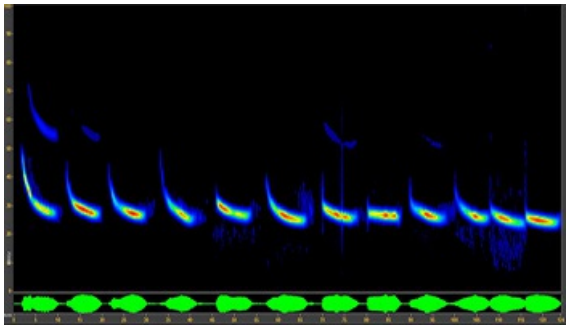
Common Noctule - call duration 7.9-8.0 ms



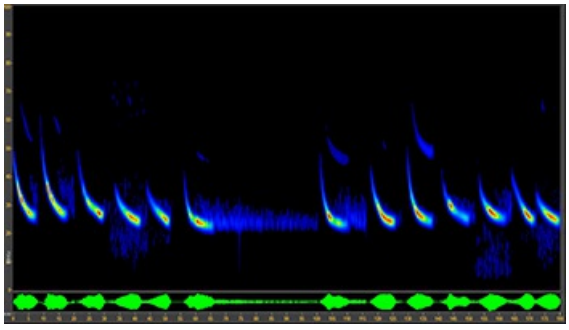
Leisler's Bat - call duration 7.9-8.0 ms



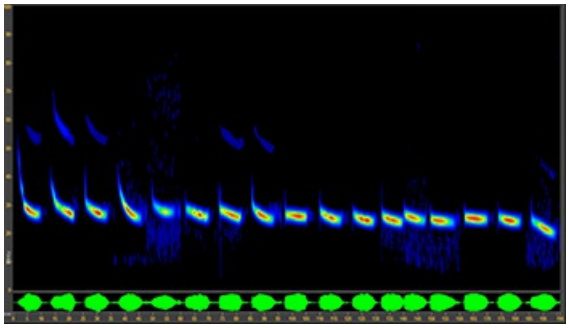
Common Noctule - call duration 8.1-8.3 ms



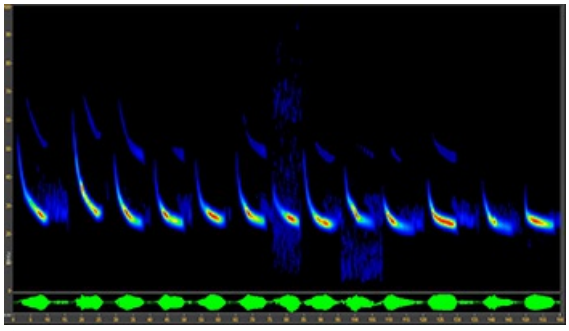
Leisler's Bat - call duration 8.1-8.3 ms



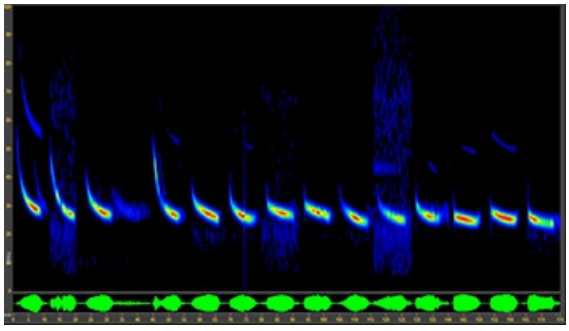
Common Noctule - call duration 8.4-8.5 ms



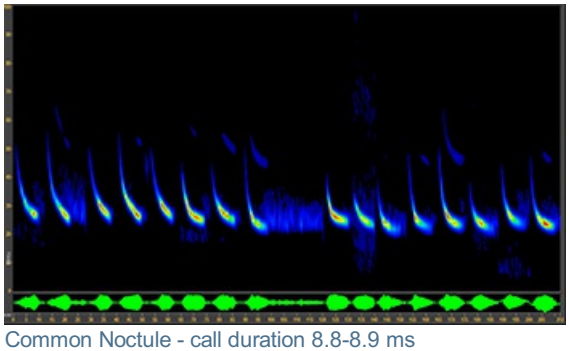
Leisler's Bat - call duration 8.4-8.5 ms



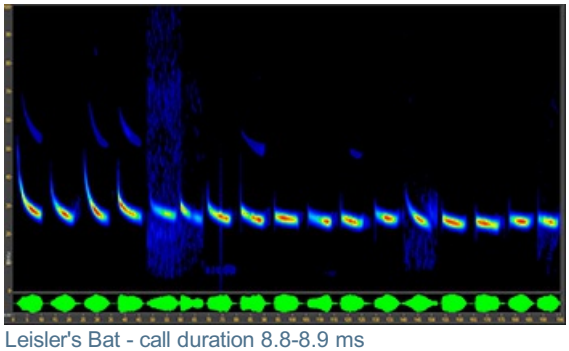
Common Noctule - call duration 8.6-8.7 ms



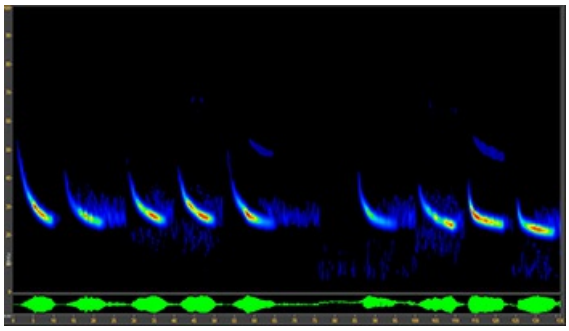
Leisler's Bat - call duration 8.6-8.7 ms



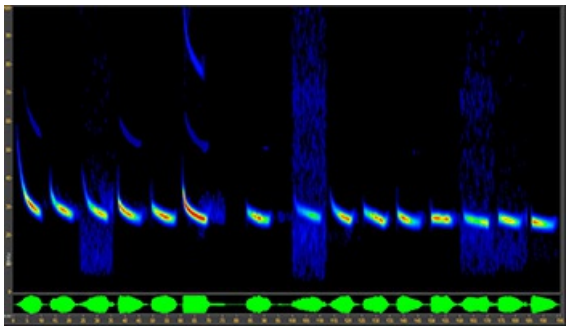
Common Noctule - call duration 8.8-8.9 ms



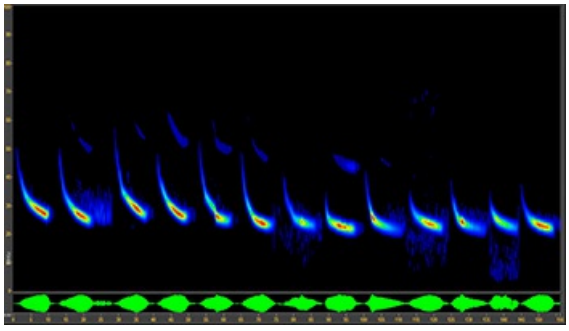
Leisler's Bat - call duration 8.8-8.9 ms



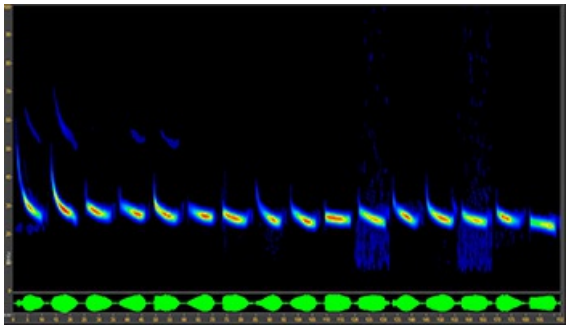
Common Noctule - call duration 9.0-9.1 ms



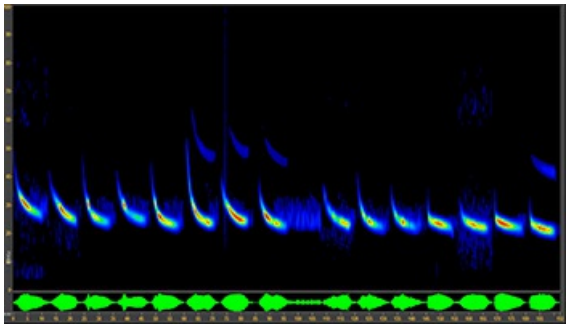
Leisler's Bat - call duration 9.0-9.1 ms



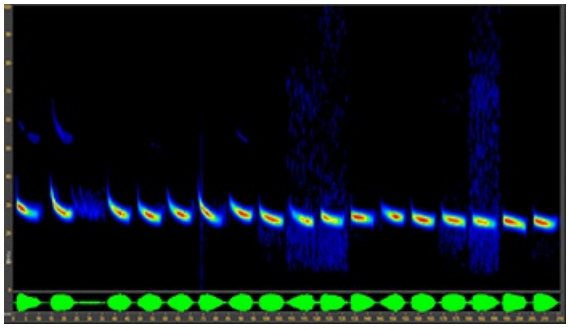
Common Noctule - call duration 9.2-9.3 ms



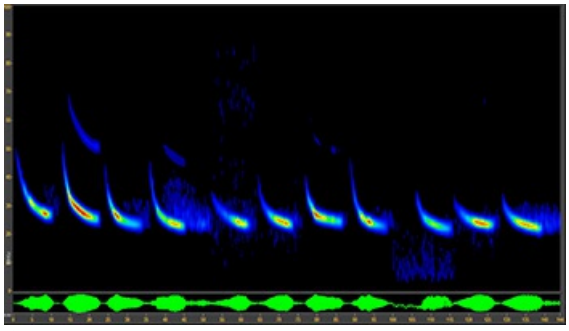
Leisler's Bat - call duration 9.2-9.3 ms



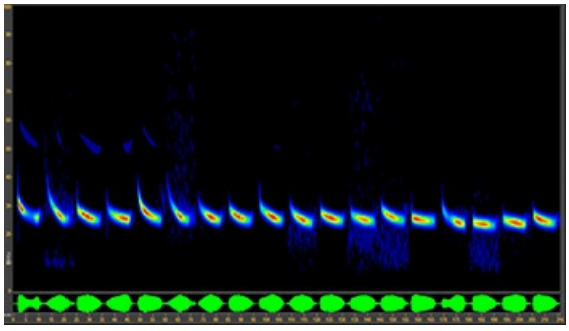
Common Noctule - call duration 9.4-9.5 ms



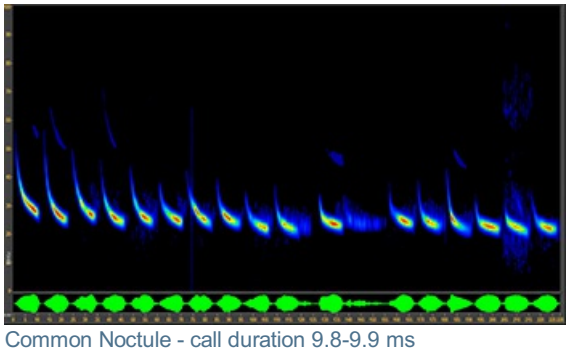
Leisler's Bat - call duration 9.4-9.5 ms



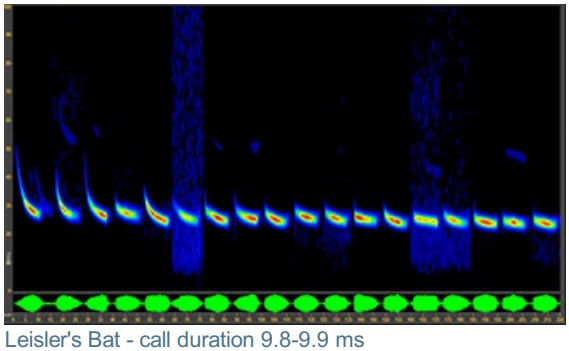
Common Noctule - call duration 9.6-9.7 ms



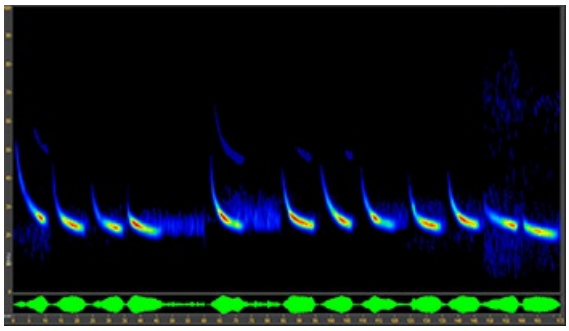
Leisler's Bat - call duration 9.6-9.7 ms



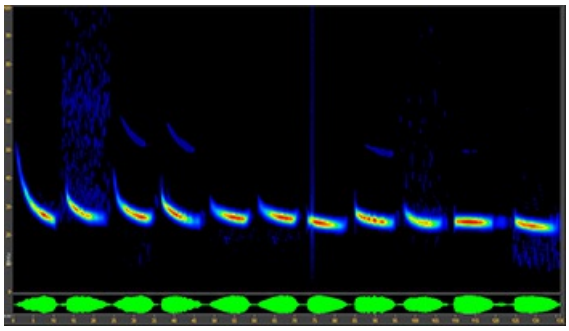
Common Noctule - call duration 9.8-9.9 ms



