

Passive acoustic monitoring on the Hepple Estate, 2024 – piloting the rewilding monitoring framework

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RECOMMENDED CITATION: Ashton-Butt, A., Gough, M., Higgins, S.L., Wetherhill, A. & Newson, S.E. 2025. Passive Acoustic Monitoring on the Hepple Estate, 2024 - Piloting the Rewilding Monitoring Framework. BTO Research Report 782, BTO, Thetford.

Cover design by M.P. Toms

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SUMMARY

Background	This report presents results from the first year of Passive Acoustic Monitoring as part of the pilot of the Rewilding Monitoring Framework. These data will contribute to baselining and monitoring rewilding progress and its impact on biodiversity.
Coverage	The project focuses on four target taxa: birds, bats, small mammals and insects that produce ultrasound. Two of these taxa, birds and bats have been chosen as key indicators in the Rewilding Monitoring Framework. We also test the use of two Soundscape indices, as another key indicator in the Monitoring Framework.
Results	In total, this study identified 90 species on the Hepple Estate including 80 bird species, 7 bat species, 2 small mammal and 1 moth species.

1. BACKGROUND

Over recent years, Rewilding Britain has increasingly been providing support to the Rewilding Network, which connects members rewilding at scale across Britain on what to measure and how to measure, in order to evidence change over time.

Rewilding is a dynamic, unpredictable process that can challenge the monitoring approaches used to track changes at more traditional nature conservation sites. Although rewilding sites collect data and can demonstrate ecological, social and economic changes to a certain extent, there is, as yet, no framework that lays out the most appropriate, measurable metrics for monitoring rewilding progress.

2. AIMS AND OBJECTIVES

We aimed to pilot the use of passive acoustic monitoring (PAM) to baseline and monitor changes in biodiversity at Rewilding Britain member sites. PAM can be used to monitor three key indicators included in the Rewilding Britain monitoring framework: birds, bats and soundscapes. We aimed to survey birds, bats, small mammals, insects that produce ultrasound, and soundscapes on rewilding sites in 2024.

3. METHODS

Planning, deployment of recording equipment, collation of audio recordings and processing through the BTO Acoustic Pipeline were undertaken by the Hepple Estate (MG) and BTO (AAB). Acoustic identification verification, data analysis and reporting were undertaken by BTO (SEN, AW and AAB).

3.1 Static recorder protocol

Our protocol enabled passive acoustic recorders (Song Meter Mini Bats) to record birds during the day, and to automatically trigger and record the calls of bats, small terrestrial mammals, or ultrasound producing moths during the night.

The recorders were placed out to record over two discrete recording sessions of a minimum of seven consecutive days at each location. Multiple days of recording increase the chance of recording species if present and are likely to reduce the impact of weather-related variation, whilst also being easy to implement logistically (once a recorder is on site, it is easy to leave it in situ for multiple days and nights).

Survey sites were taken from a 500 m grid over the whole project area, where half of the grid squares were chosen as sampling sites to achieve good coverage. For larger sites (>1000 ha), half of the sampling squares are surveyed in the first year, and half in the following year. By doing this, we aim to provide representative survey coverage of the area of interest in any year, whilst managing the sampling effort needed each year by site staff. For a 2,000 hectare site, which equates to 80 x 500-m squares, 40 sampling squares would be surveyed in total, with 20 sampling squares/year. Two survey sessions (May - July, and August - September) were chosen to cover the breeding season of birds and bats, as well as the post-breeding period for bats.

The recorders were programmed to cycle between recording birds using an acoustic microphone, and bats, small mammals and bush-crickets with an ultrasonic microphone. For birds, a sample rate of 22,050 Hz was used, recording blocks of one minute in every fifteen minutes from sunrise to sunset. For bats, a sample rate 256,000 Hz and a high pass filter of 13,000 Hz which defined the lower threshold of the frequencies of interest for the triggering mechanism. Ultrasonic recording was set to continue until no trigger was detected for a 2 second period up to a maximum of 5 seconds and activated to trigger between sunset until sunrise the following day. The recorders were mounted on 2 m poles and deployed at least 1.5 m in any direction from vegetation, water or other obstructions to avoid recording sound reflected off these surfaces.

3.2 Processing recordings and species identification

Monitoring on this scale with automated passive real-time recorders 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. Audible recordings and ultrasonic recordings require different methods of analysis and verification as detailed in the following sections.

3.2.1 Audible (bird) recordings

At the end of a recording session, the files recorded by the acoustic recorder (uncompressed wav format), including associated metadata, were processed as follows. All audible / bird recordings were saved onto an external hard drive for later processing by BTO. As the BTO Acoustic Pipeline <http://bto.org/pipeline> all bird species classifier is still in development, we also processed all recordings through BirdNet, another machine-learning based acoustic classifier developed by Cornell University.



BirdNET was configured to return all detections with a confidence score of at least 0.4 and no spatial or temporal species filters were applied. Positive identifications of each species, for each site and period (early or late) of recording were then manually verified by one observer (AW). This was done by selecting 100 detections (or as many as possible if fewer detections) of each species and location with the highest confidence scores. These were checked until at least one true positive detection was found to produce a verified species list for each site and sampling period. Vocal activity of bird species (number of calls per day) was included but should be used with caution, as the accuracy (proportion of true to false positives) and detectability (proportion of true positives to false negatives) can differ considerably between species and between sites, and there was not the resources in this project to quantify these measures.

3.2.2 Ultrasonic recordings

For the ultrasonic / bat processing, the site staff 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 acoustic recorders were deployed), which are matched automatically to the results. Once a batch of recordings is processed, the user is emailed automatically, and the raw results are then downloadable through the user account as a csv file. These provisional results are provided with the caveat that additional auditing of the results and recordings must be carried out to manually confirm identifications.

The ultrasonic processing through 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 pygmaeus*, we checked a random sample of 1,000 recordings to quantify the error rate in the dataset. For insects 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 by SN through the manual checking of spectrograms using software SonoBat (<http://sonobat.com/>) which was used as an independent check of the original species identities assigned by pipeline. The spectrograms shown in this report, were also produced using SonoBat. All subsequent analyses use final identities upon completion of the above inspection and (where necessary) correction steps.

3.2.1 Soundscape indices

Another approach to analysing audio data is whole soundscape analyses using soundscape indices. A soundscape approach focuses on broader acoustic dynamics and patterns. Soundscape indices are rapid to compute and do not

need specialist knowledge to check and validate data. We tested the use of two bioacoustic indices on audible recordings (recordings that include all audible sound, including, but not limited to bird vocalisations):

Bioacoustic Index. Higher values indicate a greater disparity between the loudest and quietest bands. Originally designed to reflect the complexity of Hawaiian birdsong, to act as a proxy for relative avian abundance. Eldridge *et al.* (2018) reported strong positive associations between the Bioacoustic Index and avian species richness in UK woodland habitat, and Bradfer-Lawrence *et al.* (2020) report strong associations between Bioacoustic Index and mean avian species richness across a range of habitats in Republic of Panama.

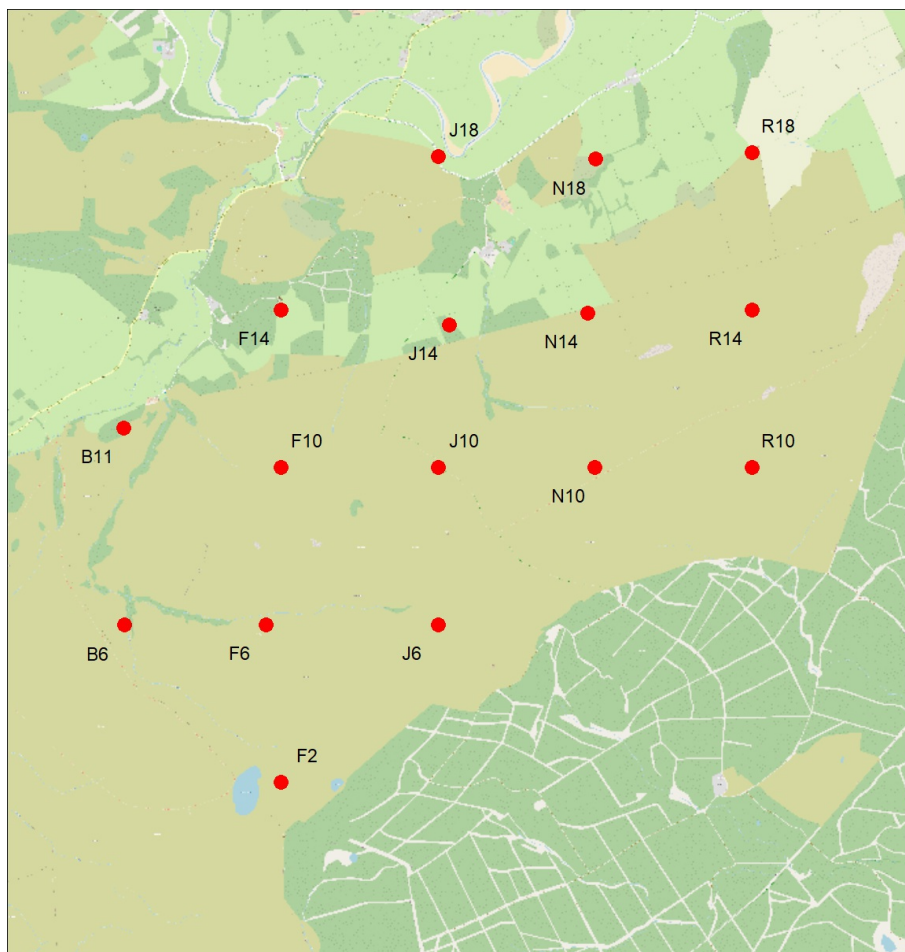
Normalised Difference Soundscape Index (NDSI) Values closer to +1 indicate a soundscape dominated by biophony (biological sounds), values closer to -1 indicates high levels of anthropophony (human sounds e.g. cars, planes). NDSI has been found to be correlated with both biotic and anthropogenic sound diversity in urban settings (Fairbrass *et al.* 2017).

4. RESULTS

4.1 Survey coverage

The distribution of sites surveyed during 2024 are shown below. Collectively across all these sites, 392 days of recording effort was conducted. The recording effort spanned 83 different days and 5 months.

Map of the study area showing locations where audio recorders were deployed in 2024.



4.2 General results

Processing of audible recordings by BirdNET followed by manual verification confirmed the presence of 80 bird species over the 16 sites. In addition to the audible data, 170,612 ultrasonic recordings were collected which, following analyses and validation, were found to include 62,149 bat recordings, and 85 small terrestrial mammal recordings. In addition, one species of audible moth species was recorded (see table below). Following validation, the presence of at least seven bat species, two small mammal species, and one audible moth species can be confirmed.

In the following tables, we consider conservation status of birds according to Birds of Conservation Concern 5 (Stanbury *et al.* 2021) which assigns species to a Red List and Amber list according to measured population declines and range contractions. For other species groups we use categories from the IUCN Red List of Threatened Species (www.iucnredlist.org/): Critically Endangered, Endangered, Vulnerable, Near Threatened, and Data Deficient.

The full list of the species detected, the proportion of sites a species was detected and the conservation status.

Bats

Species (/call type)	No. of recordings following validation	No. of different sites (% of total)	Conservation status
Brown Long-eared Bat echolocation calls, <i>Plecotus auritus</i>	1,062	15 (93.8%)	•
Brown Long-eared Bat social calls, <i>Plecotus auritus</i>	2	1 (6.2%)	
Common Noctule echolocation calls, <i>Nyctalus noctula</i>	2,270	16 (100%)	•
Common Noctule feeding buzzes, <i>Nyctalus noctula</i>	80	14 (87.5%)	
Common Noctule social calls, <i>Nyctalus noctula</i>	7	6 (37.5%)	
Common Pipistrelle echolocation calls, <i>Pipistrellus pipistrellus</i>	22,016	16 (100%)	•
Common Pipistrelle feeding buzzes, <i>Pipistrellus pipistrellus</i>	300	15 (93.8%)	
Common Pipistrelle social calls, <i>Pipistrellus pipistrellus</i>	1,743	15 (93.8%)	
Daubenton's Bat echolocation calls, <i>Myotis daubentonii</i>	2,135	16 (100%)	•
Daubenton's Bat feeding buzzes, <i>Myotis daubentonii</i>	115	7 (43.8%)	
Daubenton's Bat social calls, <i>Myotis daubentonii</i>	1	1 (6.2%)	
Natterer's Bat echolocation calls, <i>Myotis nattereri</i>	4,360	16 (100%)	•
Natterer's Bat feeding buzzes, <i>Myotis nattereri</i>	98	5 (31.2%)	
Natterer's Bat social calls, <i>Myotis nattereri</i>	3	2 (12.5%)	
Soprano Pipistrelle echolocation calls, <i>Pipistrellus pygmaeus</i>	18,175	16 (100%)	•
Soprano Pipistrelle feeding buzzes, <i>Pipistrellus pygmaeus</i>	1,996	16 (100%)	
Soprano Pipistrelle social calls, <i>Pipistrellus pygmaeus</i>	5,831	15 (93.8%)	
Whiskered or Brandt's Bat echolocation calls, <i>Myotis mystacinus</i> or <i>M. brandtii</i>	1,955	16 (100%)	•

Small mammals

Species	No. of recordings following validation	No. of different sites (% of total)	Conservation status
Eurasian Pygmy Shrew, <i>Sorex minutus</i>	84	13 (81.2%)	
Wood Mouse, <i>Apodemus sylvaticus</i>	1	1 (6.2%)	

Moths

Species	No. of different locations (% of total)	Conservation status
Green Silver-lines, <i>Pseudoips prasinana</i>	1 (6.2%)	

Birds, bats and small mammals recorded by site between May-July (early survey) and August-September (late survey). For bats and small mammals we present the average number of recordings / night (rounded to nearest whole number) as a measure of activity. For birds, we present the average number of detections / day (rounded to nearest whole number).