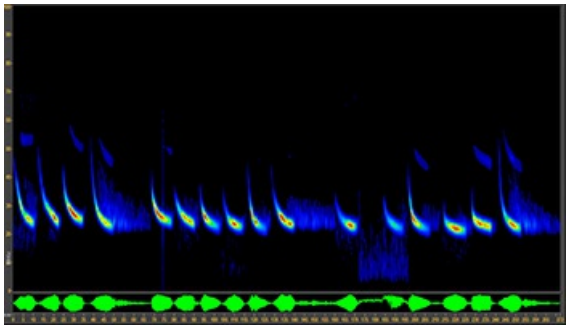
Leisler's Bat - call duration 9.8-9.9 ms



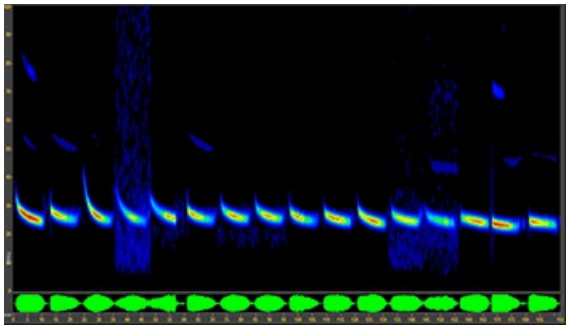
Common Noctule - call duration 10.0-10.1 ms



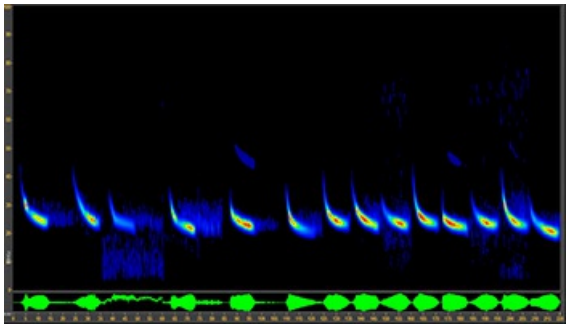
Leisler's Bat - call duration 10.0-10.1 ms



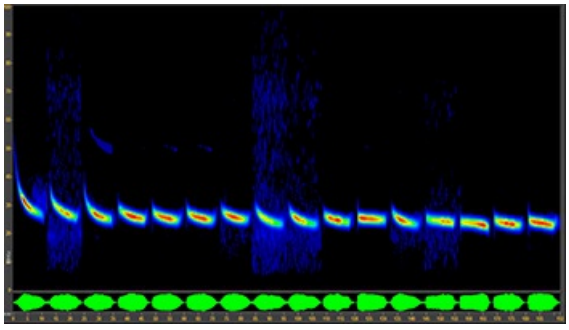
Common Noctule - call duration 10.2-10.3 ms



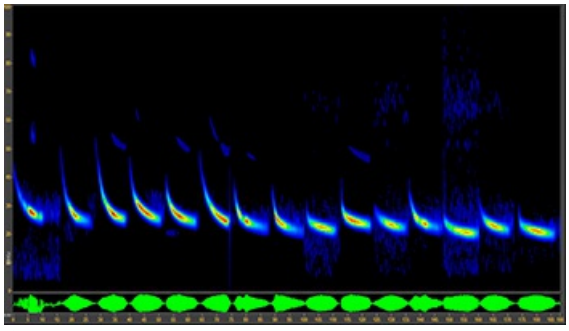
Leisler's Bat - call duration 10.2-10.3 ms



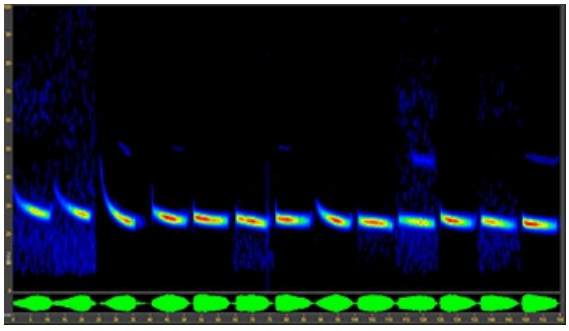
Common Noctule - call duration 10.4-10.5 ms



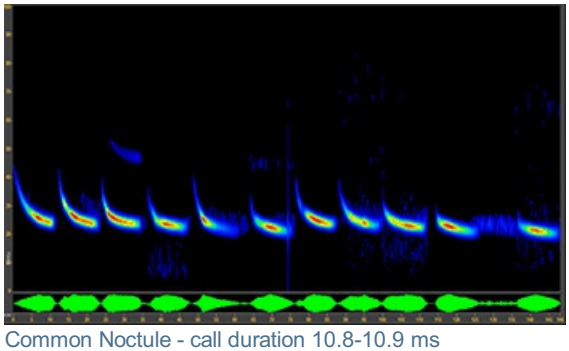
Leisler's Bat - call duration 10.4-10.5 ms



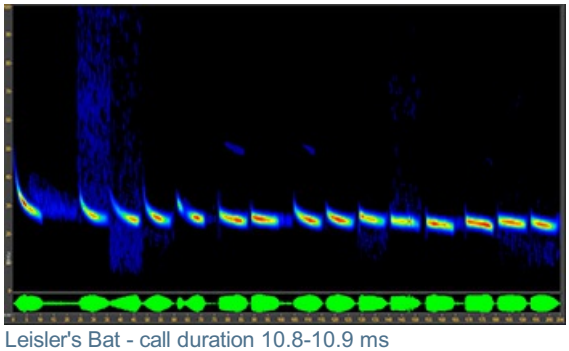
Common Noctule - call duration 10.6-10.7 ms



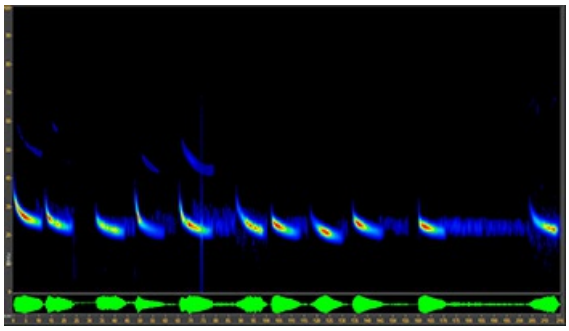
Leisler's Bat - call duration 10.6-10.7 ms



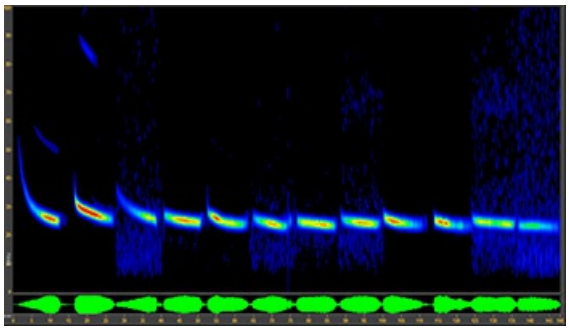
Common Noctule - call duration 10.8-10.9 ms



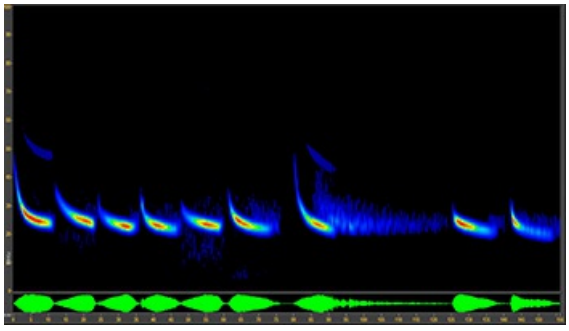
Leisler's Bat - call duration 10.8-10.9 ms



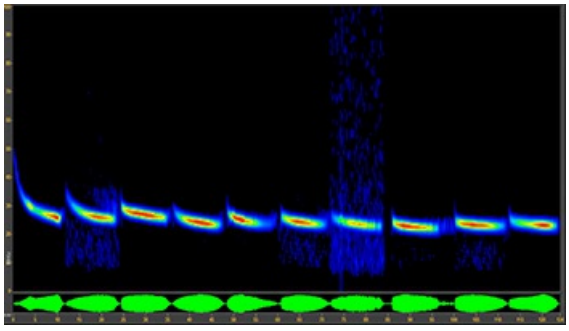
Common Noctule - call duration 11.0-11.1 ms



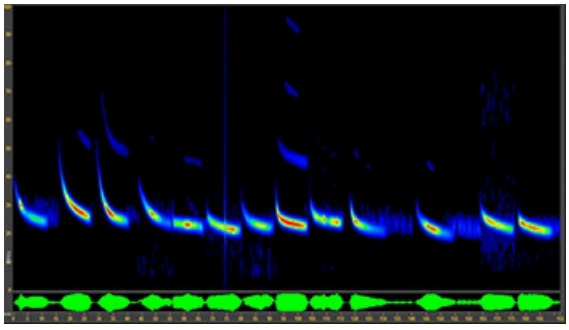
Leisler's Bat - call duration 11.0-11.1 ms



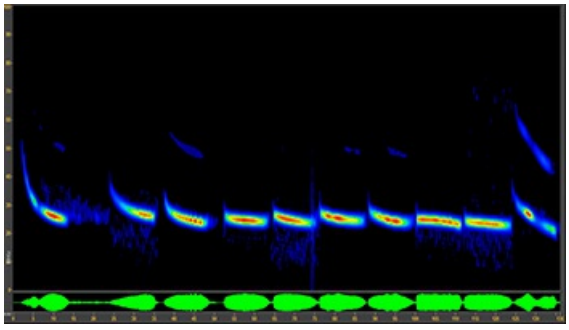
Common Noctule - call duration 11.2-11.3 ms



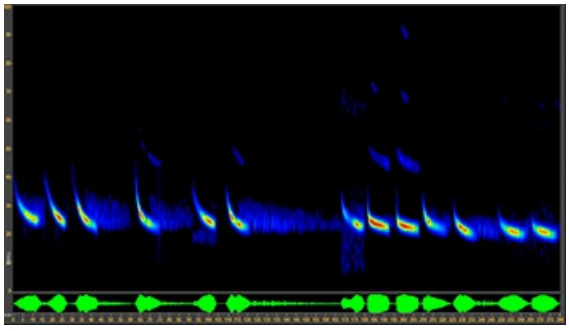
Leisler's Bat - call duration 11.2-11.3 ms



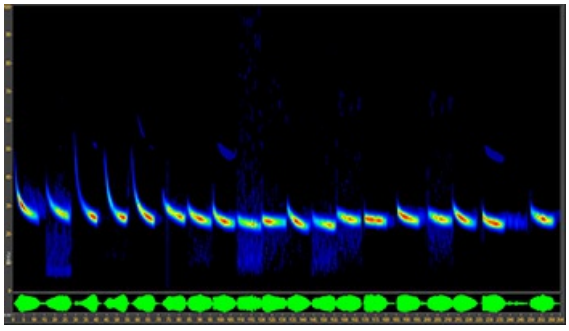
Common Noctule - call duration 11.4-11.5 ms



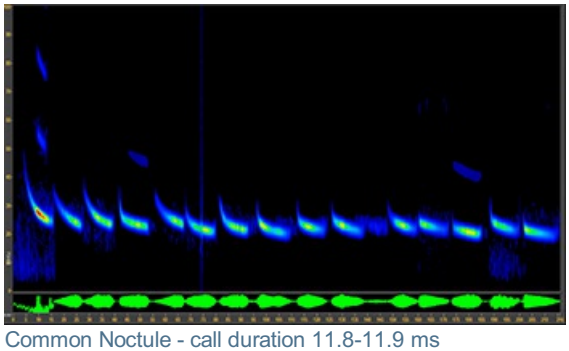
Leisler's Bat - call duration 11.4-11.5 ms



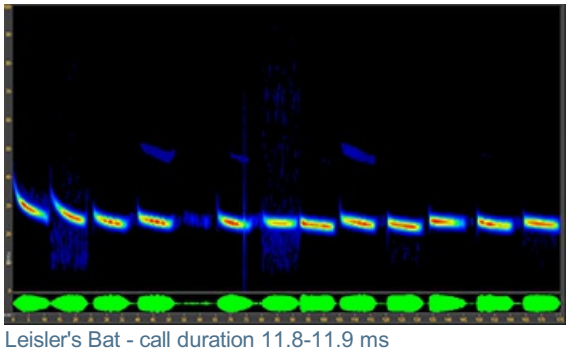
Common Noctule - call duration 11.6-11.7 ms



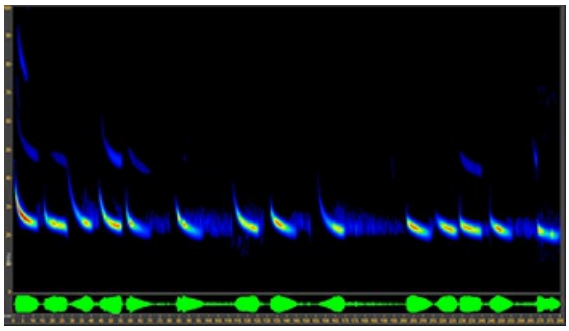
Leisler's Bat - call duration 11.6-11.7 ms



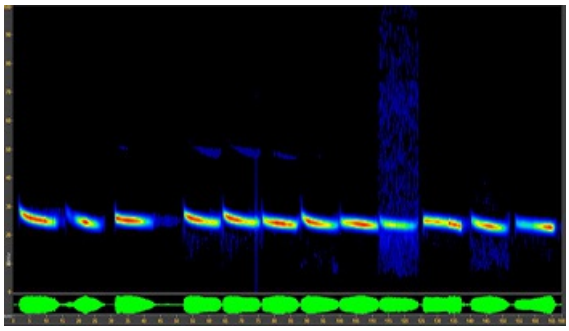
Common Noctule - call duration 11.8-11.9 ms