Birds

	B11		B6		F10		F14		F2		F6		J10		J14		J18		J6		N10		N14		N18		R10		R14		R18	
	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L
Blackbird	1	0	0	0	0	0	3	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	13	0	0	0	0	0	1	0
Blackcap	6	5	0	0	0	0	7	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0
Blue Tit	1	1	0	0	0	0	0	1	0	0	0	0	0	0	1	2	1	0	0	0	0	0	0	0	1	2	0	0	0	0	1	0
Bullfinch	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Buzzard	1	1	5	0	1	0	1	2	1	0	1	0	1	1	2	4	0	3	1	1	1	2	1	4	1	13	1	0	0	1	1	5
Canada Goose	1	0	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	2
Carrion Crow	1	3	0	0	1	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1
Chaffinch	11	5	1	0	0	0	27	1	0	0	0	0	0	0	1	2	2	1	0	0	0	0	0	0	1	1	0	0	0	0	0	10
Chiffchaff	10	0	1	1	0	0	16	6	0	0	0	14	0	0	7	33	0	2	0	0	0	1	0	1	11	35	0	0	1	0	1	9
Coal Tit	1	1	0	1	0	0	4	6	0	0	0	0	1	0	0	1	6	1	0	0	0	0	0	1	0	2	0	0	0	0	0	1
Common Redpoll	1	0	1	1	1	0	1	1	1	0	3	2	1	1	17	7	2	1	1	0	3	0	1	1	2	9	0	0	1	0	0	1
Common Sandpiper	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Crossbill	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Cuckoo	5	0	5	0	3	0	4	0	1	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	2	0	0	0	0	0
Curlew	1	0	1	0	1	0	0	0	0	0	0	0	1	0	1	0	2	1	2	0	1	0	1	0	1	2	0	0	1	1	2	4
Duncock	1	0	2	2	0	0	0	0	0	1	1	11	5	5	1	6	0	0	1	1	2	3	1	0	1	2	1	0	3	0	1	1
Garden Warbler	0	0	0	0	0	0	0	0	0	0	1	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Goldcrest	0	0	1	0	0	0	1	1	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
Golden Plover	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0
Goldfinch	1	0	1	0	0	0	1	0	0	0	1	0	1	0	1	6	19	2	1	0	0	0	1	1	4	4	0	0	0	0	1	4
Great Spotted Woodpecker	0	0	0	0	0	0	5	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	1	0	2	0	0	0	0	0	0
Great Tit	1	2	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
Green Sandpiper	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Greenfinch	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Greenshank	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	1
Grey Wagtail	0	0	1	1	0	0	0	0	0	0	0	0	0	1	0	1	0	4	0	0	0	1	0	0	0	1	0	0	0	0	0	1
Greylag Goose	1	0	0	0	1	0	1	0	2	0	1	0	1	0	0	1	0	0	1	0	0	0	0	1	0	5	0	0	0	0	0	7
House Martin	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	0	1	0	0	0	1	0	1	0	1	0	0	0	0	0	0
Jay	2	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	1	0	2	0	0	0	0	0	4
Kestrel	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	2	2	0	0	0	0	0	1
Lapwing	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Linnet	1	1	10	1	1	0	0	0	0	0	2	0	1	0	18	4	17	1	0	0	1	2	9	3	3	2	2	1	17	4	8	3
Long-tailed Tit	3	0	0	0	0	0	2	0	0	0	0	0	0	0	2	6	0	5	0	0	0	0	0	0	1	7	0	0	0	0	0	5
Magpie	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	1
Mallard	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Meadow Pipit	1	0	9	5	53	0	0	0	69	6	13	2	34	10	19	36	26	41	16	4	80	97	76	57	24	33	94	87	23	31	68	92
Merlin	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mistle Thrush	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	5	3	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Mute Swan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Nuthatch	2	0	0	0	0	0	2	7	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	1
Oystercatcher	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1
Peregrine	0	0	1	0	0	0	0	0	0	0	6	2	1	1	1	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	1

	B11		B6		F10		F14		F2		F6		J10		J14		J18		J6		N10		N14		N18		R10		R14		R18		
	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	
Pheasant	8	1	1	2	2	0	22	4	0	0	0	0	0	0	2	5	3	1	1	0	0	0	0	10	8	4	16	0	0	1	0	1	8
Pied Flycatcher	0	0	0	0	0	0	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Pied Wagtail	0	0	1	1	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	
Pink-footed Goose	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	2	0	0	0	0	
Raven	1	0	1	0	1	0	0	1	0	0	0	0	0	1	0	1	0	1	0	1	0	0	0	1	0	1	1	1	1	0	0	1	
Redshank	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Redstart	37	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1	0	0	0	0	2	1	
Reed Bunting	1	0	1	0	0	0	0	0	1	2	0	0	1	0	0	1	0	0	0	0	0	0	4	0	43	20	0	0	0	1	0	3	
Ringed Plover	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Robin	6	11	1	1	0	0	22	5	0	0	1	3	0	0	0	6	0	0	0	0	0	0	0	0	1	8	0	0	2	0	0	1	
Rook	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	7	0	0	0	0	1	0	1	2	0	0	0	0	1	9	
Sand Martin	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1	0	2	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	
Short-eared Owl	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
Siskin	1	1	1	0	1	0	1	7	2	0	1	1	2	0	4	3	9	0	1	0	1	1	1	1	2	3	0	1	1	0	1	1	
Skylark	0	0	0	0	0	0	0	0	2	0	0	0	5	0	11	2	5	0	1	0	2	0	106	29	1	1	13	4	2	0	15	15	
Snipe	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	
Song Thrush	1	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1	0	1	1	1	0	0	0	0	1	0	0	0	0	0	0	1	
Spotted Flycatcher	0	7	0	0	0	0	9	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	
Starling	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Stock Dove	1	1	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	
Stonechat	0	0	1	1	0	0	0	0	4	5	2	12	5	8	1	1	1	1	0	0	1	8	0	0	1	5	0	0	1	9	2	0	
Swallow	1	1	1	1	1	0	0	2	0	0	0	1	0	1	0	1	0	0	1	0	0	1	1	1	1	2	0	1	0	0	2	1	
Swift	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	
Tawny Owl	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Tree Pipit	1	0	0	2	0	0	0	0	0	1	0	1	0	3	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	2	
Treecreeper	8	2	0	0	0	0	6	2	0	0	0	0	0	0	0	1	3	0	0	0	0	0	0	0	1	1	0	0	0	0	0	1	
Wheatear	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Whinchat	0	0	1	0	0	0	0	0	0	0	0	1	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Whitethroat	0	0	29	0	9	0	0	0	5	0	159	3	24	0	8	0	56	2	0	0	1	0	1	0	0	1	0	0	1	0	6	0	
Willow Warbler	14	1	1	0	0	0	2	1	1	0	28	2	25	1	15	0	13	0	0	0	0	0	1	0	44	0	0	0	31	0	1	1	
Woodcock	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Woodpigeon	22	23	1	1	1	0	35	12	0	0	1	1	0	0	4	25	6	2	0	0	0	0	2	5	18	28	1	0	1	0	3	10	
Wren	59	17	35	6	121	0	56	3	17	2	114	63	163	17	31	18	33	5	157	5	145	58	1	2	3	19	10	6	148	63	1	1	
Yellowhammer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	

Bats

	B11		B6		F10		F14		F2		F6		J10		J14		J18		J6		N10		N14		N18		R10		R14		R18	
	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L
Brown Long-eared Bat echolocation calls	3	10	0	2	0	0	6	43	0	5	2	15	0	2	1	9	2	4	1	12	0	13	3	8	6	13	0	11	4	11	3	11
Brown Long-eared Bat social calls	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	B11		B6		F10		F14		F2		F6		J10		J14		J18		J6		N10		N14		N18		R10		R14		R18	
	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L
Common Noctule echolocation calls	13	12	45	49	41	17	25	29	1	4	6	21	7	12	6	60	33	80	0	11	33	10	5	15	12	12	0	5	5	13	3	6
Common Noctule feeding buzzes	1	1	8	3	3	0	2	1	0	0	0	2	1	3	1	3	1	9	0	1	2	1	0	2	0	1	0	1	0	0	0	1
Common Noctule social calls	0	0	0	2	1	0	1	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Common Pipistrelle echolocation calls	690	3,413	47	176	61	9	111	29	11	107	120	299	27	4	7	97	71	44	28	26	8	58	22	79	33	20	1	8	22	314	12	18
Common Pipistrelle feeding buzzes	14	62	1	0	2	0	2	1	1	0	1	2	1	0	0	9	3	0	2	1	0	1	1	0	2	1	0	0	1	2	0	1
Common Pipistrelle social calls	42	501	2	18	2	0	6	5	0	2	5	16	1	0	0	15	3	5	0	1	0	2	0	3	1	0	0	0	0	52	0	5
Daubenton's Bat echolocation calls	79	344	3	5	1	0	20	20	4	7	7	26	2	1	0	12	33	5	6	10	0	4	21	8	7	5	0	3	21	10	2	3
Daubenton's Bat feeding buzzes	8	26	0	0	0	0	3	2	0	0	0	3	0	0	0	1	8	1	0	2	0	0	0	0	1	1	0	0	0	0	0	0
Daubenton's Bat social calls	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Natterer's Bat echolocation calls	12	28	4	15	1	0	162	38	0	7	3	18	0	9	8	9	49	8	2	10	3	14	8	15	40	91	0	90	7	5	2	14
Natterer's Bat feeding buzzes	1	0	0	0	0	0	4	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	8	0	4	0	0	0	0
Natterer's Bat social calls	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Soprano Pipistrelle echolocation calls	223	676	9	101	15	0	461	571	4	13	19	25	5	4	2	74	213	54	9	19	1	20	7	46	30	58	0	13	6	189	10	18
Soprano Pipistrelle feeding buzzes	18	94	1	4	2	0	84	33	0	4	5	4	0	1	0	16	80	31	1	7	0	4	0	6	7	37	0	1	0	20	2	4
Soprano Pipistrelle social calls	34	463	1	54	1	0	48	456	0	1	1	10	0	0	0	11	12	10	0	2	0	1	0	3	1	10	0	1	0	51	1	2
Whiskered or Brandt's Bat echolocation calls	96	84	6	6	0	1	240	7	0	11	0	15	0	2	63	15	15	6	2	12	0	2	8	5	4	2	0	5	8	4	0	2

Small mammals

	B11		B6		F10		F14		F2		F6		J10		J14		J18		J6		N10		N14		N18		R10		R14		R18	
	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L
Eurasian Pygmy Shrew	4	1	0	1	10	1	0	1	0	1	11	1	21	1	0	0	0	2	0	0	1	2	0	1	2	0	0	2	0	0	1	
Wood Mouse			1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

The number of species of Birds of Conservation Concern 5 (BOCC5) and IUCN (International Union for Conservation of Nature) Red List species detected overall.