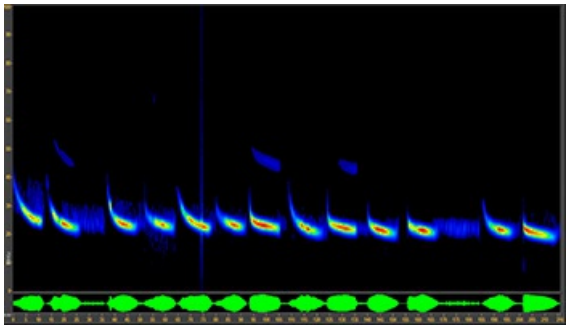
Leisler's Bat - call duration 11.8-11.9 ms



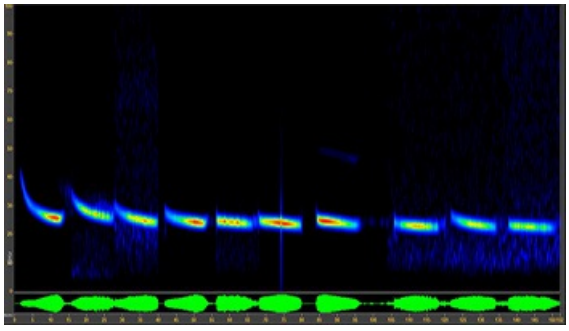
Common Noctule - call duration 12.0-12.2 ms



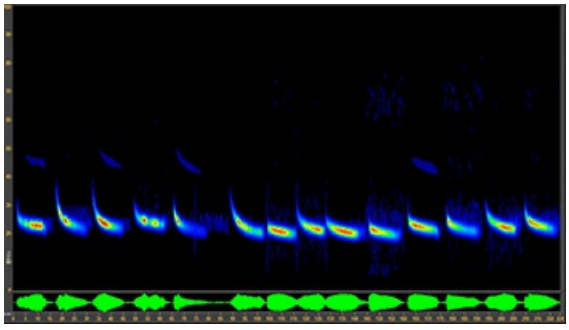
Leisler's Bat - call duration 12.0-12.2 ms



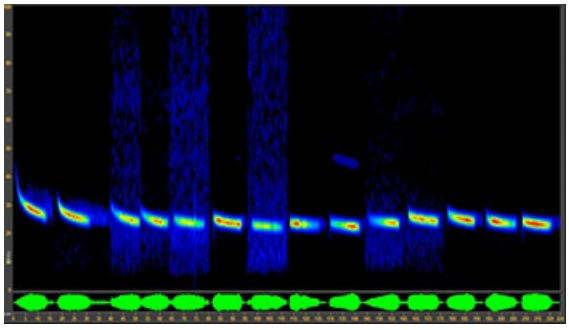
Common Noctule - call duration 12.3-12.4 ms



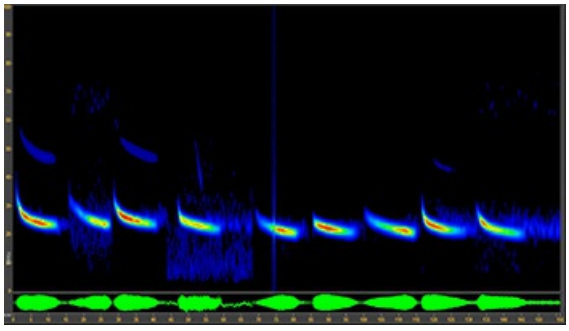
Leisler's Bat - call duration 12.3-12.4 ms



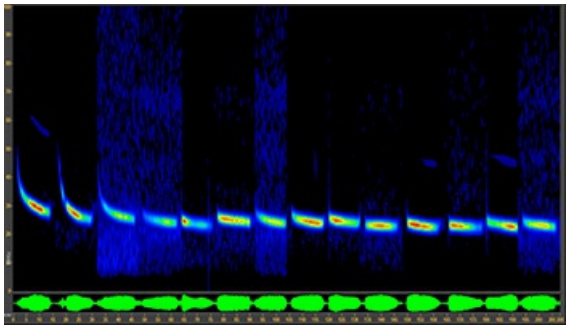
Common Noctule - call duration 12.5-12.7 ms



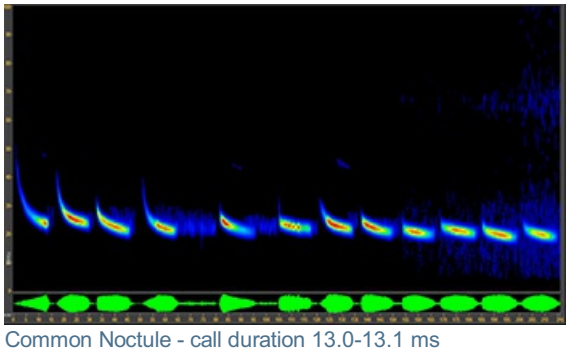
Leisler's Bat - call duration 12.5-12.7 ms



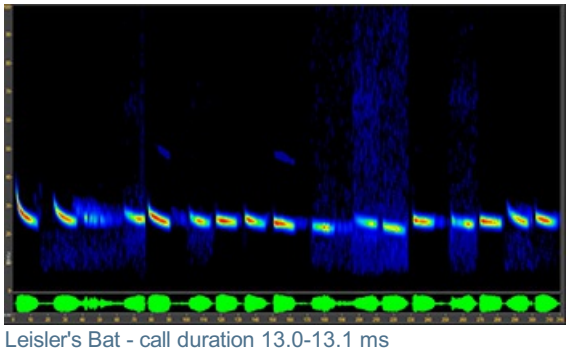
Common Noctule - call duration 12.8-12.9 ms



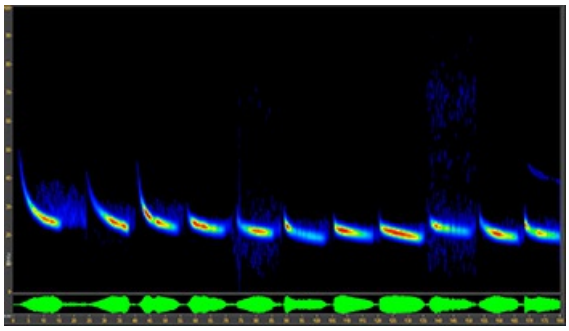
Leisler's Bat - call duration 12.8-12.9 ms



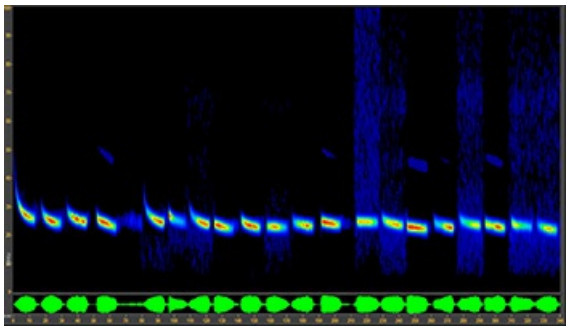
Common Noctule - call duration 13.0-13.1 ms



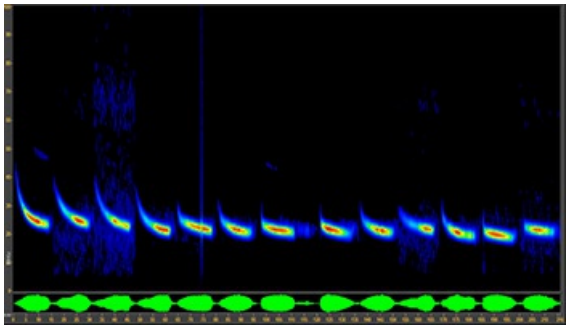
Leisler's Bat - call duration 13.0-13.1 ms



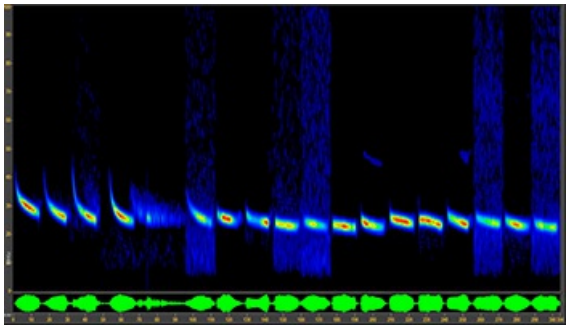
Common Noctule - call duration 13.2-13.3 ms



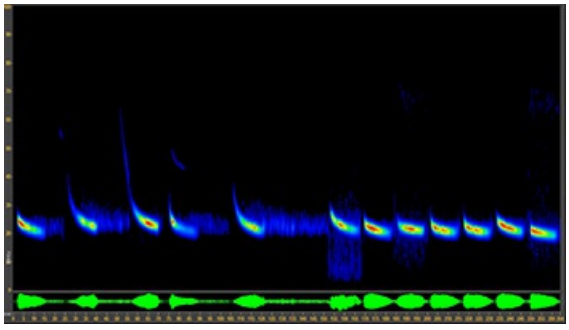
Leisler's Bat - call duration 13.2-13.3 ms



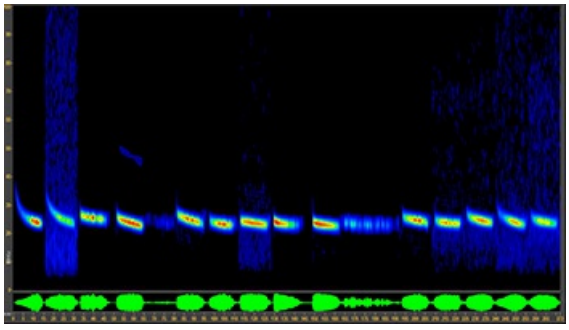
Common Noctule - call duration 13.4-13.5 ms



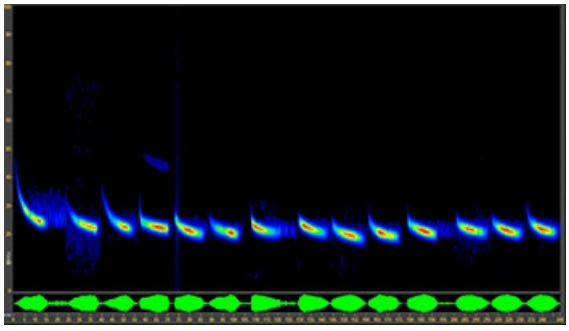
Leisler's Bat - call duration 13.4-13.5 ms



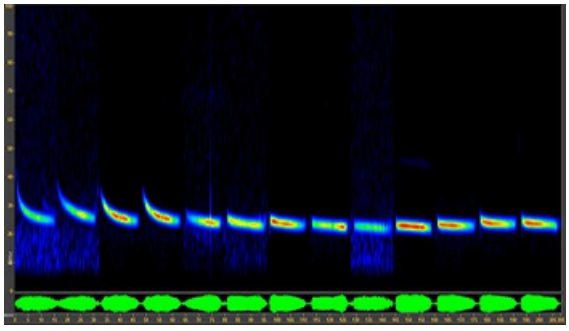
Common Noctule - call duration 13.6-13.7 ms



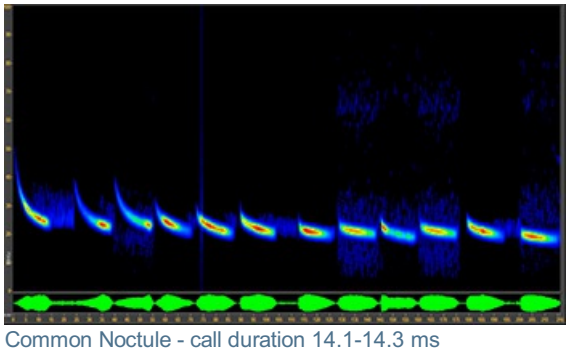
Leisler's Bat - call duration 13.6-13.7 ms



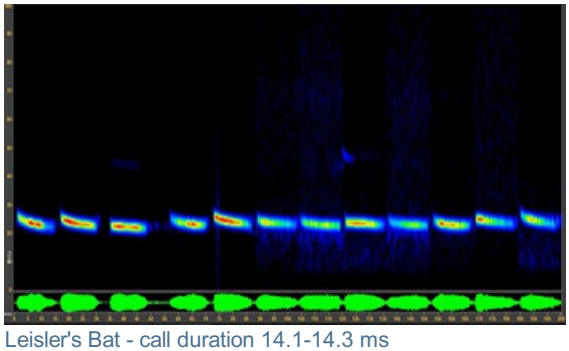
Common Noctule - call duration 13.8-14.0 ms



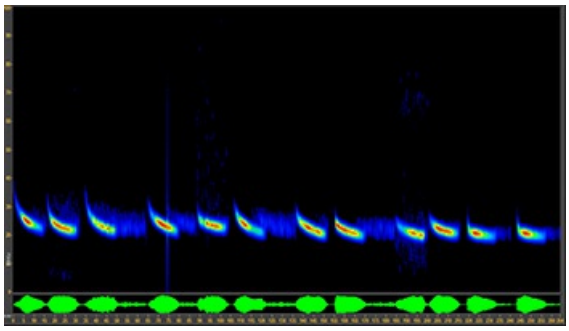
Leisler's Bat - call duration 13.8-14.0 ms