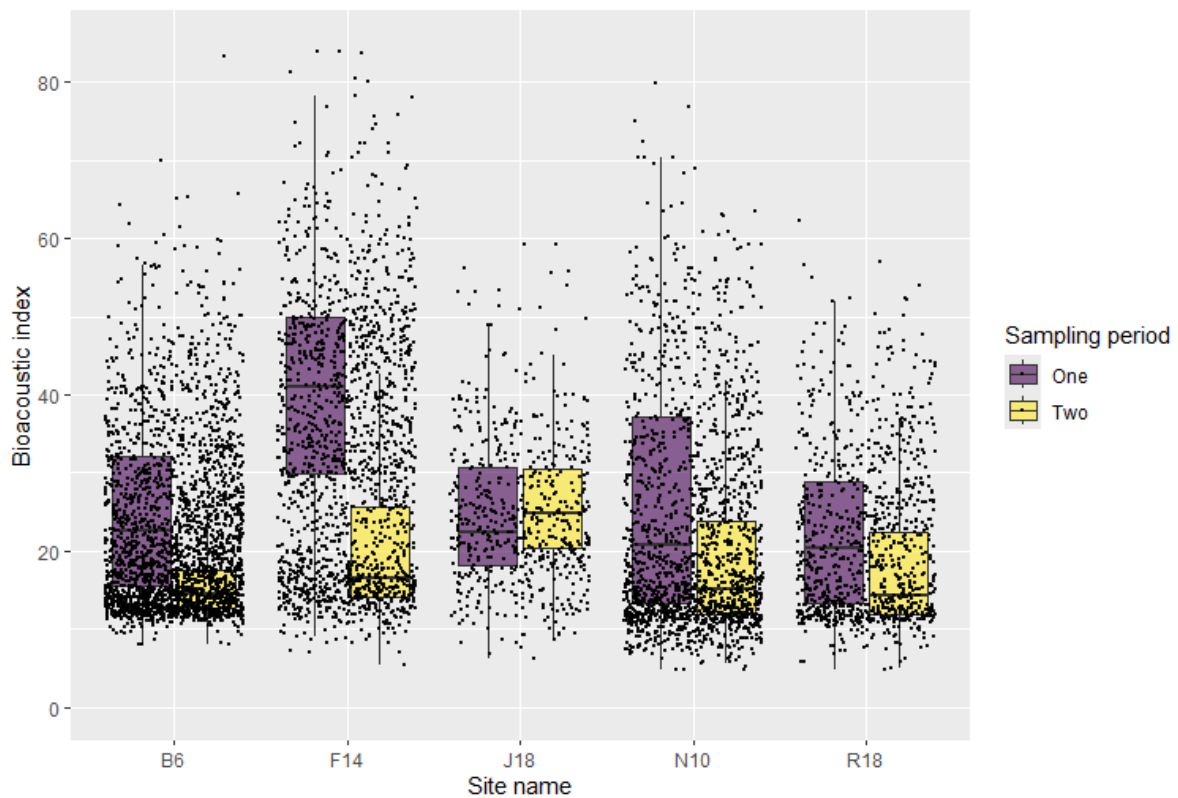
	Number of species
All birds	80
Birds of Conservation Concern 5 (BOCC5) - Red-listed	0
Birds of Conservation Concern 5 (BOCC5) - Amber-listed	0
All bats	7
IUCN Red Listed Threatened Species - Near threatened	0
IUCN Red Listed Threatened Species - Vulnerable	0
All small mammals	2
All moths	1

The number of species of Birds of Conservation Concern 5 (BOCC5) and IUCN (International Union for Conservation of Nature) Red List species detected at each site.

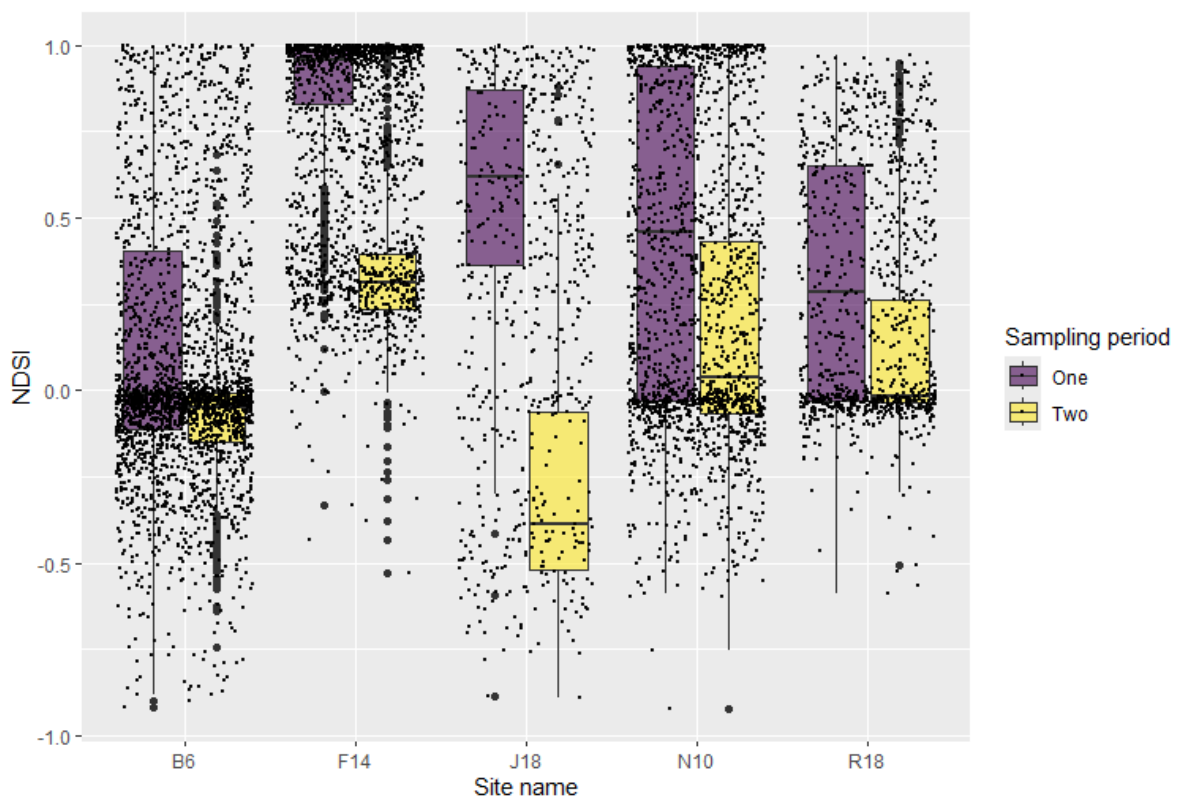
	B11	F14	R18	J6	F6	N14	N10	J14	F10	R10	N18	J18	J10	F2	B6	R14
All birds	45	23	36	36	48	23	31	20	35	54	49	43	20	33	27	22
BOCC5 - Red-listed	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BOCC5 - Amber-listed	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
All bats	7	6	7	7	7	7	7	7	7	7	7	7	7	7	7	7
IUCN - Near threatened	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IUCN - Vulnerable	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
All small mammals	2	1	1	1	0	1	1	0	1	1	1	0	1	1	1	1
All moths	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

4.3 Soundscape indices

The following figure displays box and whisker plots of Bioacoustic Index soundscape indices for five sites at Hepple, separated by sampling period. The Bioacoustic Index was calculated for every one-minute low frequency recording at each site. Horizontal lines represent the 25%, 50% and 75% quantiles and all values are plotted using a jitter function so the spread of the data can be seen. A higher Bioacoustic Index has been found to correlate with bird species richness in previous studies, so sites with higher values may indicate a greater diversity of species.



The following figure displays box and whisker plots of NDSI soundscape indices for five sites at Hepple, separated by sampling period. The NDSI was calculated for every one-minute low frequency recording at each site. Horizontal lines represent the 25%, 50% and 75% quantiles and all values are plotted using a jitter function so the spread of the data can be seen. High NDSI values indicate soundscapes dominated by animal noises and low values indicate sites dominated by anthropogenic noises.



4.4 Species and call-type activity results

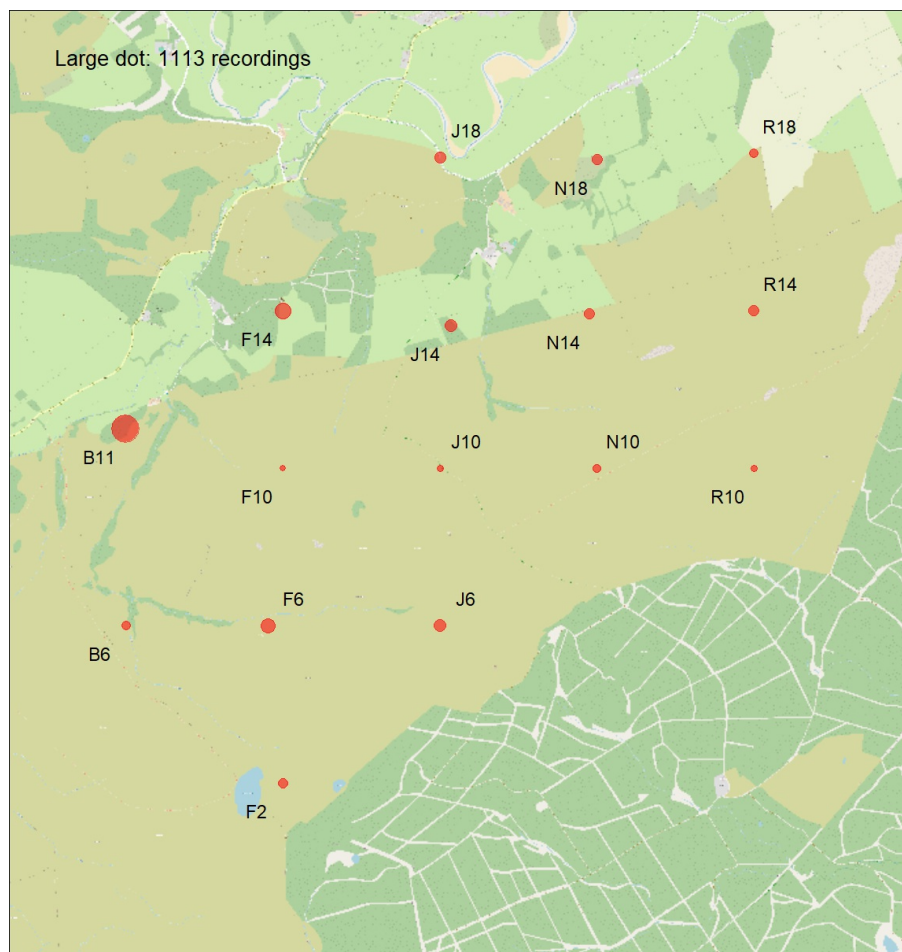
The following sections provide results for each species and/or call type for bats, small mammals and moths based on the number of triggered recordings as a measure of activity.

4.4.1 Bat species

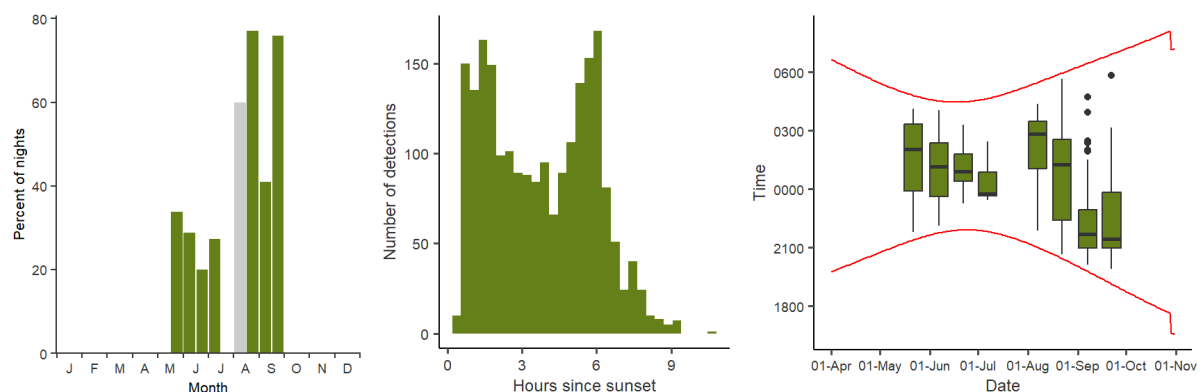
Daubenton's Bat echolocation calls

Daubenton's Bat echolocation calls *Myotis daubentonii* was recorded on 64 nights, from 16 locations, giving a total of 2,135 recordings.

Spatial pattern of activity



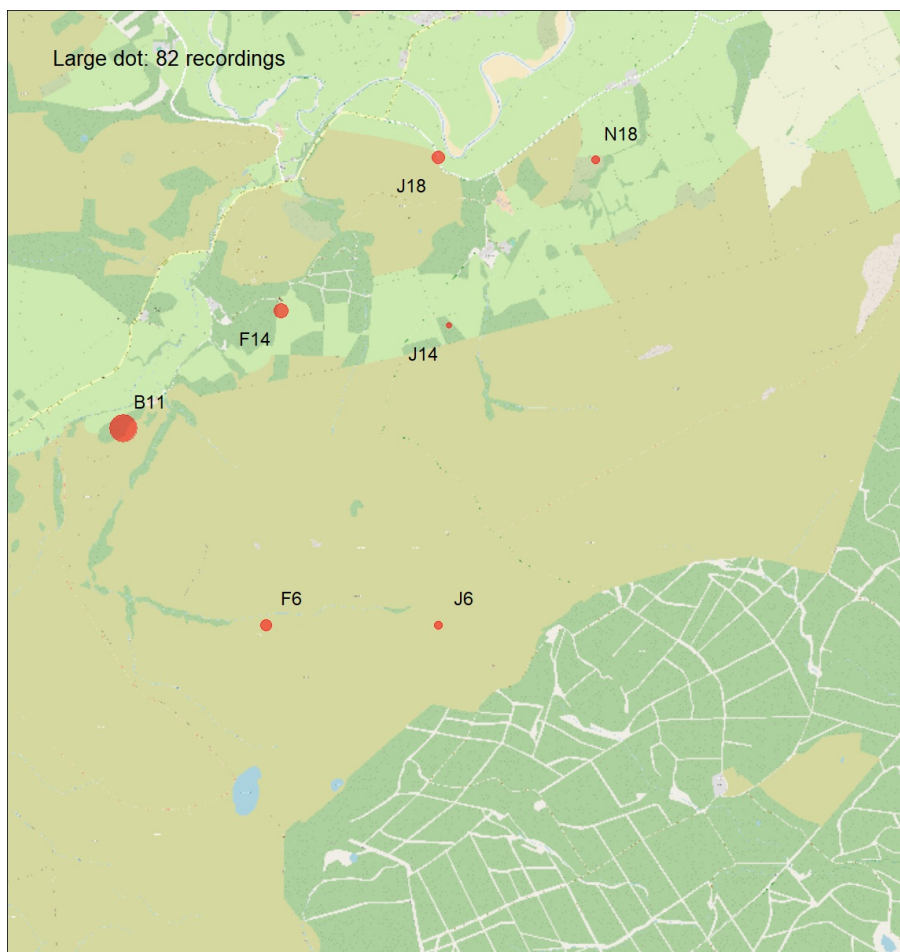
Seasonal and nightly activity



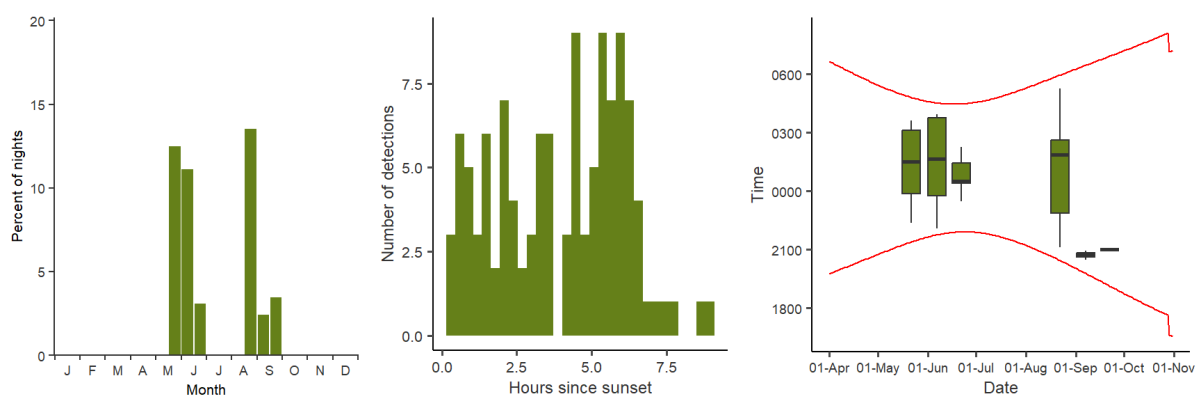
Daubenton's Bat feeding buzzes

Daubenton's Bat feeding buzzes *Myotis daubentonii* were recorded on 25 nights, from 7 locations, giving a total of 115 recordings.

Spatial pattern of activity



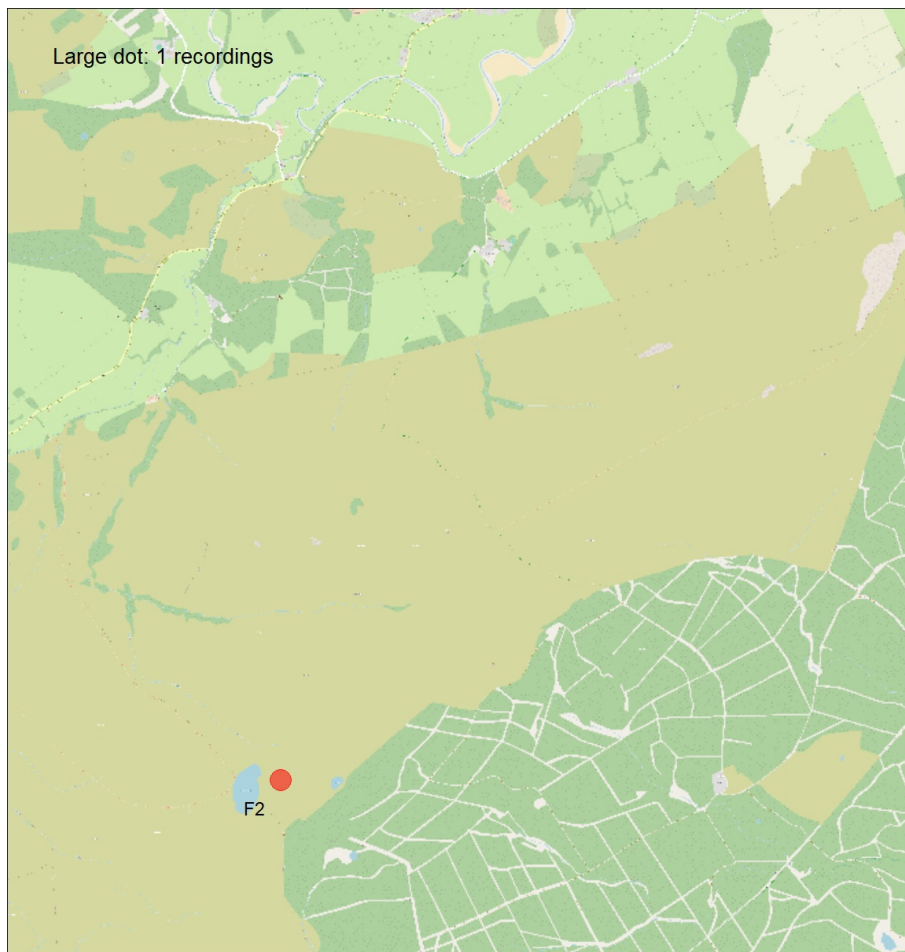
Seasonal and nightly activity



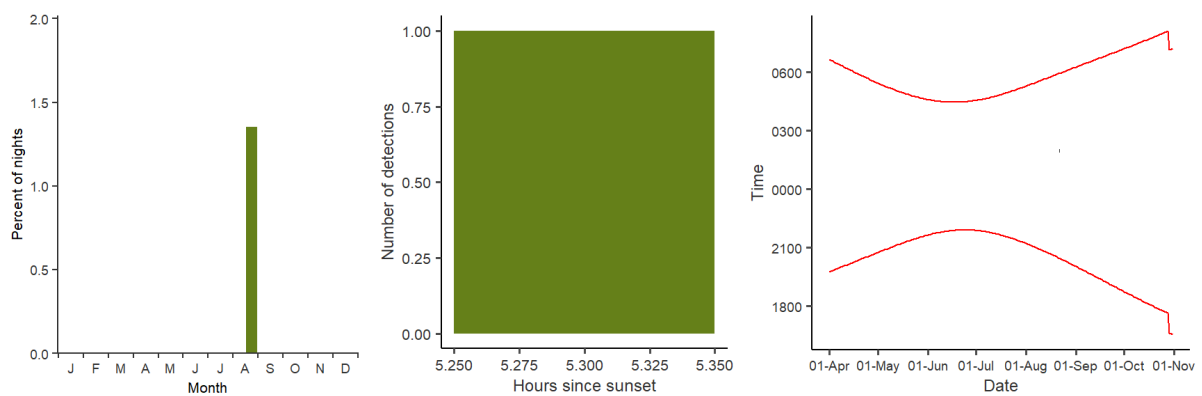
Daubenton's Bat social calls

Daubenton's Bat social calls *Myotis daubentonii* were recorded on one night, from 1 location, giving a total of 1 recording.

Spatial pattern of activity



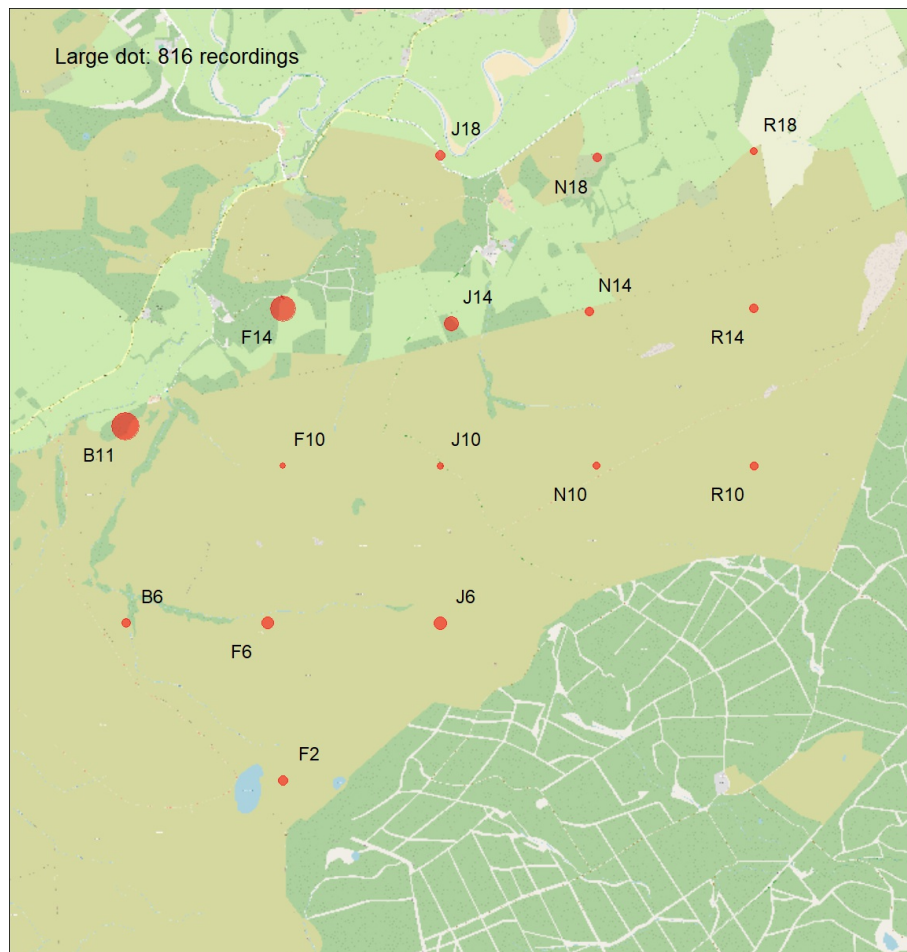
Seasonal and nightly activity



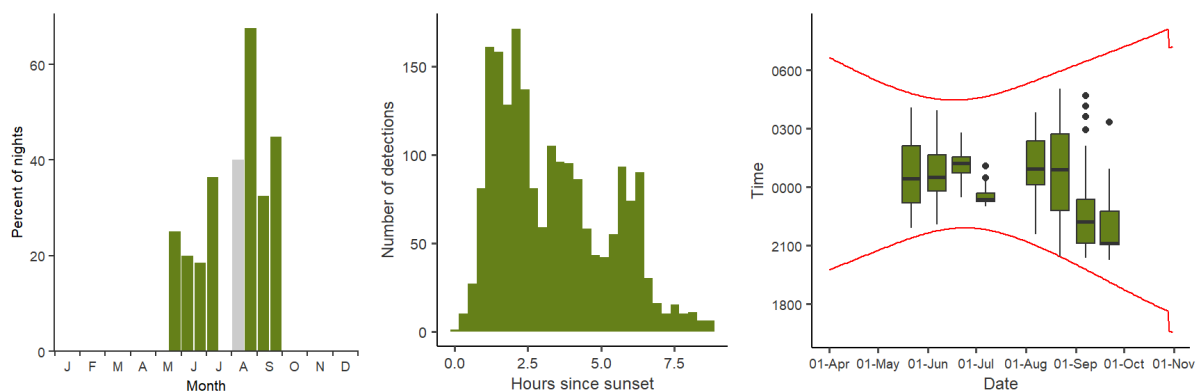
Whiskered or Brandt's Bat echolocation calls

Whiskered or Brandt's Bat echolocation calls *Myotis mystacinus* or *M. brandtii* was recorded on 62 nights, from 16 locations, giving a total of 1,955 recordings.