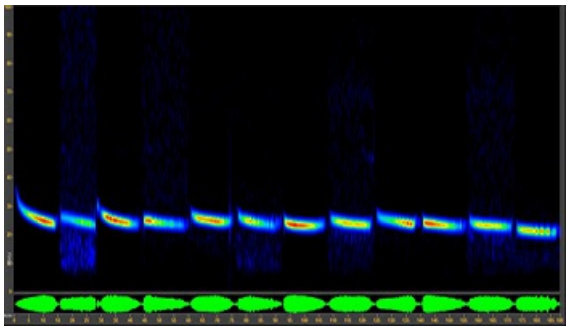
Common Noctule - call duration 14.1-14.3 ms



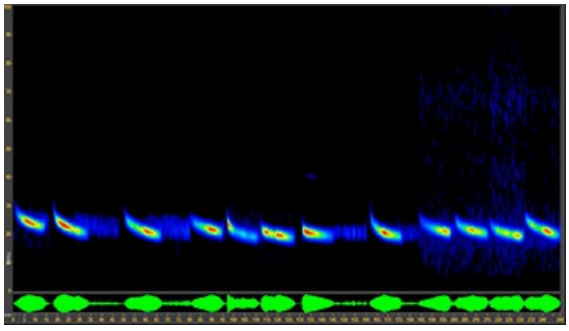
Leisler's Bat - call duration 14.1-14.3 ms



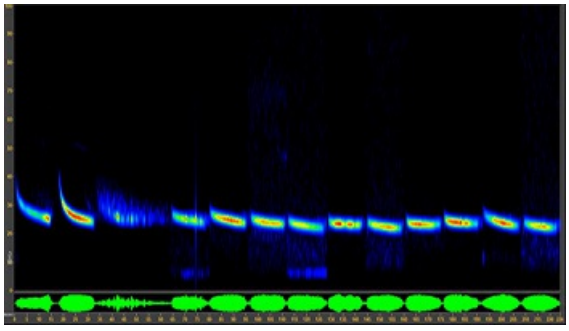
Common Noctule - call duration 14.4-14.5 ms



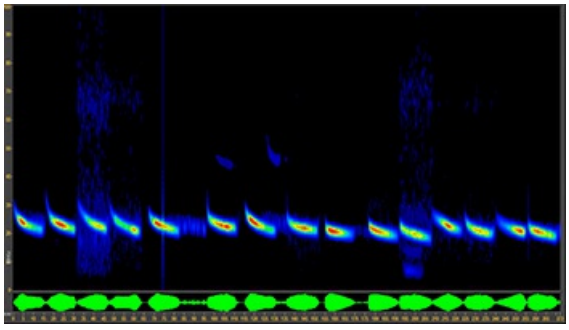
Leisler's Bat - call duration 14.4-14.5 ms



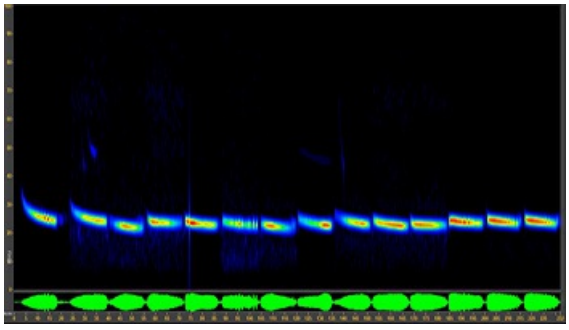
Common Noctule - call duration 14.6-14.8 ms



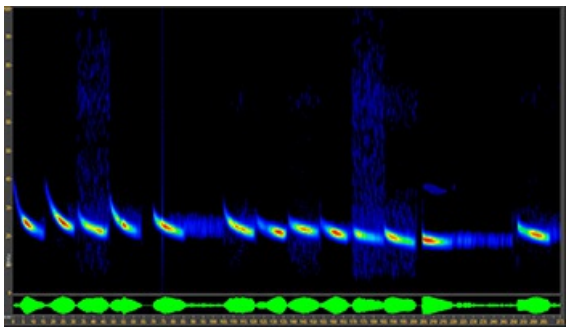
Leisler's Bat - call duration 14.6-14.8 ms



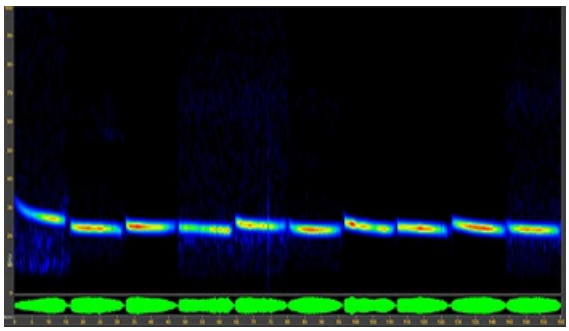
Common Noctule - call duration 14.9-15.1 ms



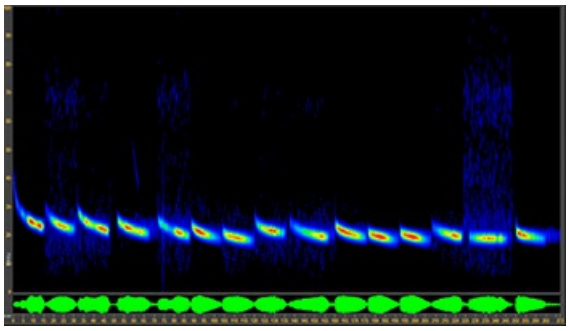
Leisler's Bat - call duration 14.9-15.1 ms



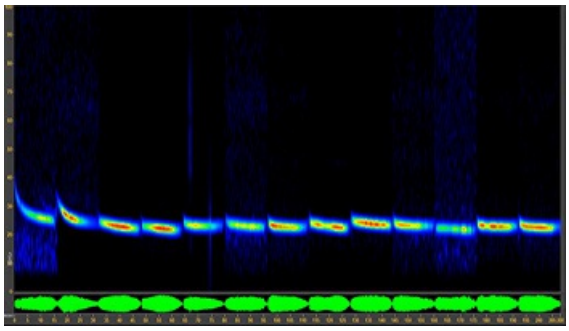
Common Noctule - call duration 15.2-15.3 ms



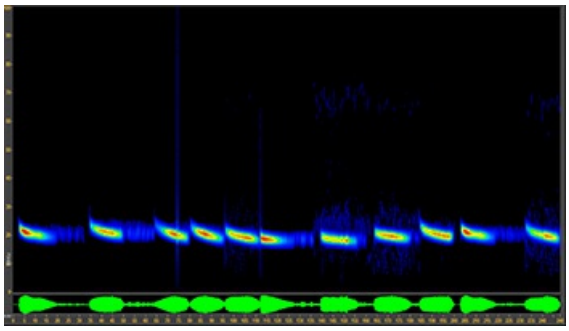
Leisler's Bat - call duration 15.2-15.3 ms



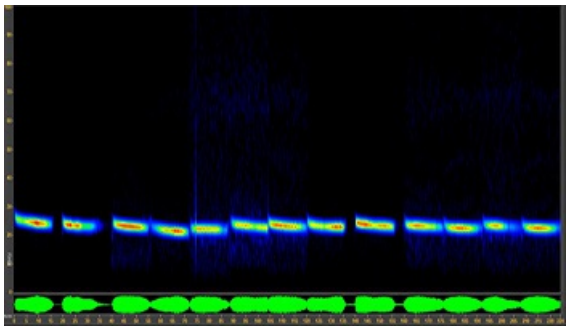
Common Noctule - call duration 15.4-15.7 ms



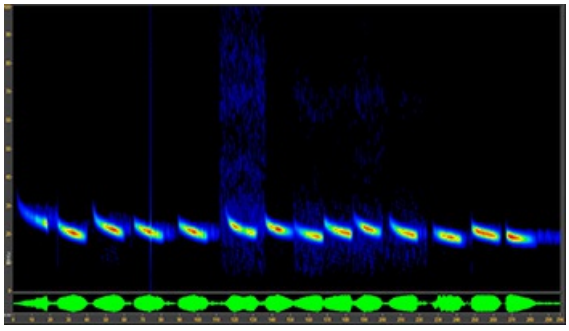
Leisler's Bat - call duration 15.4-15.7 ms



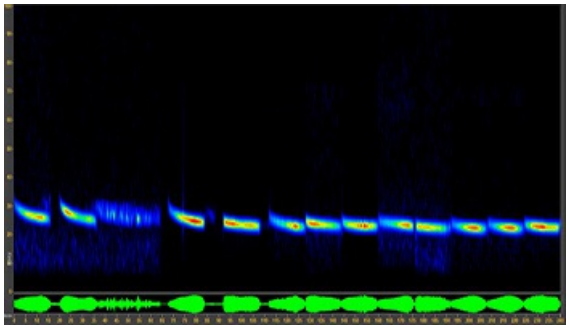
Common Noctule - call duration 15.8-16.0 ms



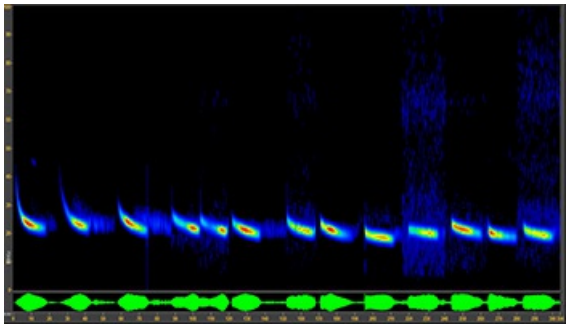
Leisler's Bat - call duration 15.8-16.0 ms



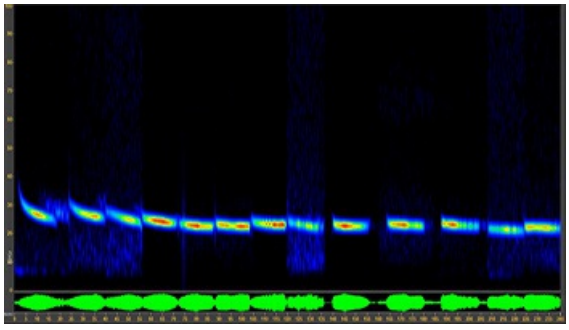
Common Noctule - call duration 16.1-16.3 ms



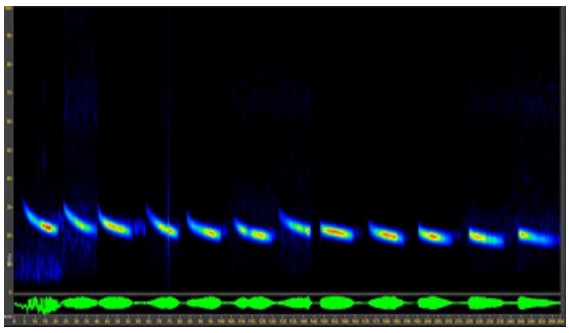
Leisler's Bat - call duration 16.1-16.3 ms



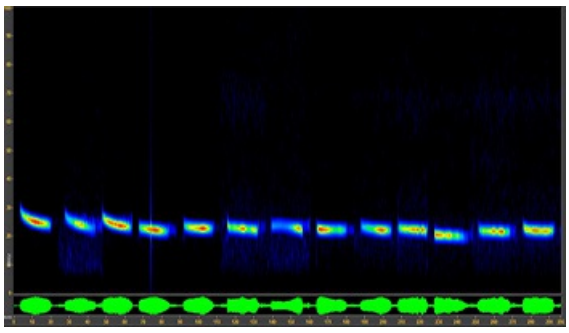
Common Noctule - call duration 16.4-16.6 ms



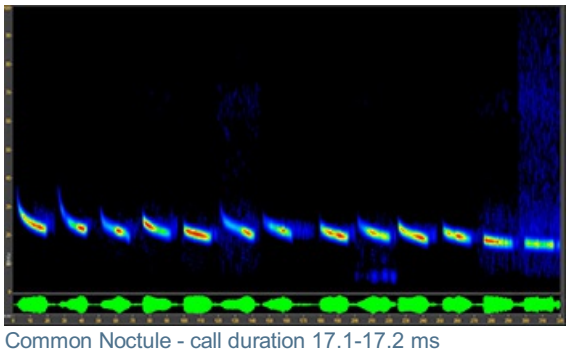
Leisler's Bat - call duration 16.4-16.6 ms



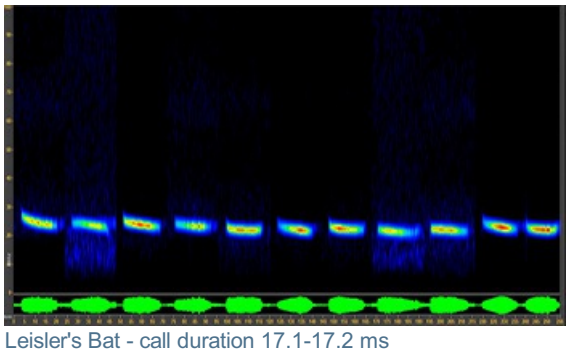
Common Noctule - call duration 16.7-17.0 ms



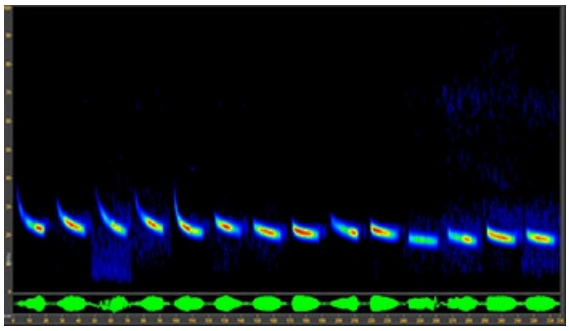
Leisler's Bat - call duration 16.7-17.0 ms