Spatial pattern of activity



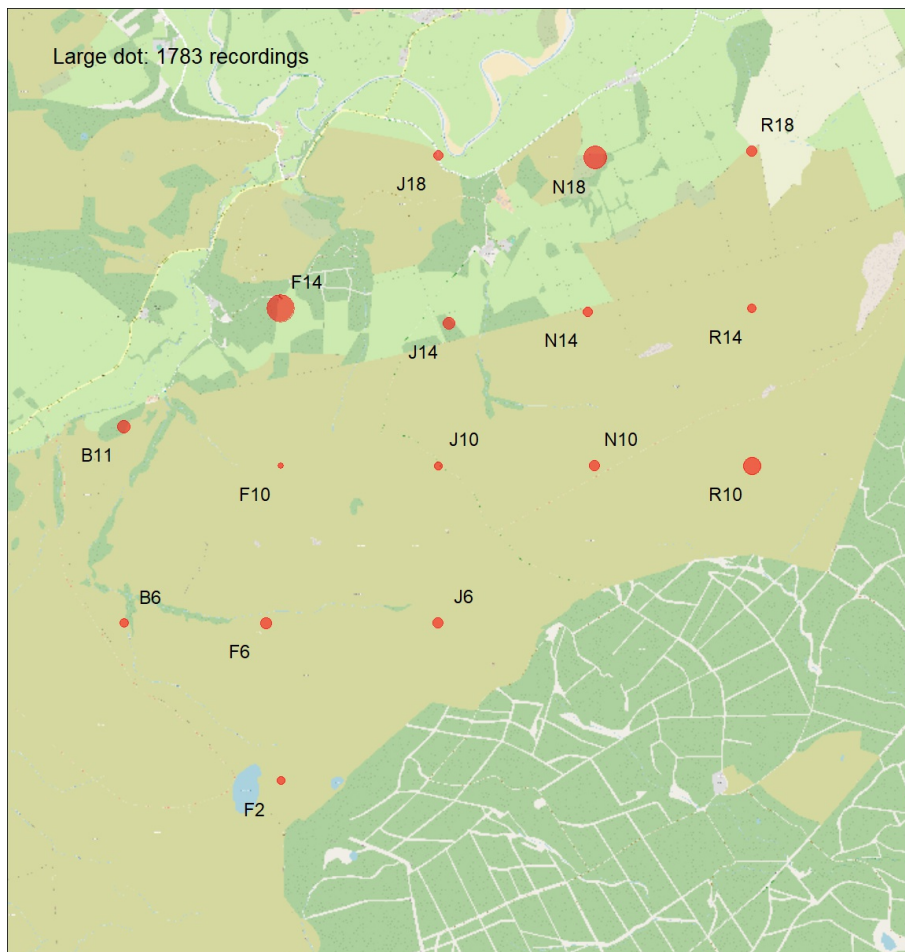
Seasonal and nightly activity



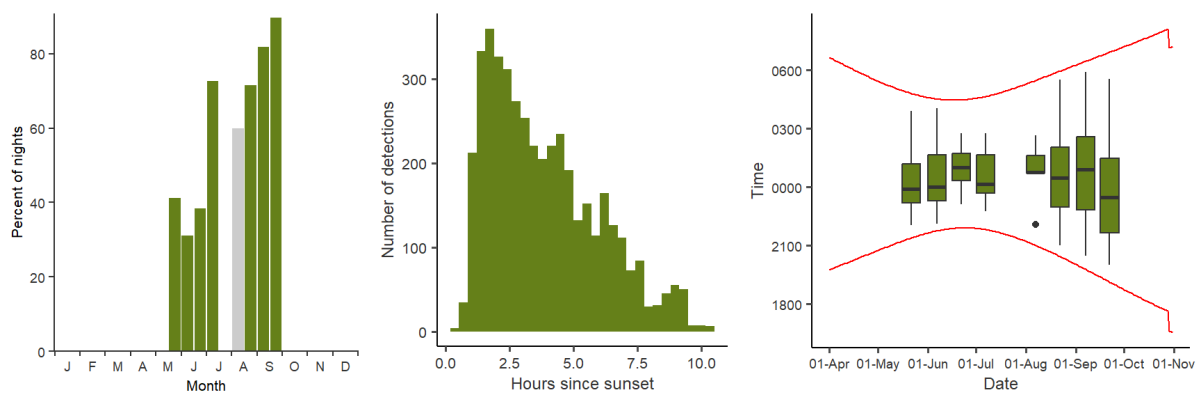
Natterer's Bat echolocation calls

Natterer's Bat echolocation calls *Myotis nattereri* was recorded on 74 nights, from 16 locations, giving a total of 4,360 recordings.

Spatial pattern of activity



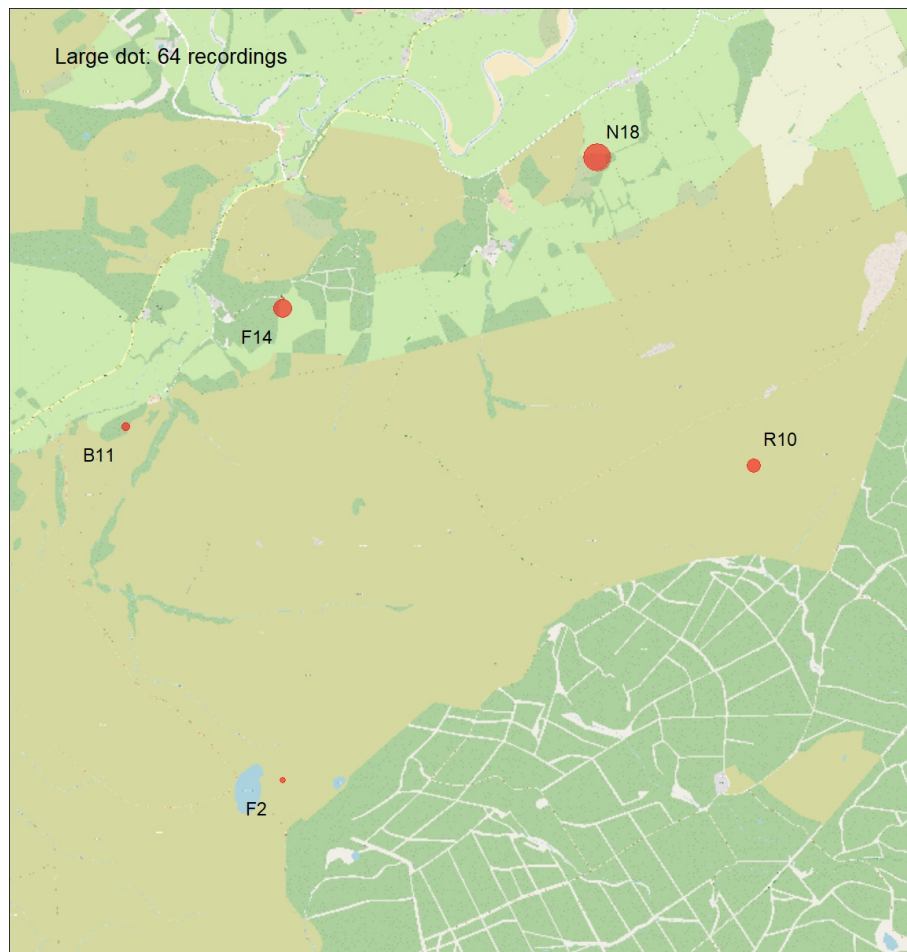
Seasonal and nightly activity



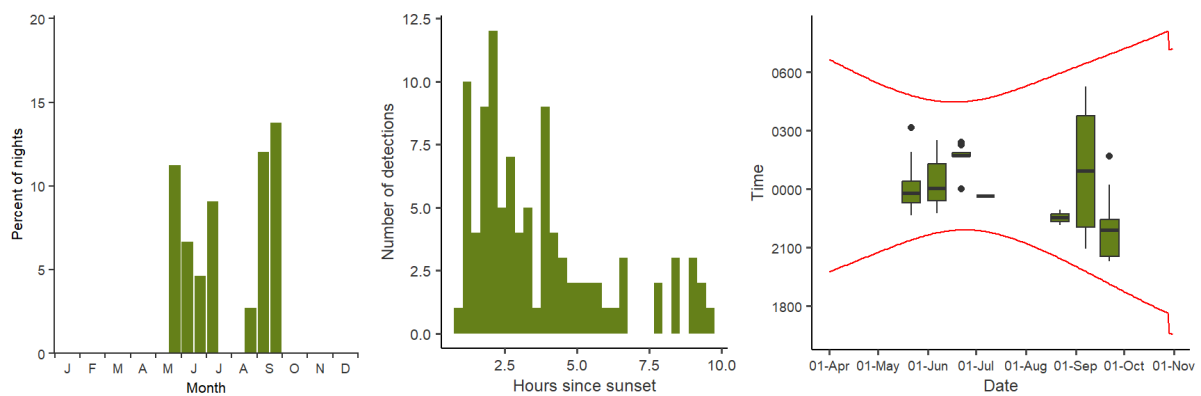
Natterer's Bat feeding buzzes

Natterer's Bat feeding buzzes *Myotis nattereri* were recorded on 30 nights, from 5 locations, giving a total of 98 recordings.

Spatial pattern of activity



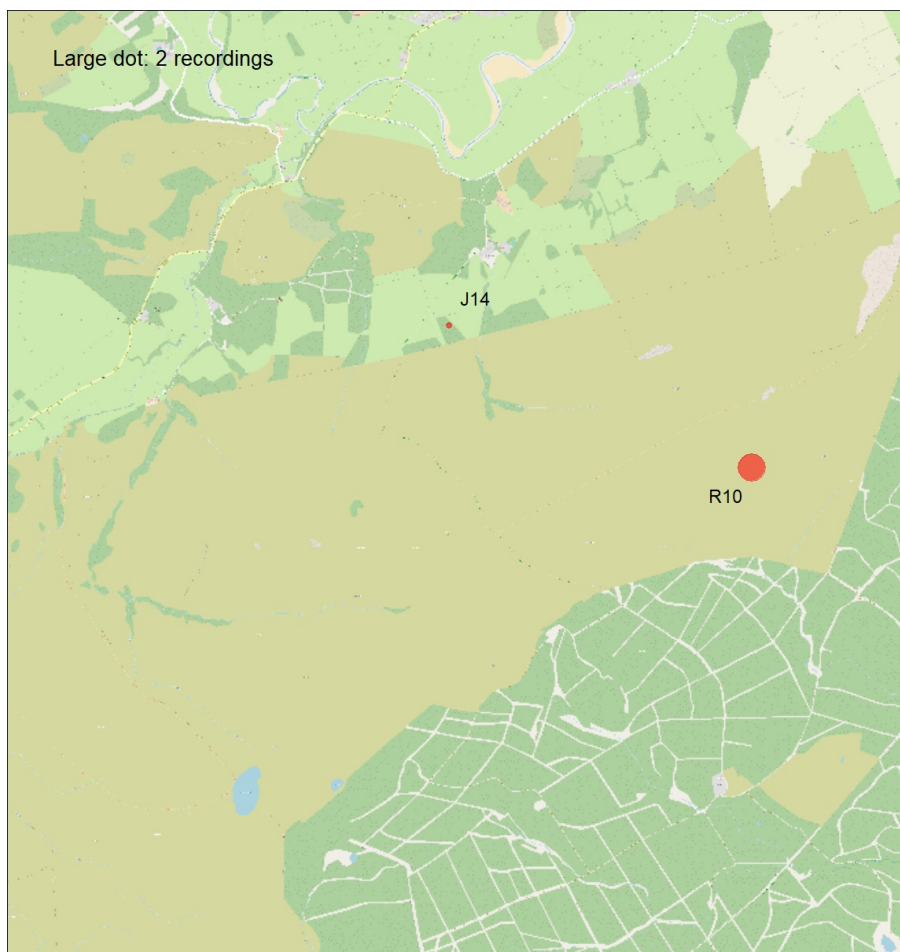
Seasonal and nightly activity



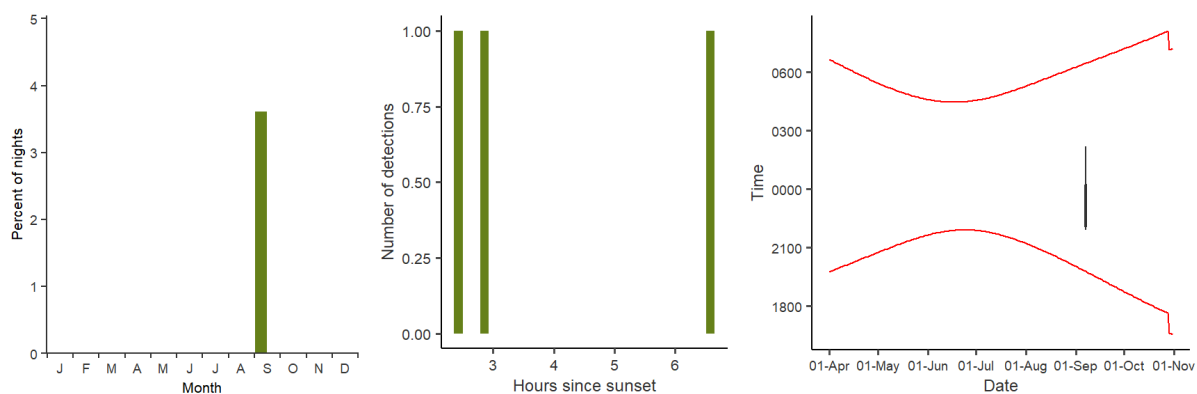
Natterer's Bat social calls

Natterer's Bat social calls *Myotis nattereri* were recorded on two nights, from 2 locations, giving a total of 3 recordings.

Spatial pattern of activity



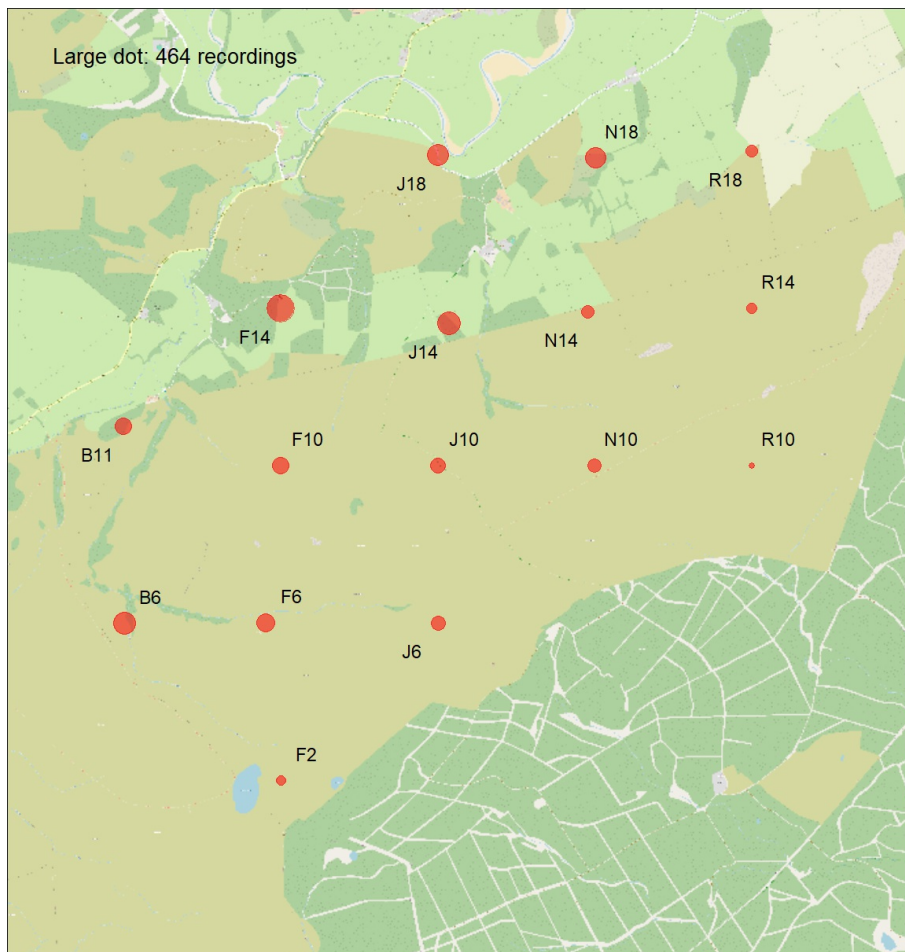
Seasonal and nightly activity



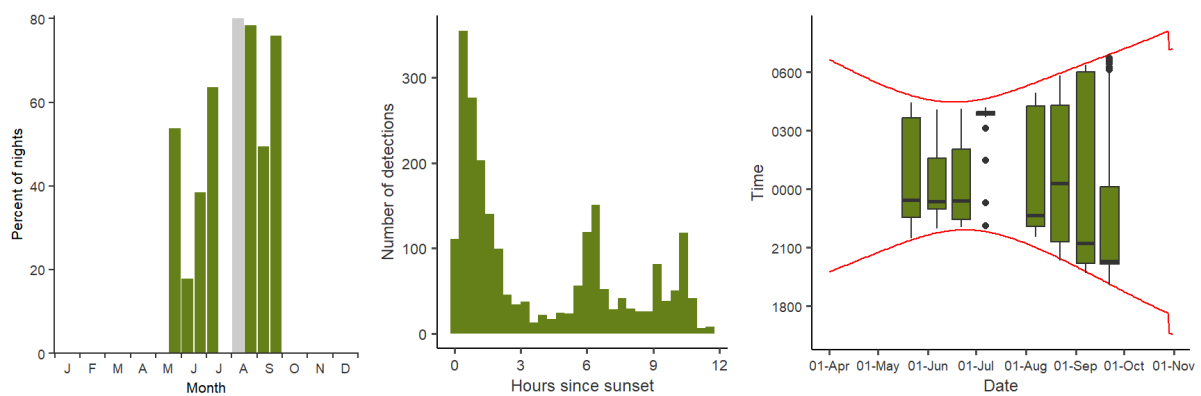
Common Noctule echolocation calls

Common Noctule echolocation calls *Nyctalus noctula* was recorded on 70 nights, from 16 locations, giving a total of 2,270 recordings.

Spatial pattern of activity



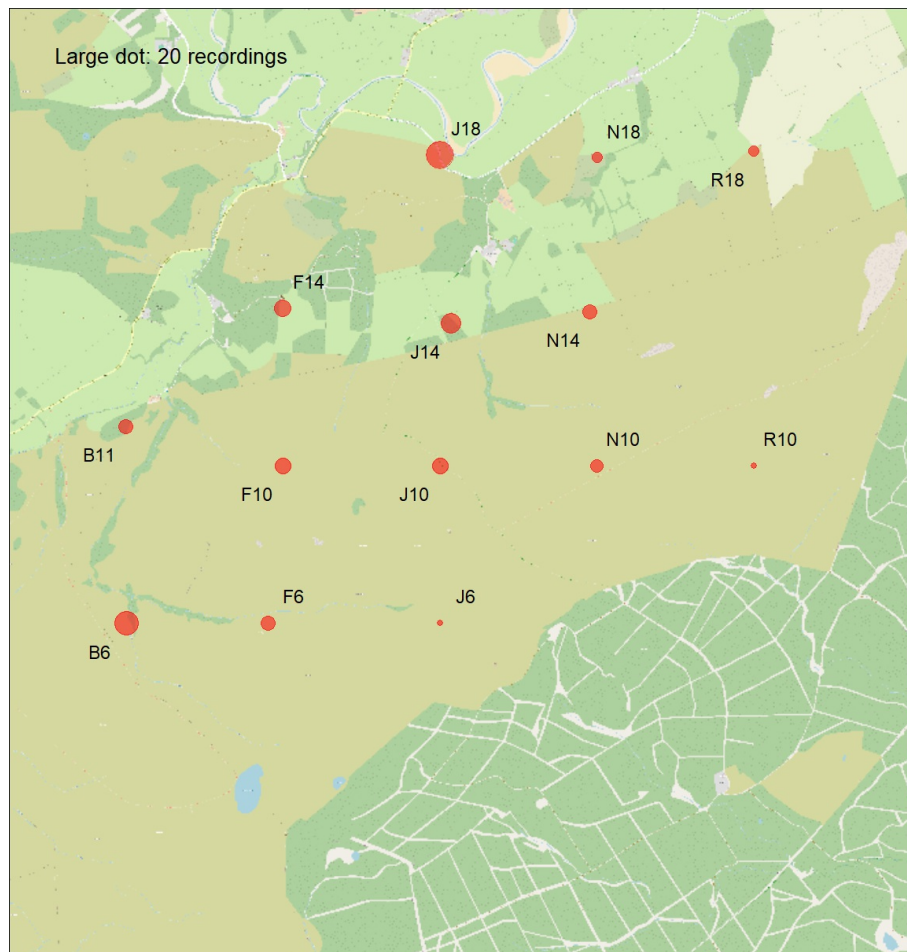
Seasonal and nightly activity



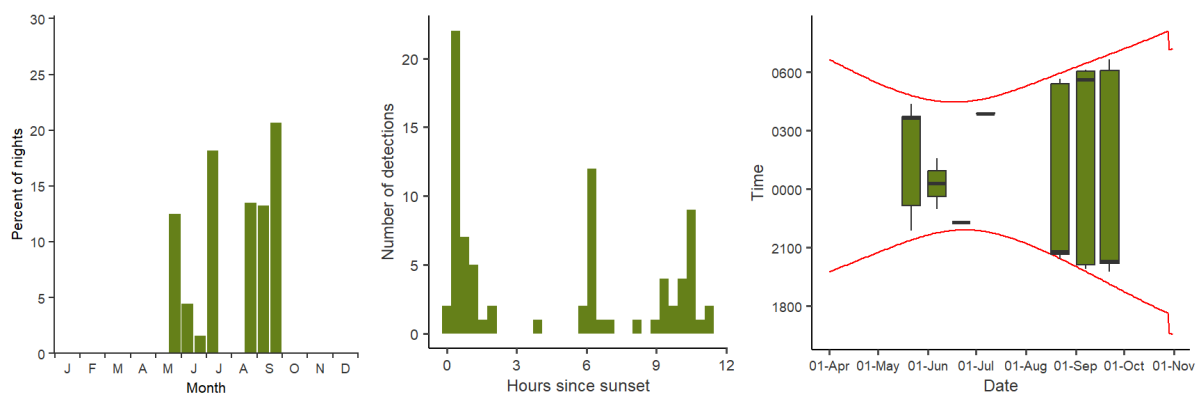
Common Noctule feeding buzzes

Common Noctule feeding buzzes *Nyctalus noctula* were recorded on 28 nights, from 14 locations, giving a total of 80 recordings.

Spatial pattern of activity



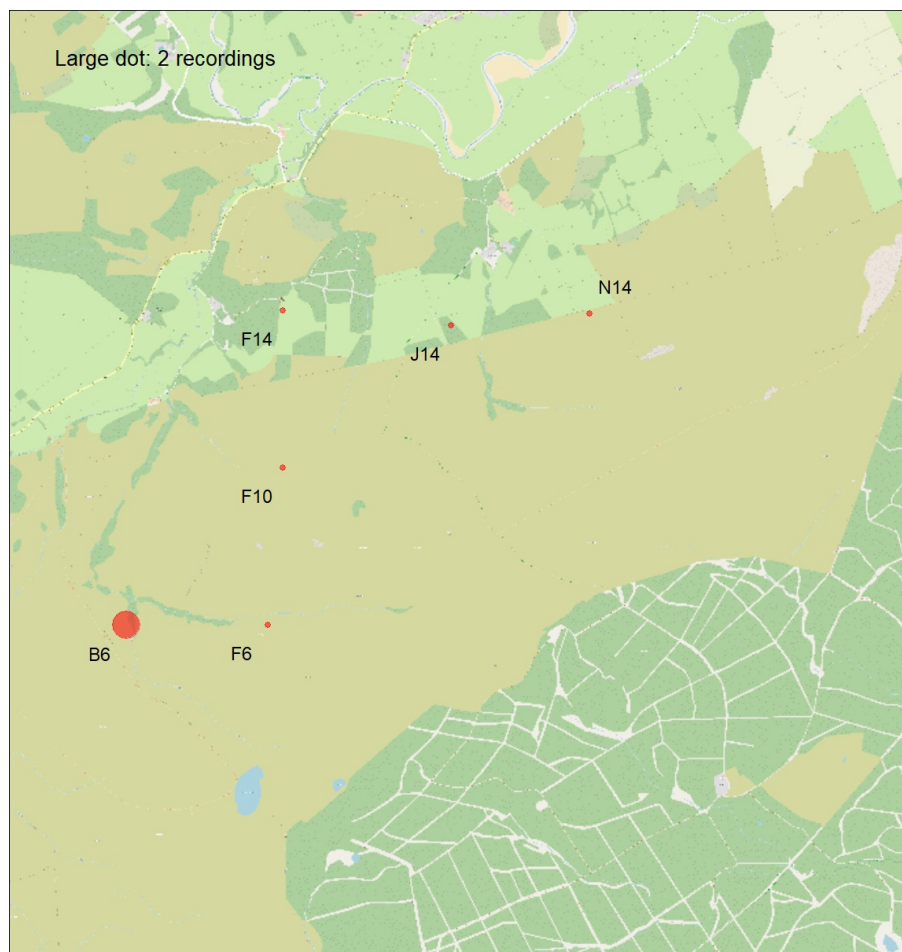
Seasonal and nightly activity



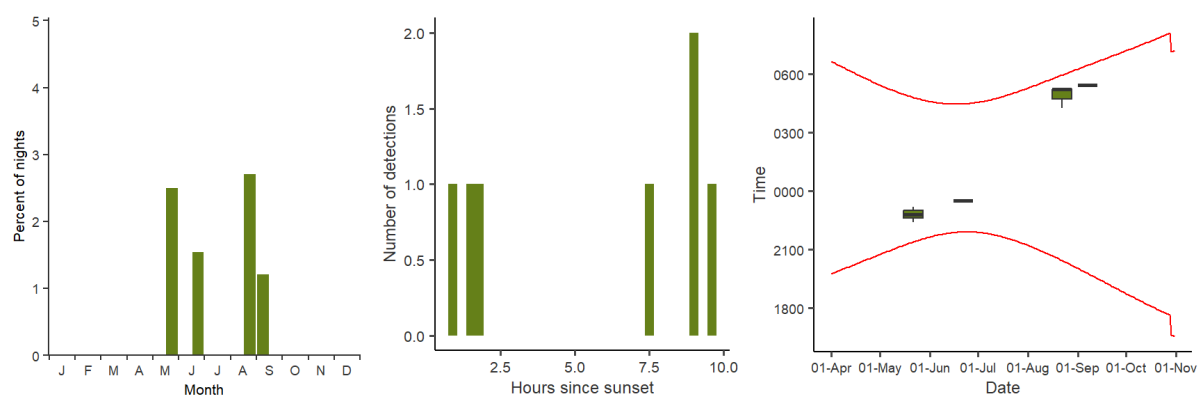
Common Noctule social calls

Common Noctule social calls *Nyctalus noctula* were recorded on five nights, from 6 locations, giving a total of 7 recordings.