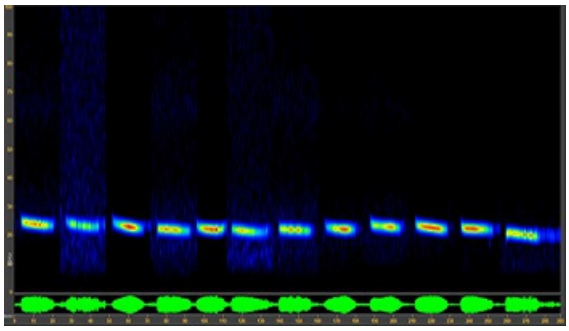
Common Noctule - call duration 17.1-17.2 ms



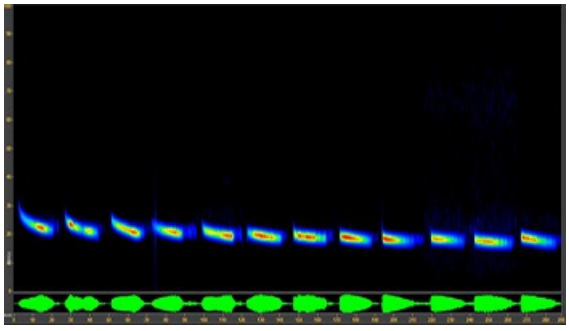
Leisler's Bat - call duration 17.1-17.2 ms



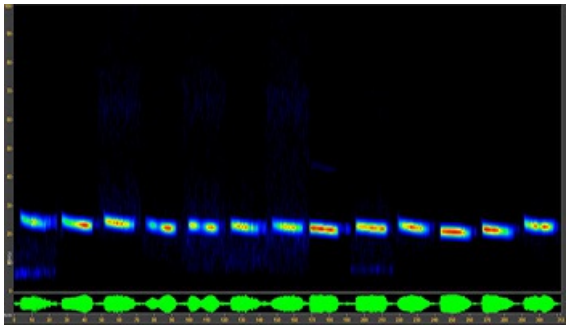
Common Noctule - call duration 17.3-17.4 ms



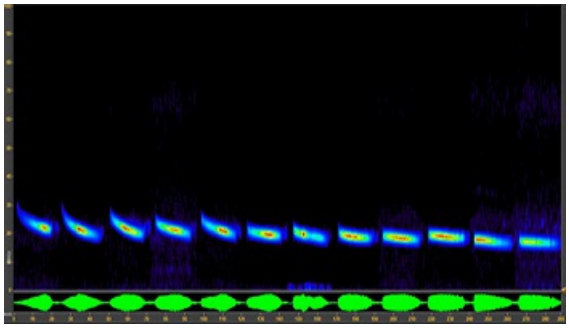
Leisler's Bat - call duration 17.3-17.4 ms



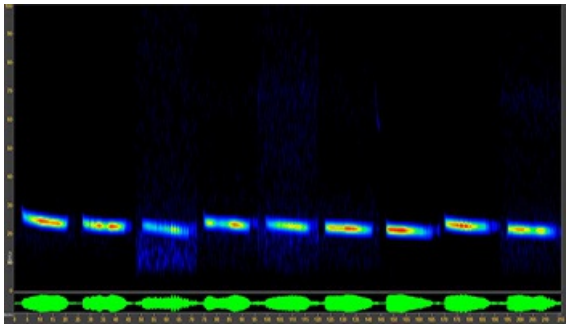
Common Noctule - call duration 17.5-18.2 ms



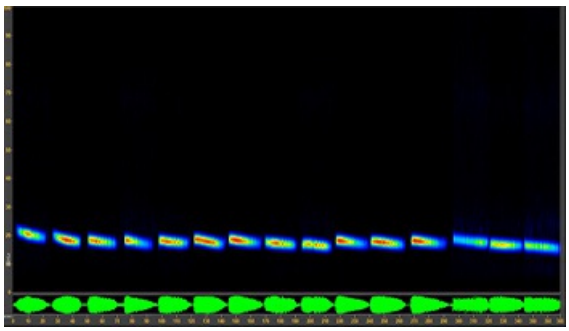
Leisler's Bat - call duration 17.5-18.2 ms



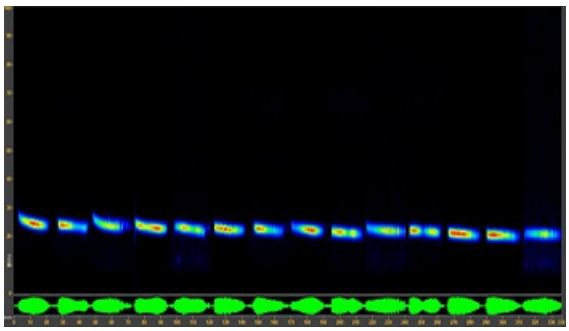
Common Noctule - call duration 18.3-18.7 ms



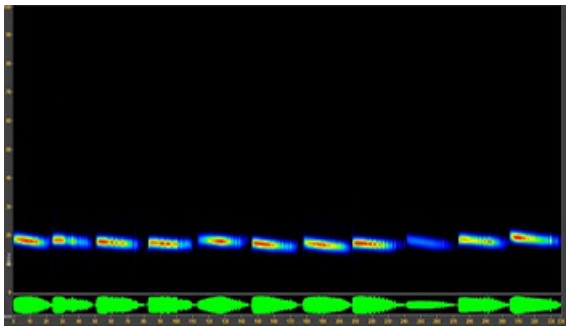
Leisler's Bat - call duration 18.3-18.7 ms



Common Noctule - call duration 18.8-24.0 ms



Leisler's Bat - call duration 18.8-24.0 ms



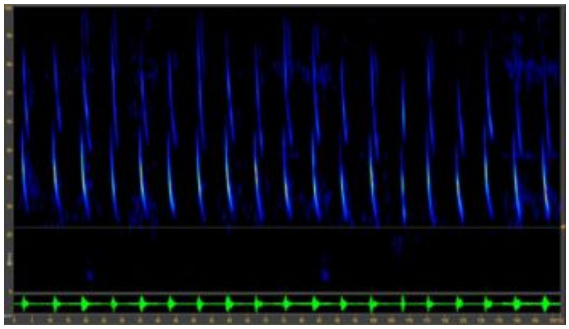
Common Noctule - call duration 24.1-31.7 ms

Leisler's Bat - no examples for this call duration

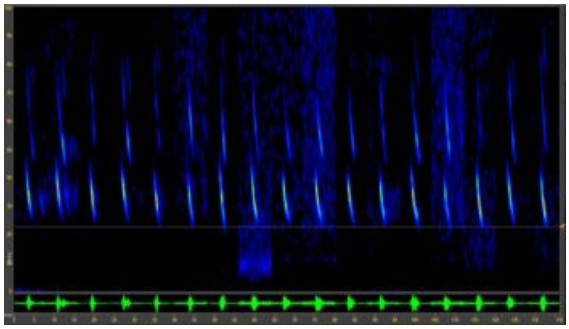
Identification appendix 5: Grey Long-eared Bat *Plecotus austriacus* and Brown Long-eared Bat *Plecotus auritus*

The echolocation and social calls of Grey Long-eared Bat are very similar to Brown Long-eared Bat, but given good recordings and an understanding of what the calls of the two species should look like given the call duration, it should be possible to assign a majority of recordings to species. To illustrate we provide a visual comparison below of similar duration echolocation and type c social calls of known Grey Long-eared Bat and Brown Long-eared Bat.

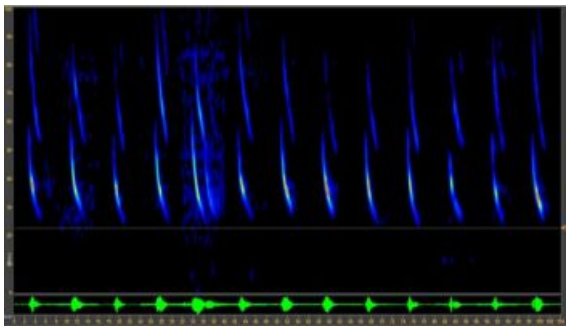
Despite this, it is very possible that a small number of Brown Long-eared Bat recordings will be missed, either in recordings not assigned to species (for example assigned instead to *Plecotus* species, and not considered in this report), or potentially to Grey Long-eared Bat in error. The latter is most likely where there is attenuation of the weaker ends of the calls of Brown Long-eared Bat, making the calls look less broadband than they really are, but in most cases, it should be clear where there are problems with the quality of a recording, so we expect that the error will be small. Some, but not all social calls of Brown Long-eared Bat, can also look very similar those of Grey Long-eared Bat. Where an identification is not clear, we take a cautious approach and do not assign these to species. As a general point, the chance of misidentifying of Grey Long-eared Bat as Brown Long-eared is less likely. Whilst Grey Long-eared Bat is not an obvious confusion species for *Nyctalus*, it is worth noting that this species commonly produces long duration calls of 7-10ms in open areas, which are longer than have been documented elsewhere (Barataud, 2015; Russ, 2021).



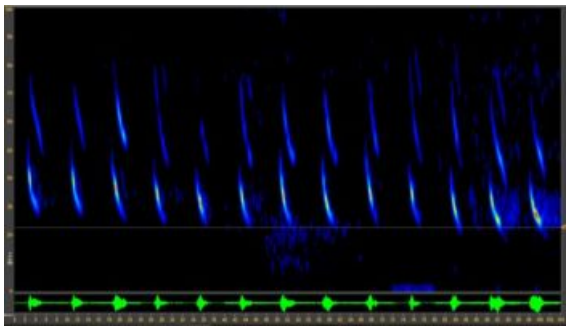
Brown Long-eared Bat - call duration 1.0-1.8 ms



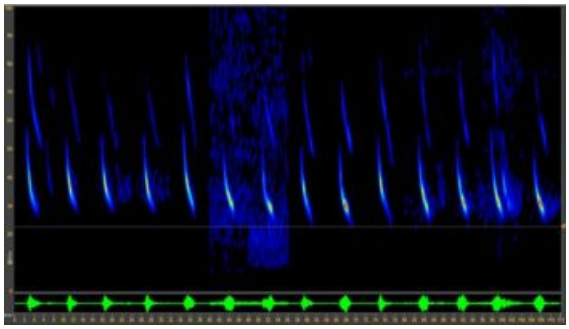
Grey Long-eared Bat - call duration 1.2-1.6 ms



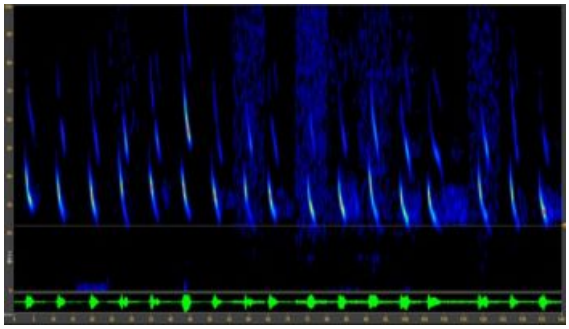
Brown Long-eared Bat - call duration 1.9-2.0 ms



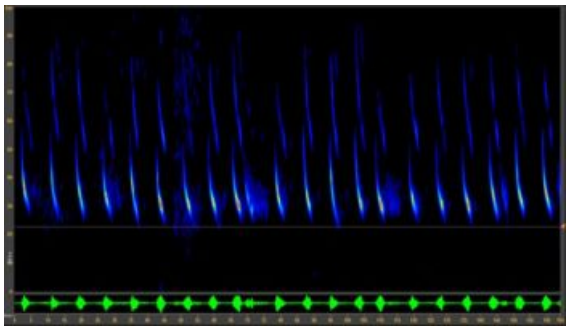
Grey Long-eared Bat - call duration 1.9-2.0 ms



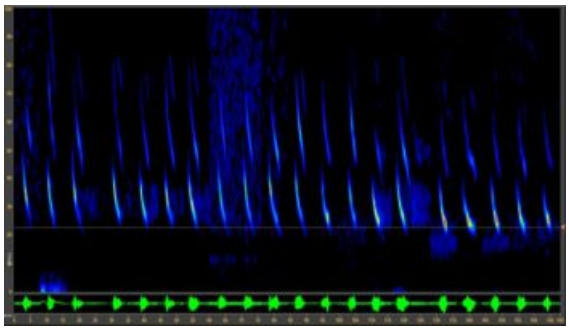
Brown Long-eared Bat - call duration 2.1-2.2 ms



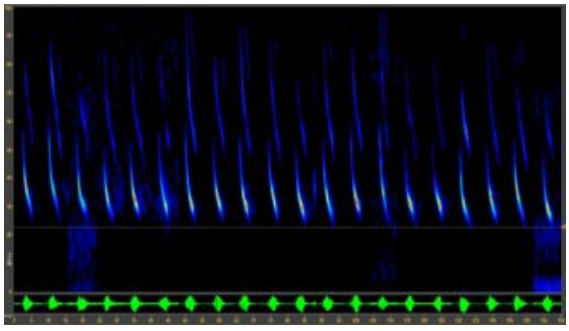
Grey Long-eared Bat - call duration 2.1-2.2 ms



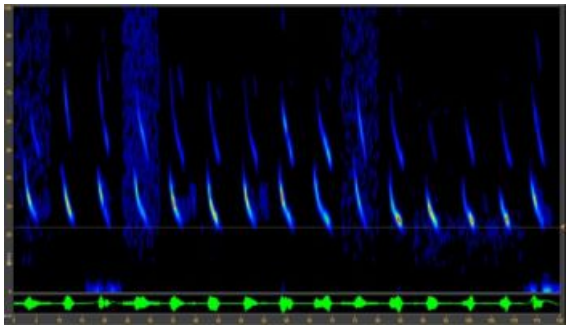
Brown Long-eared Bat - call duration 2.5-2.6 ms



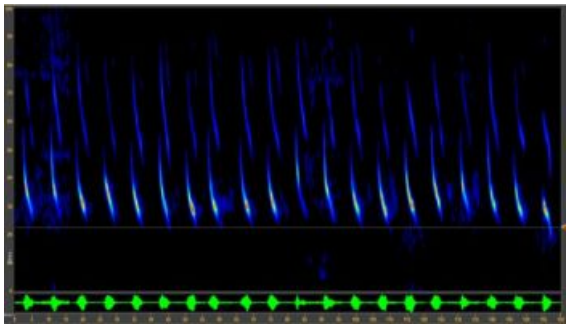
Grey Long-eared Bat - call duration 2.3-2.6 ms



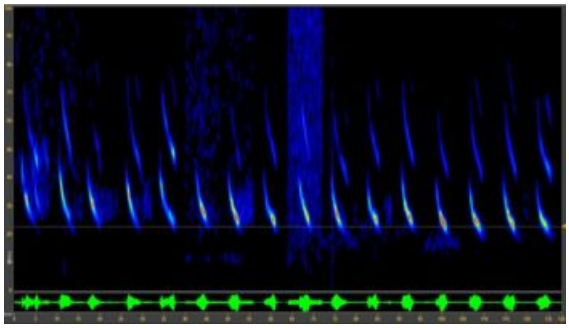
Brown Long-eared Bat - call duration 2.7-2.8 ms



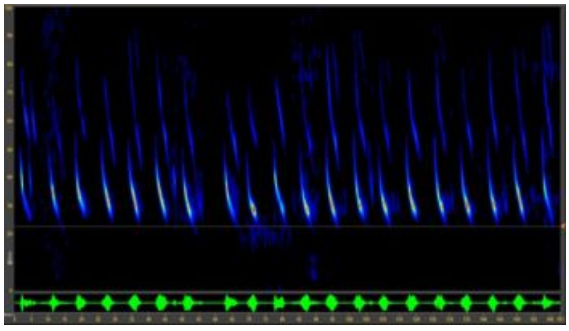
Grey Long-eared Bat - call duration 2.7-2.8 ms



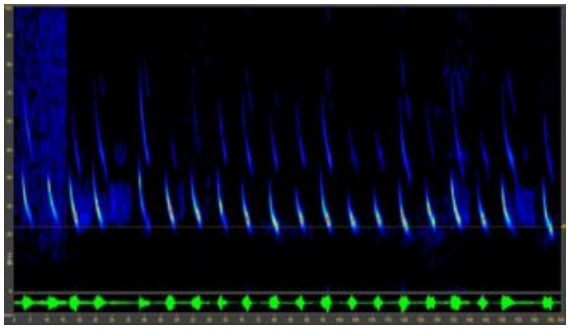
Brown Long-eared Bat - call duration 2.9-3.0 ms



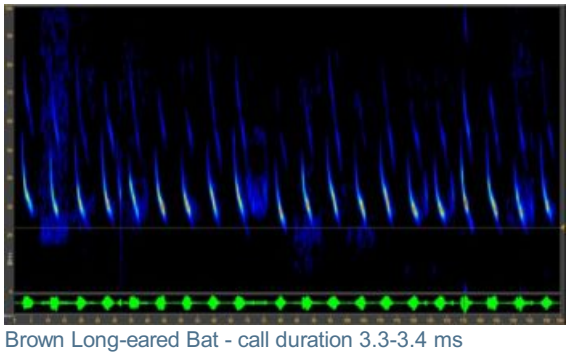
Grey Long-eared Bat - call duration 2.9-3.0 ms



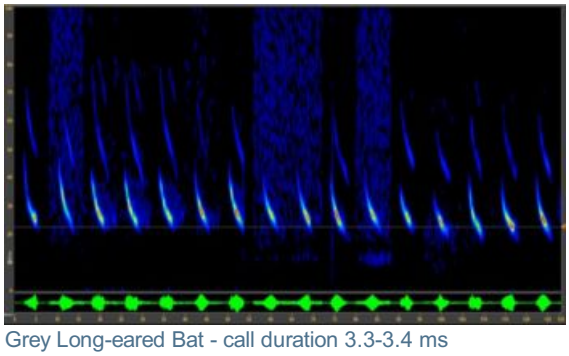
Brown Long-eared Bat - call duration 3.1-3.2 ms



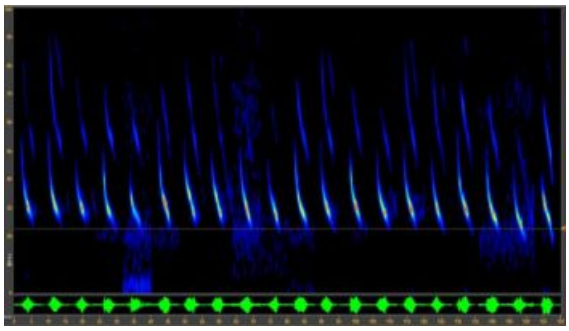
Grey Long-eared Bat - call duration 3.1-3.2 ms



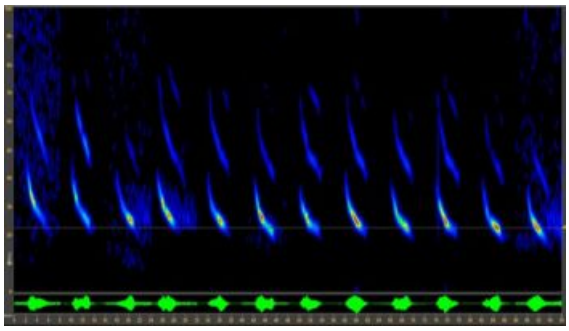
Brown Long-eared Bat - call duration 3.3-3.4 ms



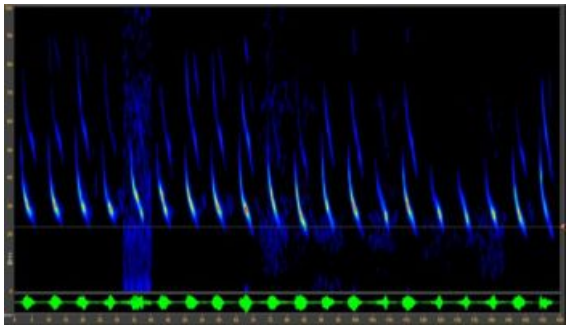
Grey Long-eared Bat - call duration 3.3-3.4 ms



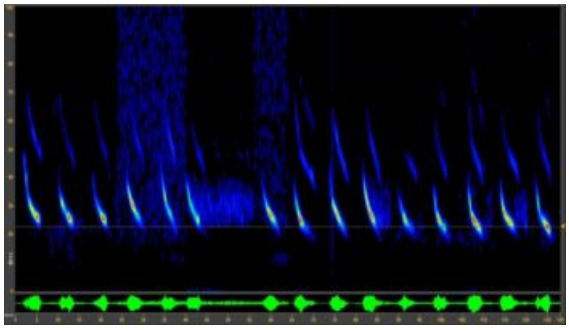
Brown Long-eared Bat - call duration 3.5-3.6 ms



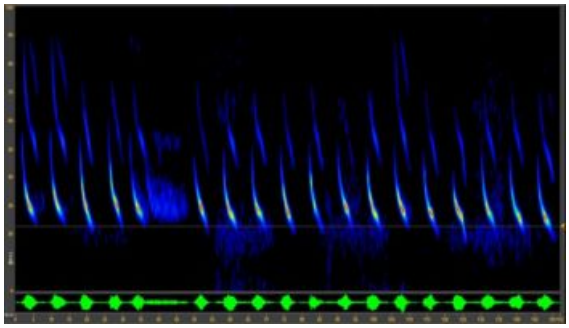
Grey Long-eared Bat - call duration 3.5-3.6 ms



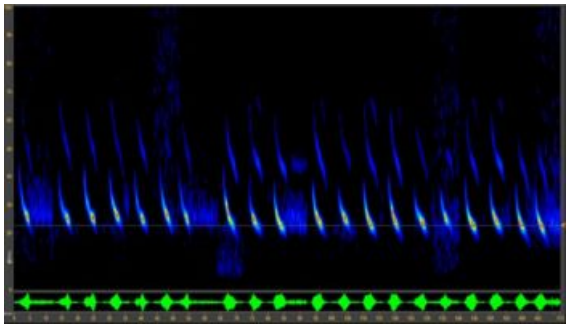
Brown Long-eared Bat - call duration 3.7-3.8 ms



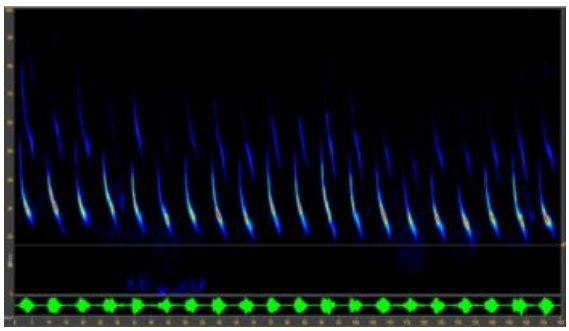
Grey Long-eared Bat - call duration 3.7-3.8 ms



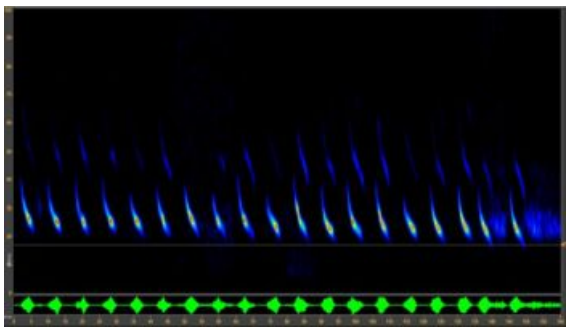
Brown Long-eared Bat - call duration 3.9-4.0 ms



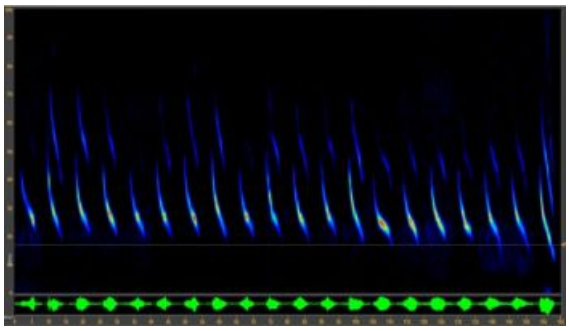
Grey Long-eared Bat - call duration 3.9-4.0 ms



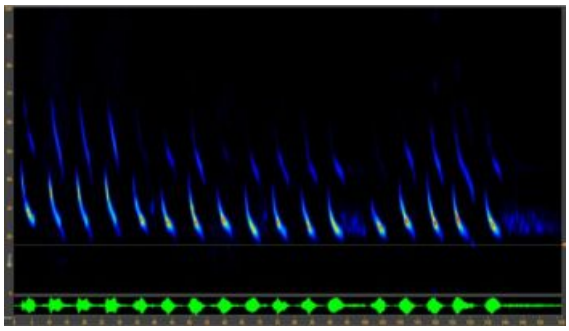
Brown Long-eared Bat - call duration 4.1-4.2 ms



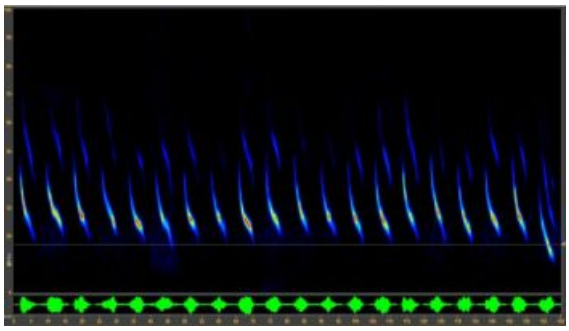
Grey Long-eared Bat - call duration 4.1-4.2 ms



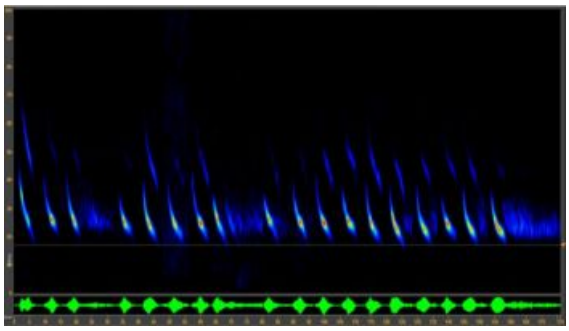
Brown Long-eared Bat - call duration 4.3-4.4 ms