Spatial pattern of activity



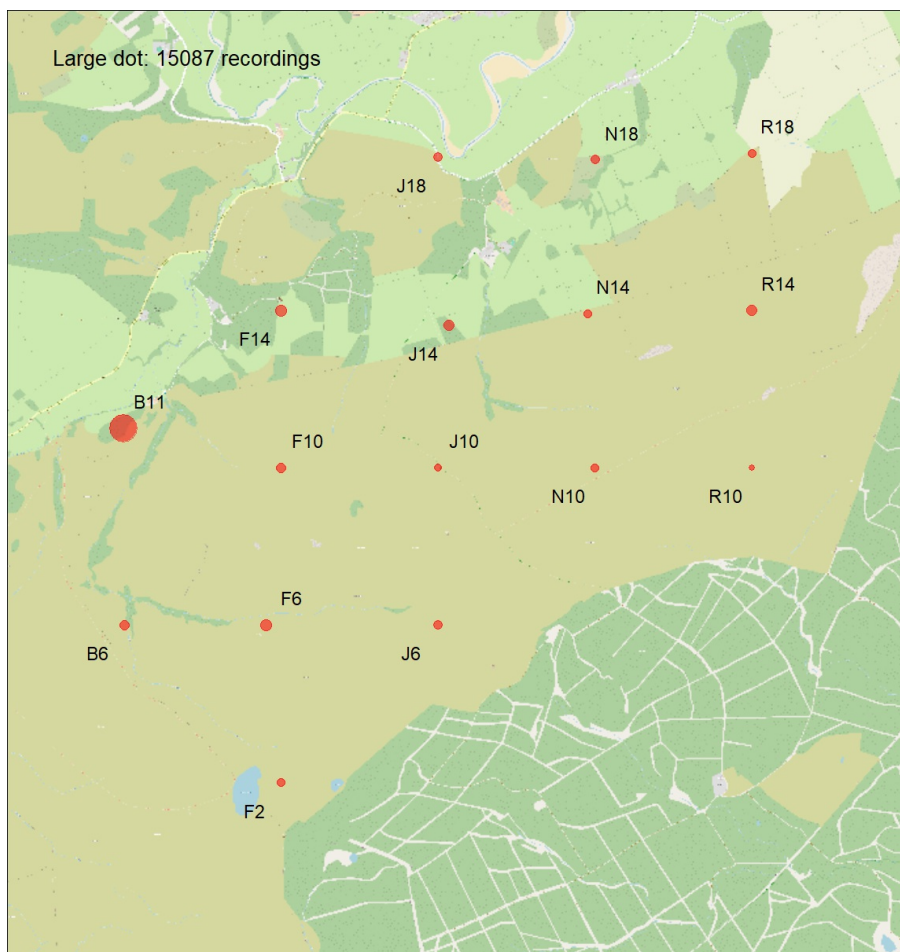
Seasonal and nightly activity



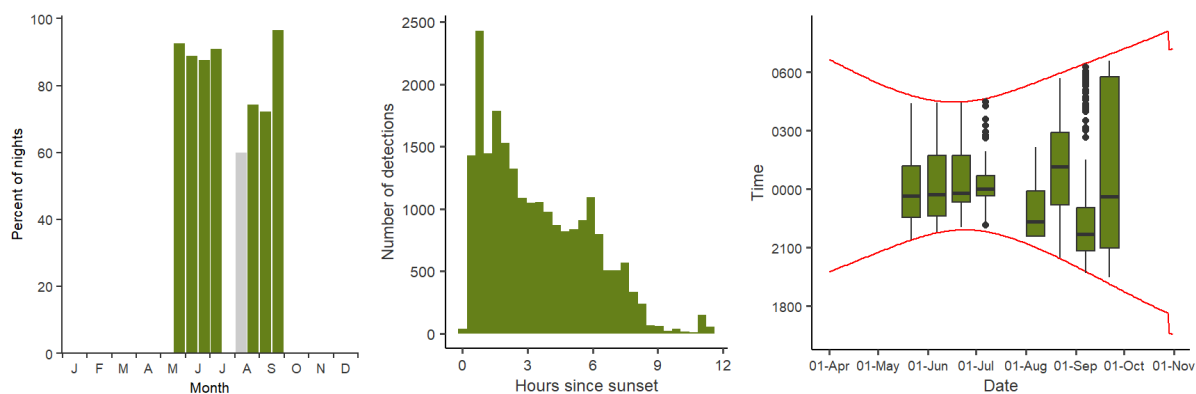
Common Pipistrelle echolocation calls

Common Pipistrelle echolocation calls *Pipistrellus pipistrellus* was recorded on 82 nights, from 16 locations, giving a total of 22,016 recordings.

Spatial pattern of activity



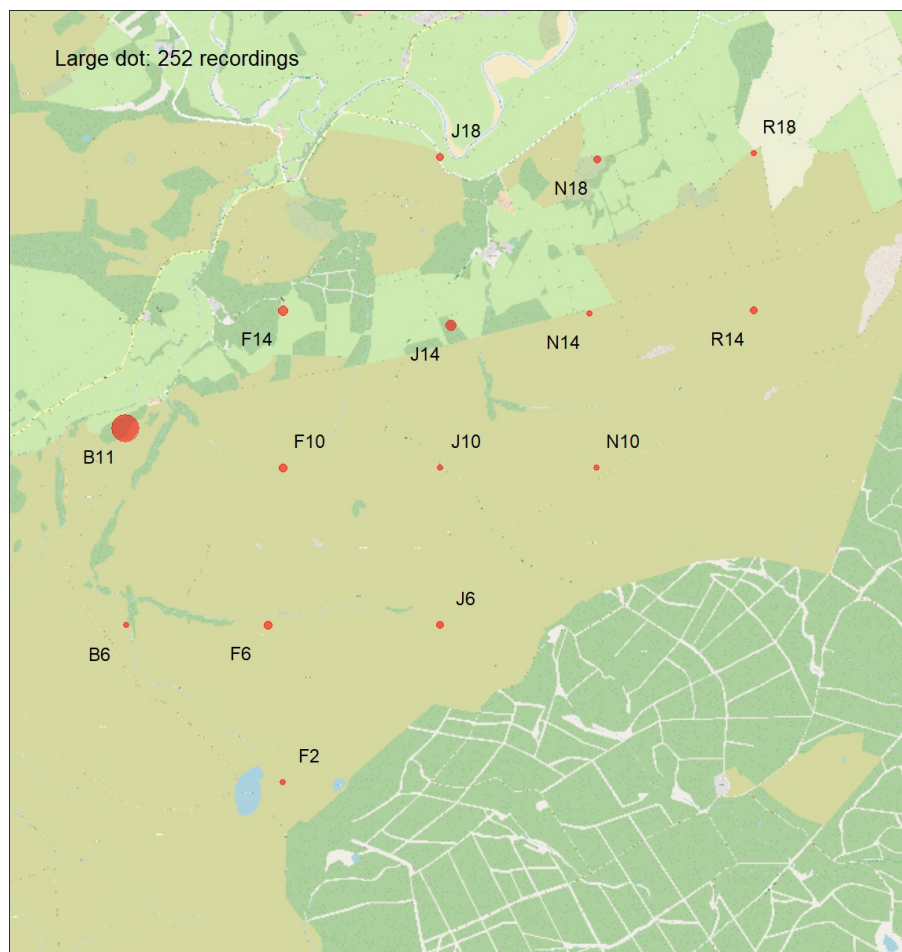
Seasonal and nightly activity



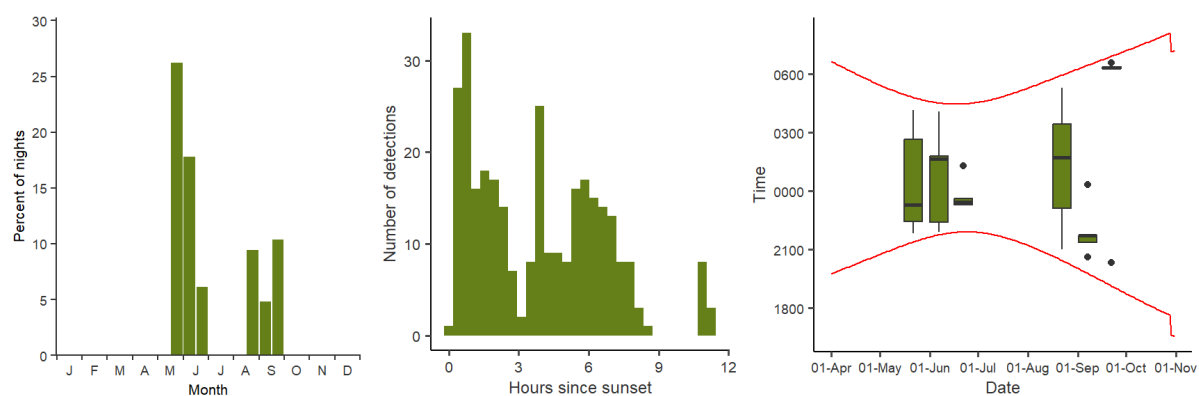
Common Pipistrelle feeding buzzes

Common Pipistrelle feeding buzzes *Pipistrellus pipistrellus* were recorded on 36 nights, from 15 locations, giving a total of 300 recordings.

Spatial pattern of activity



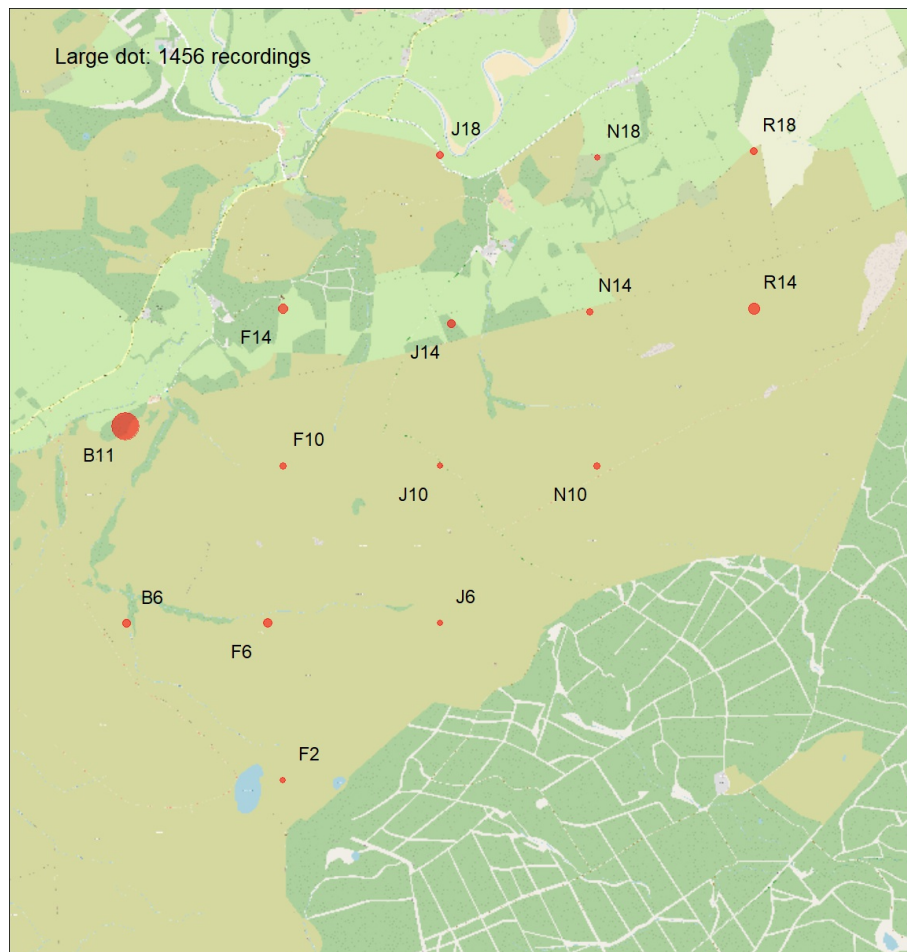
Seasonal and nightly activity



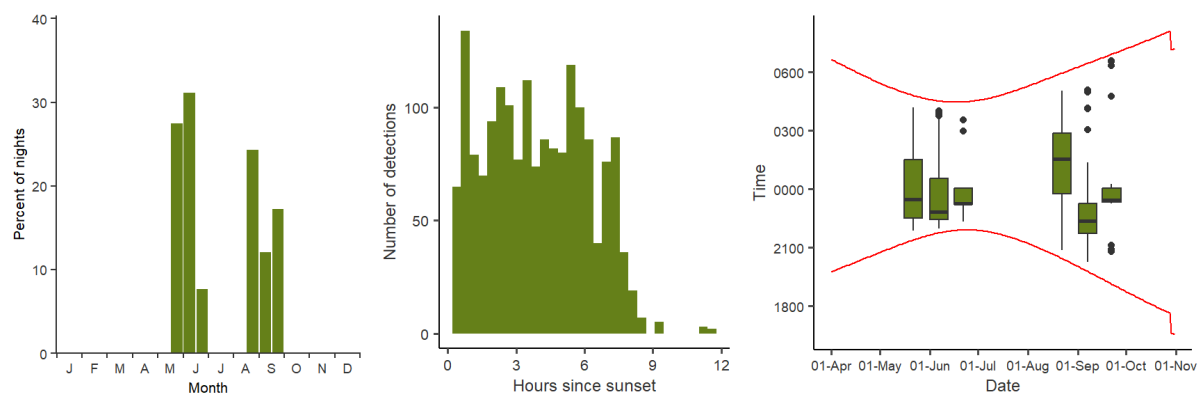
Common Pipistrelle social calls

Common Pipistrelle social calls *Pipistrellus pipistrellus* were recorded on 47 nights, from 15 locations, giving a total of 1,743 recordings.