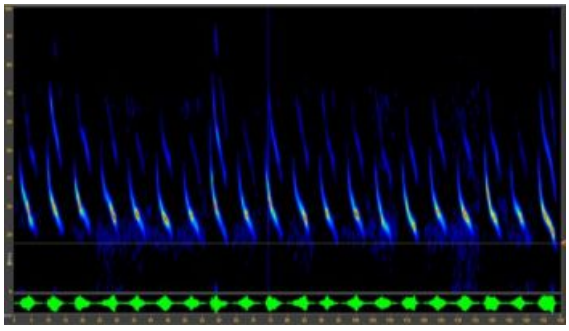
Grey Long-eared Bat - call duration 4.3-4.4 ms



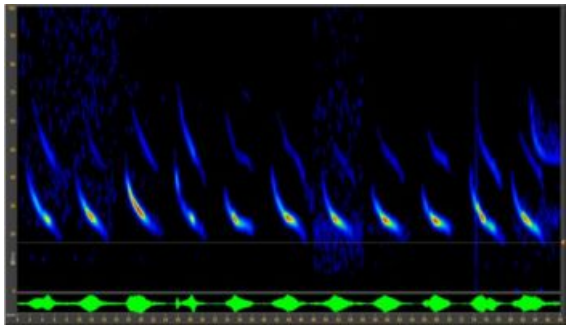
Brown Long-eared Bat - call duration 4.5-4.6 ms



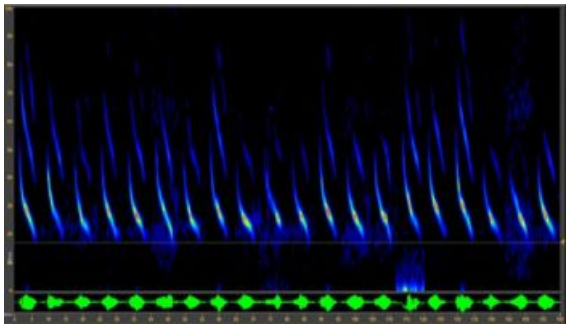
Grey Long-eared Bat - call duration 4.5-4.6 ms



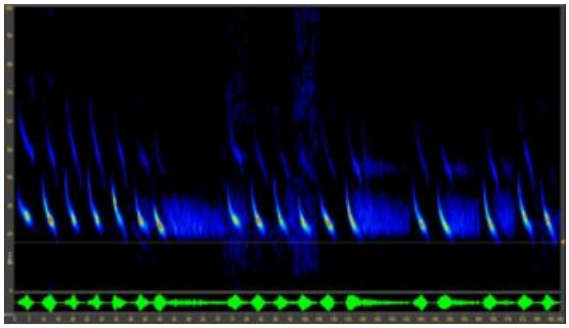
Brown Long-eared Bat - call duration 4.7-4.8 ms



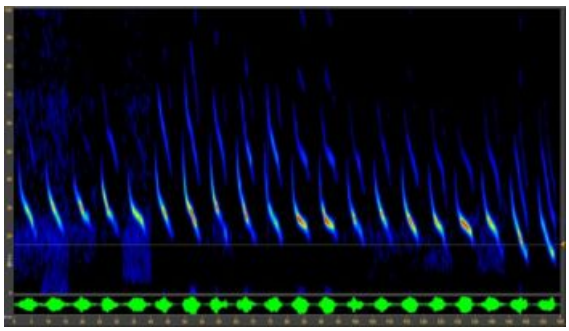
Grey Long-eared Bat - call duration 4.7-4.8 ms



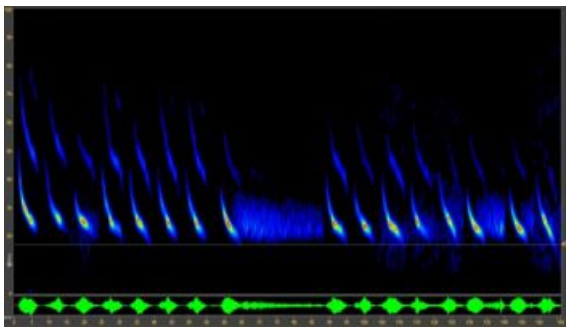
Brown Long-eared Bat - call duration 4.9-5.0 ms



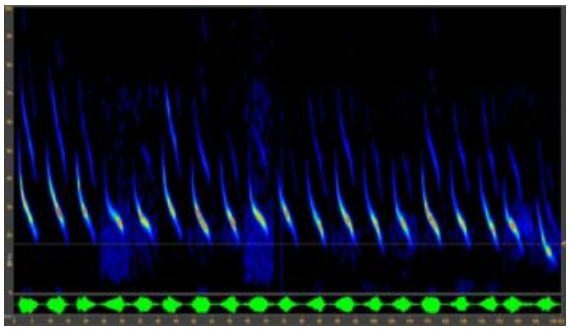
Grey Long-eared Bat - call duration 4.9-5.0 ms



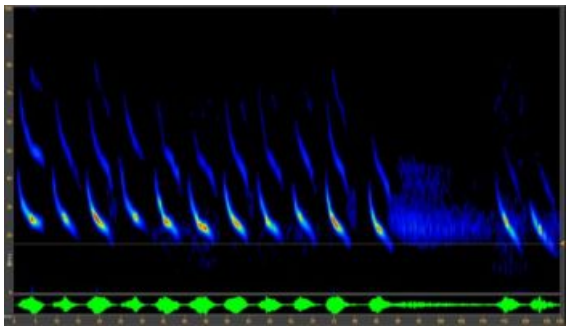
Brown Long-eared Bat - call duration 5.1-5.2 ms



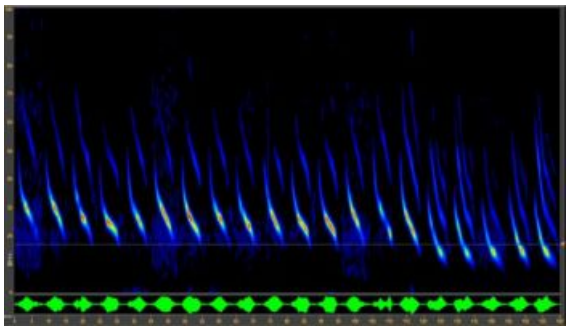
Grey Long-eared Bat - call duration 5.1-5.2 ms



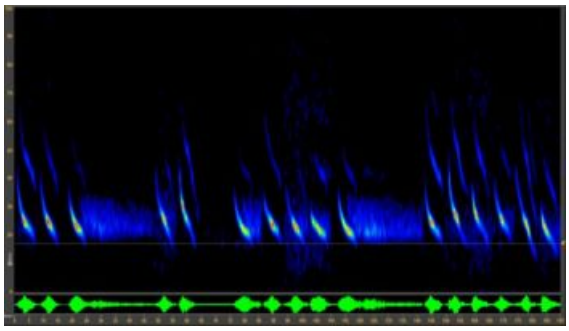
Brown Long-eared Bat - call duration 5.3-5.4 ms



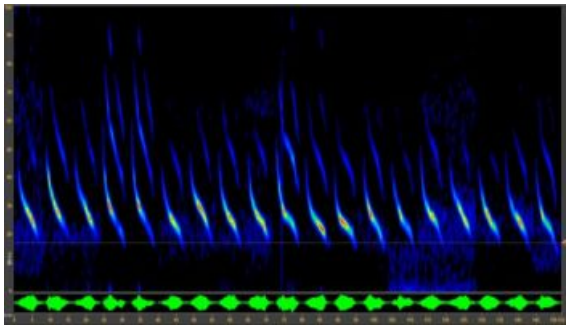
Grey Long-eared Bat - call duration 5.3-5.5 ms



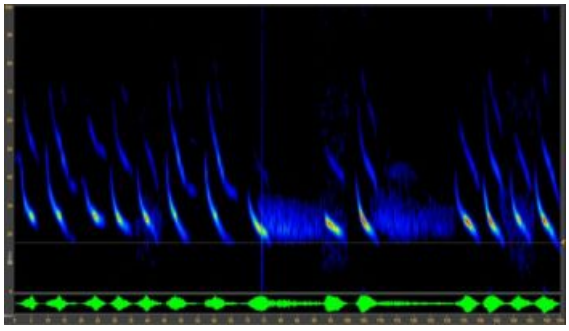
Brown Long-eared Bat - call duration 5.5-5.8 ms



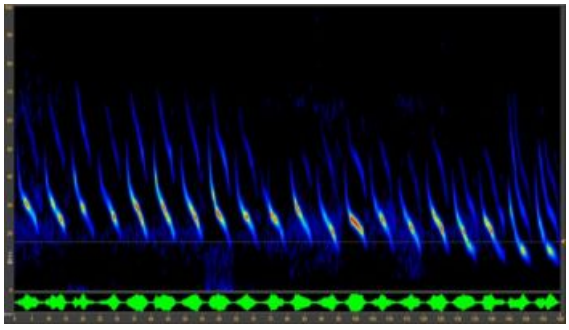
Grey Long-eared Bat - call duration 5.6-5.8 ms



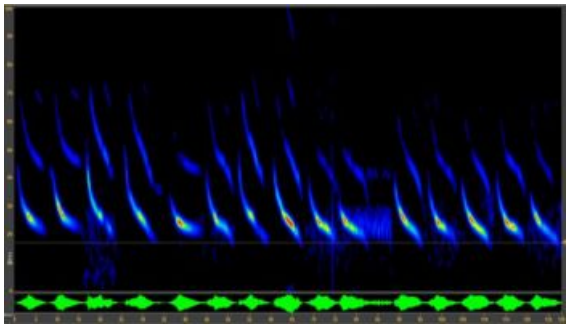
Brown Long-eared Bat - call duration 5.9-6.2 ms



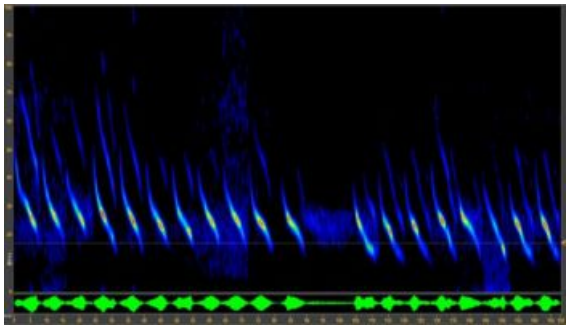
Grey Long-eared Bat - call duration 5.9-6.2 ms



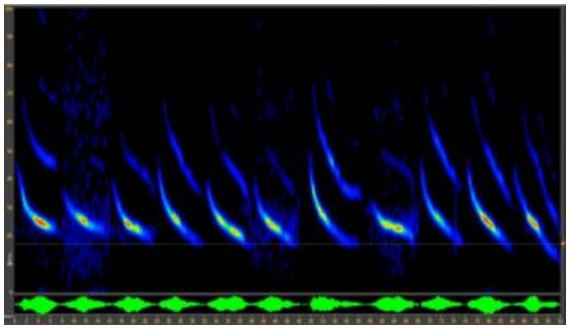
Brown Long-eared Bat - call duration 6.3-6.4 ms



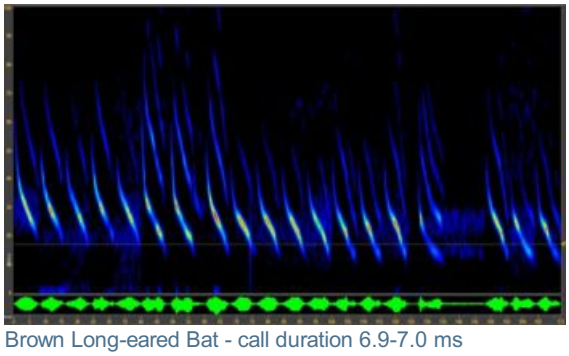
Grey Long-eared Bat - call duration 6.3-6.5 ms



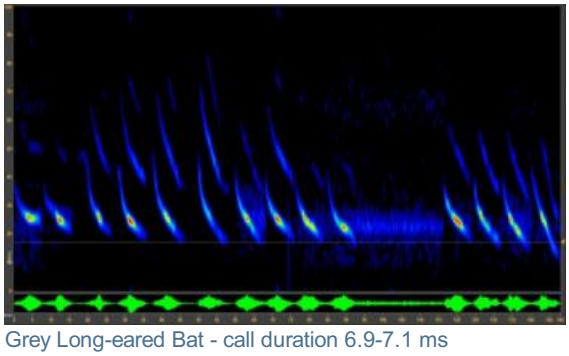
Brown Long-eared Bat - call duration 6.7-6.8 ms



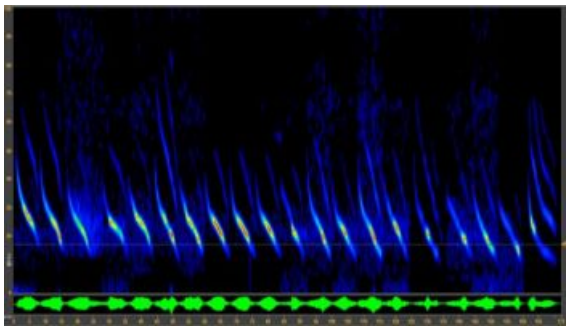
Grey Long-eared Bat - call duration 6.6-6.8 ms



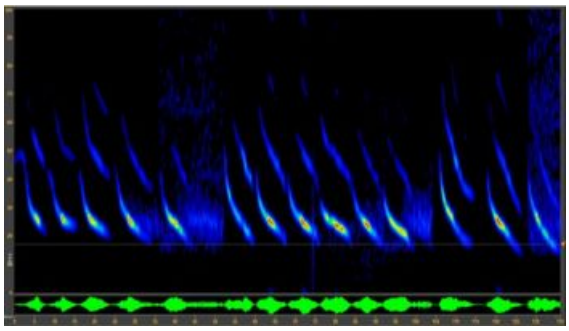
Brown Long-eared Bat - call duration 6.9-7.0 ms



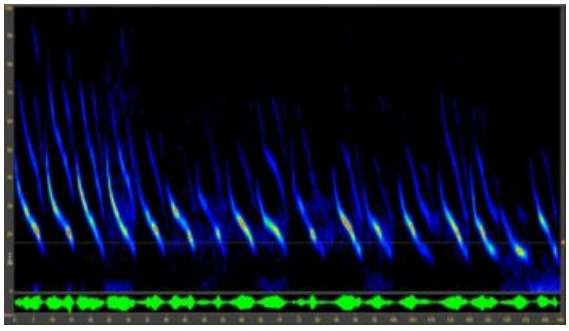
Grey Long-eared Bat - call duration 6.9-7.1 ms



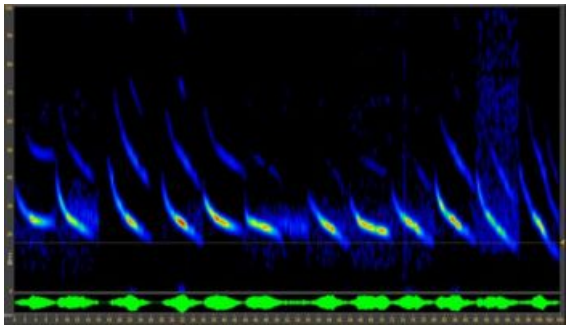
Brown Long-eared Bat - call duration 7.3-7.4 ms



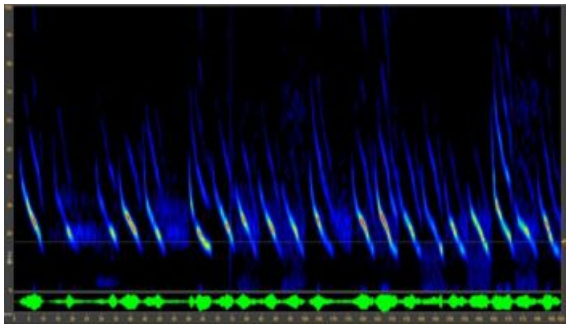
Grey Long-eared Bat - call duration 7.2-7.4 ms



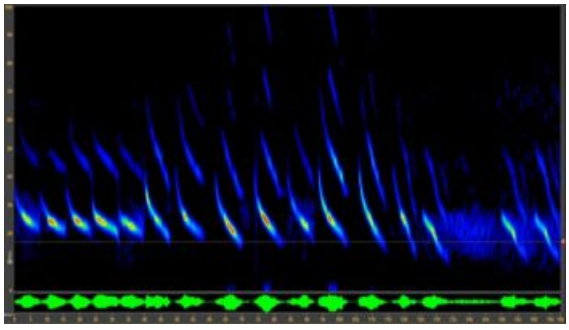
Brown Long-eared Bat - call duration 7.5-7.6 ms



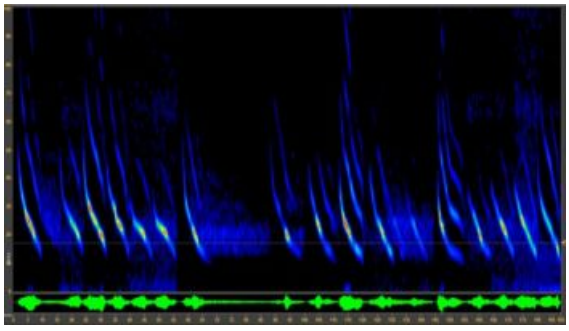
Grey Long-eared Bat - call duration 7.5-7.6 ms



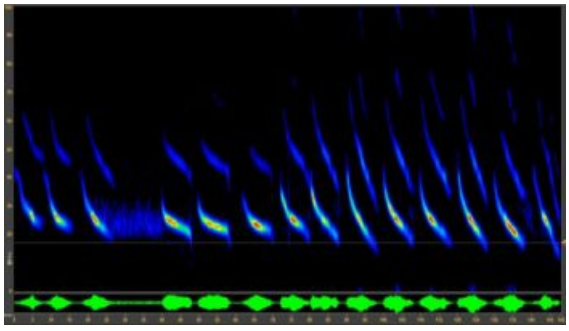
Brown Long-eared Bat - call duration 7.7-7.8 ms



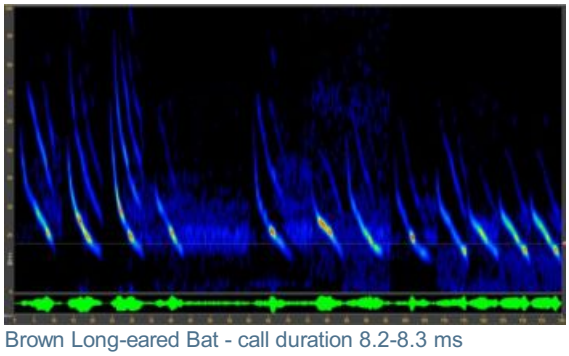
Grey Long-eared Bat - call duration 7.7-7.8 ms



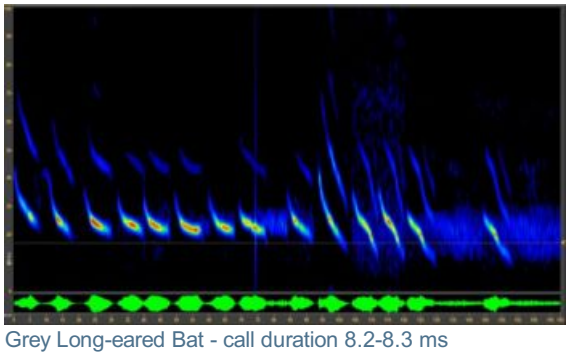
Brown Long-eared Bat - call duration 7.9-8.1 ms



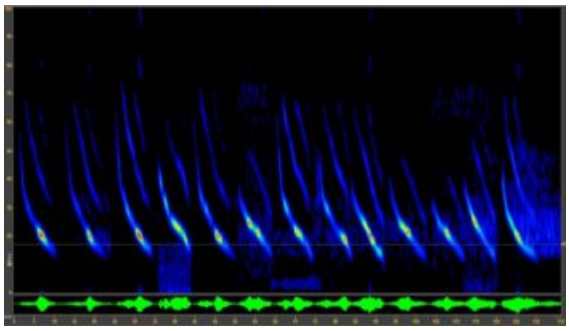
Grey Long-eared Bat - call duration 7.9-8.1 ms



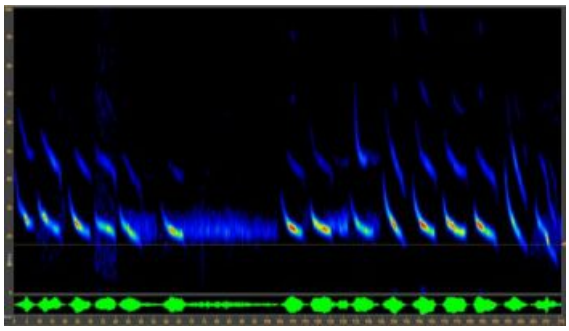
Brown Long-eared Bat - call duration 8.2-8.3 ms



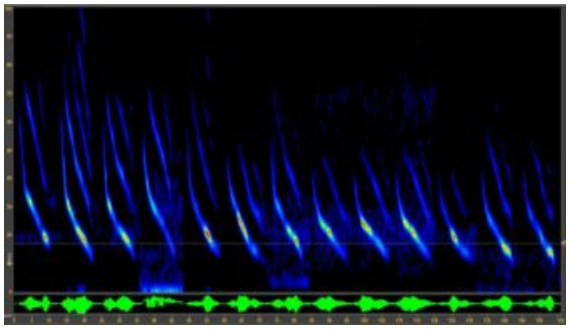
Grey Long-eared Bat - call duration 8.2-8.3 ms



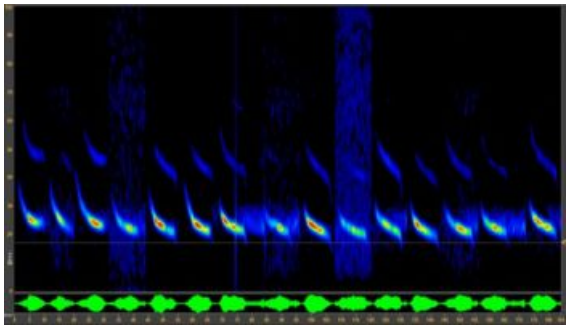
Brown Long-eared Bat - call duration 8.4-8.6 ms



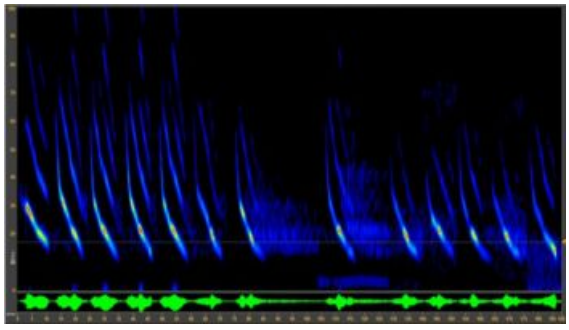
Grey Long-eared Bat - call duration 8.4-8.7 ms



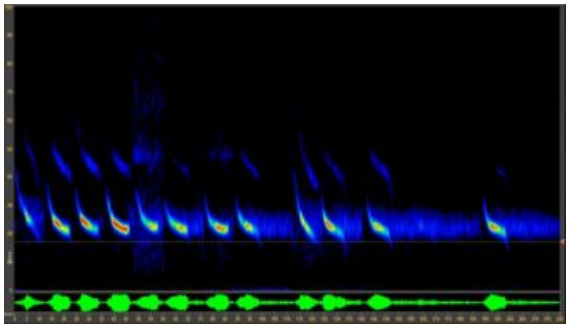
Brown Long-eared Bat - call duration 8.7-9.0 ms



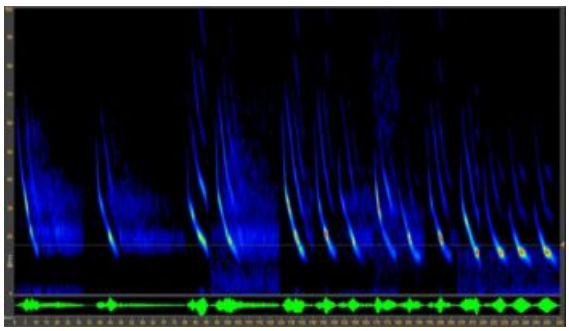
Grey Long-eared Bat - call duration 8.8-9.1 ms



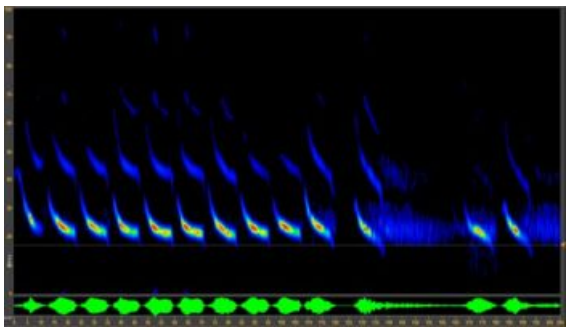
Brown Long-eared Bat - call duration 9.1-9.5 ms



Grey Long-eared Bat - call duration 9.2-9.6 ms



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



Grey Long-eared Bat - call duration 9.7-10.5 ms




Images: Common Pipistrelle, by John Black; Wood Mouse, by Moss Taylor; Speckled Bush-cricket, by Mike Toms; Green silver-lines, by Andy Musgrove.
Cover image: Grey Long-eared Bat, by Henry Schofield.

Silvopasture Biodiversity – Beetles and Bats: providing the infrastructure and protocols that farmers can follow to participate in biodiversity monitoring using passive acoustic monitoring

Acoustic monitoring has developed as a promising approach for surveying biodiversity and quantifying change (e.g. biodiversity credits), due its potential for low-cost, and scalable data collection. This has been driven by the development of better hardware which autonomously collects high-quality data, and machine-learning classifiers that allow for rapid identification of acoustic data. Through this report we demonstrate the possibilities that acoustics using the BTO Acoustic Pipeline (AP) can offer for farmers to self-monitor bats, small mammals, bush-crickets on their land.

Despite the successes of the project, it also highlighted that there remain some substantial barriers to real-world use of acoustic monitoring at scale, due to the lack of accessible tools to aid in survey design, data processing, management and outputs, especially across multiple species groups. At the moment, validation of records is a necessary, but time-consuming, and specialist process. This adds substantial costs to the conducting acoustic monitoring surveys for specialists and means non-specialist users lack the resources to choose appropriate machine-learning classifiers and interpret their outputs. These barriers ultimately mean that users that could benefit most from the advantages of acoustic monitoring (e.g. farmers and other land managers, citizen scientists, developers and NGOs) still need substantial expert input to carry-out projects, negating the cost-saving and accessibility benefits of acoustic monitoring over traditional surveys, such as point counts or roost surveys. Furthermore, lack of standardisation of data processing and outputs from acoustic data means that valuable data cannot feed directly into national monitoring and record schemes without substantial and resource-intensive validation. In a confidential version of this report, we describe solutions to these challenges, and present a vision for the future of acoustic monitoring.

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