Spatial pattern of activity



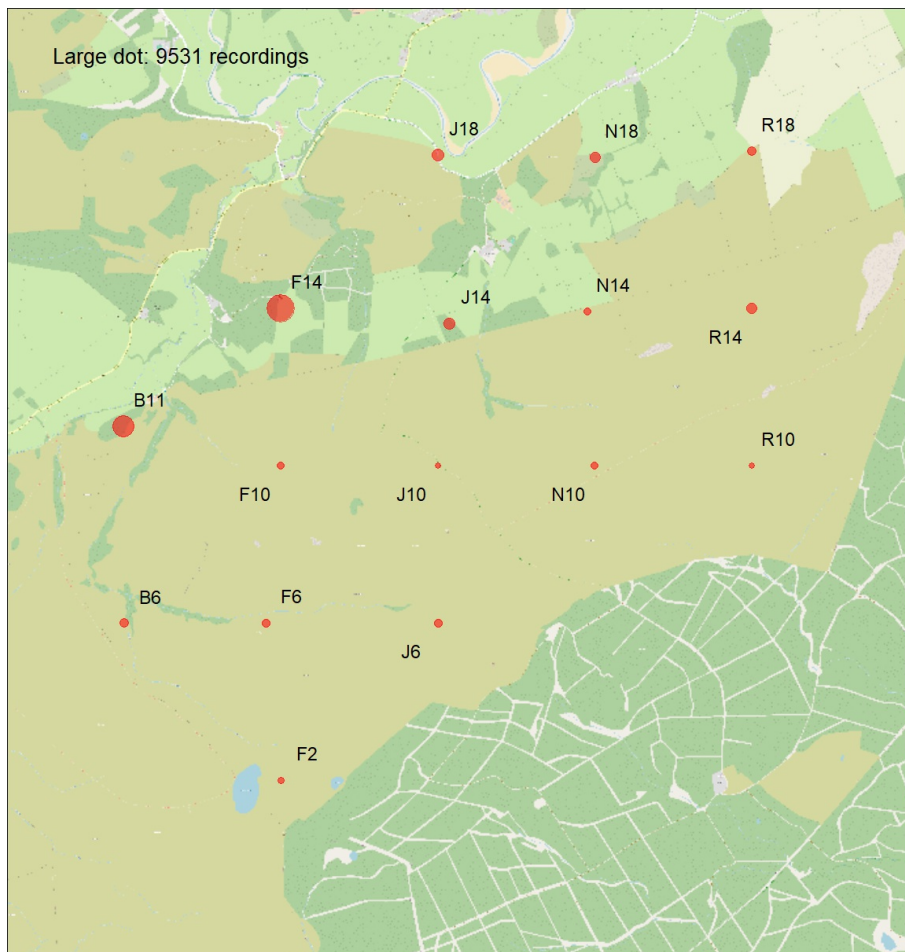
Seasonal and nightly activity



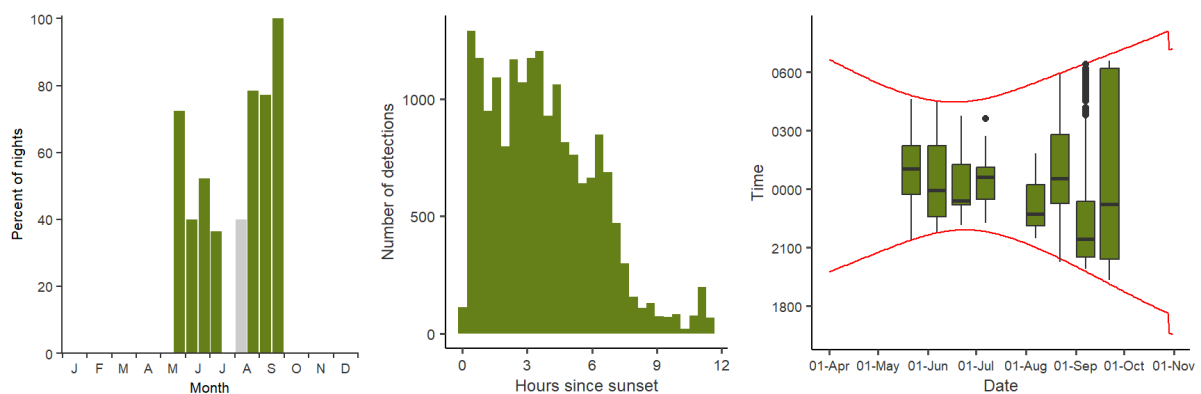
Soprano Pipistrelle echolocation calls

Soprano Pipistrelle echolocation calls *Pipistrellus pygmaeus* was recorded on 77 nights, from 16 locations, giving a total of 18,175 recordings.

Spatial pattern of activity



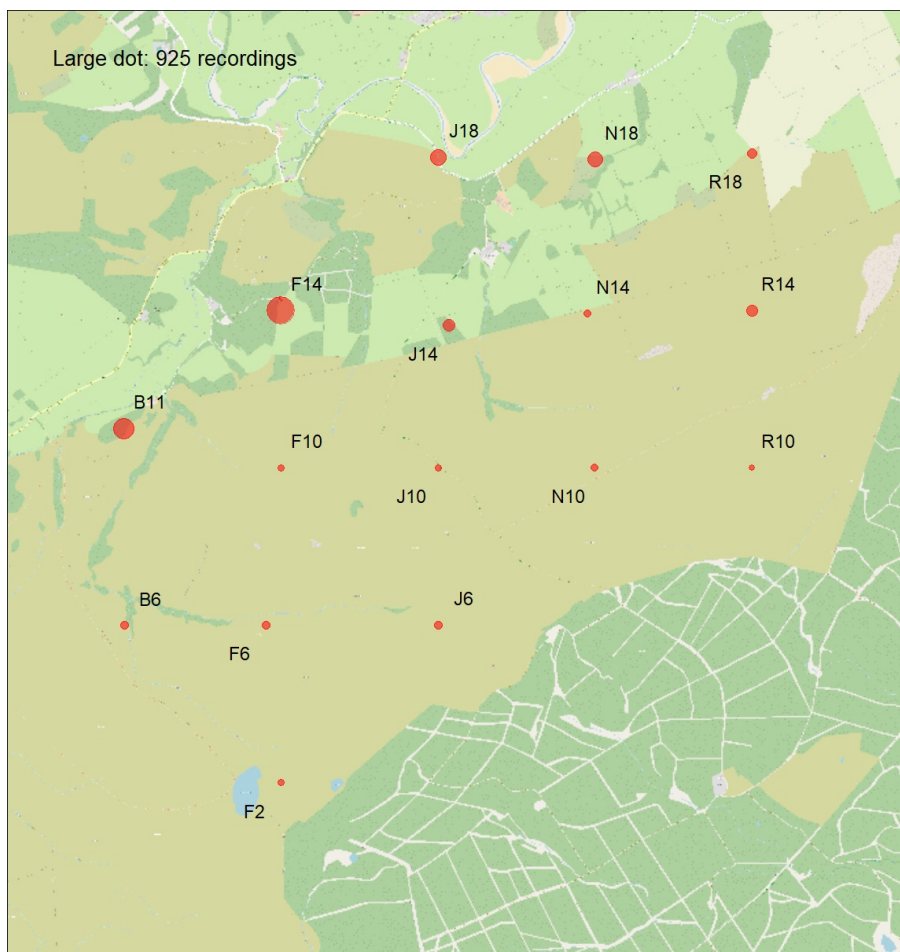
Seasonal and nightly activity



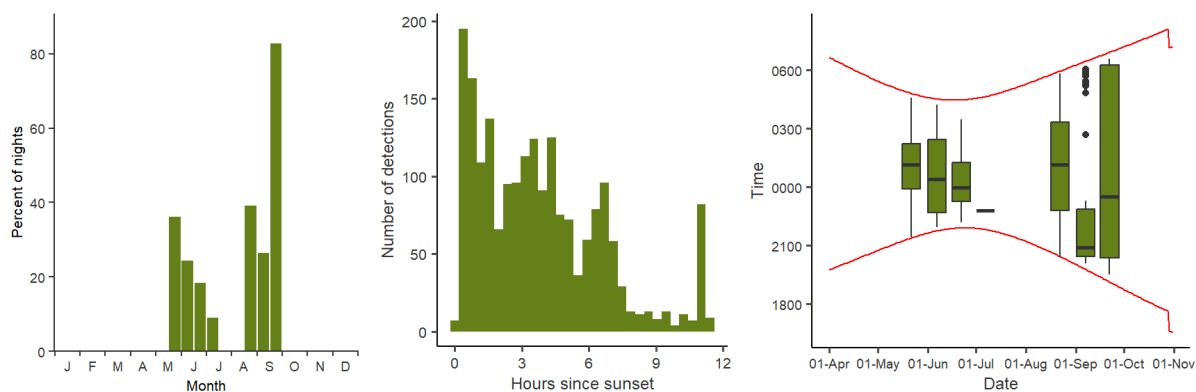
Soprano Pipistrelle feeding buzzes

Soprano Pipistrelle feeding buzzes *Pipistrellus pygmaeus* were recorded on 64 nights, from 16 locations, giving a total of 1,996 recordings.

Spatial pattern of activity



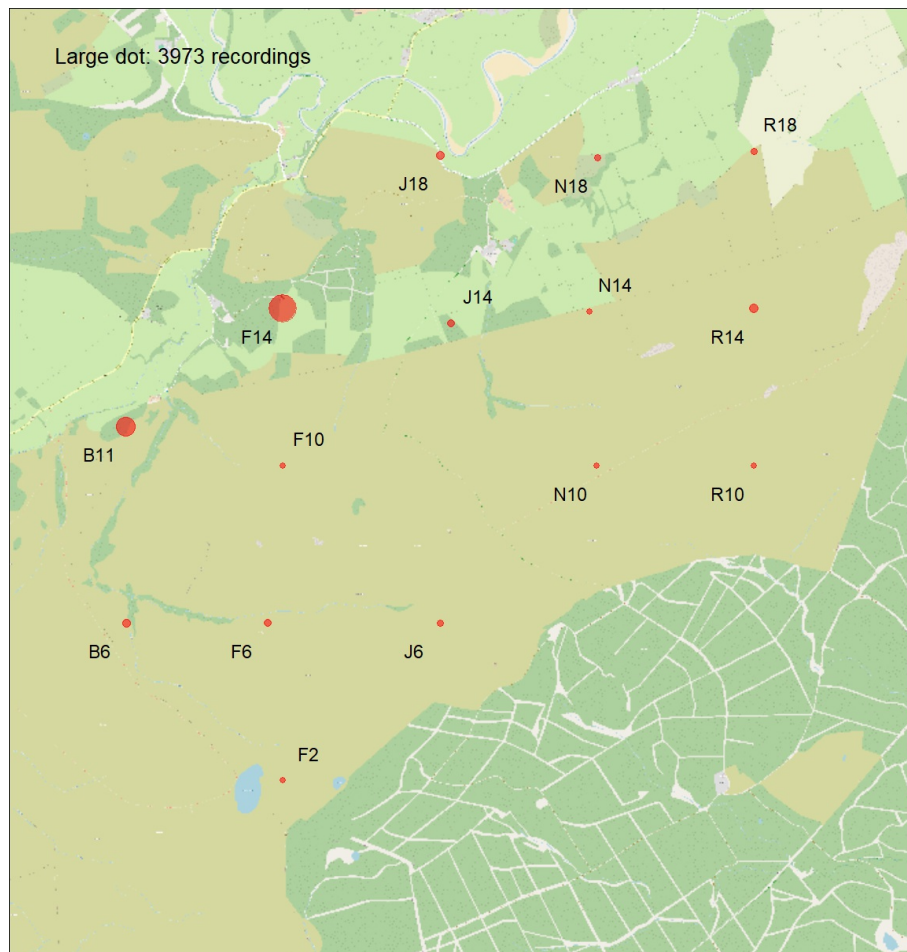
Seasonal and nightly activity



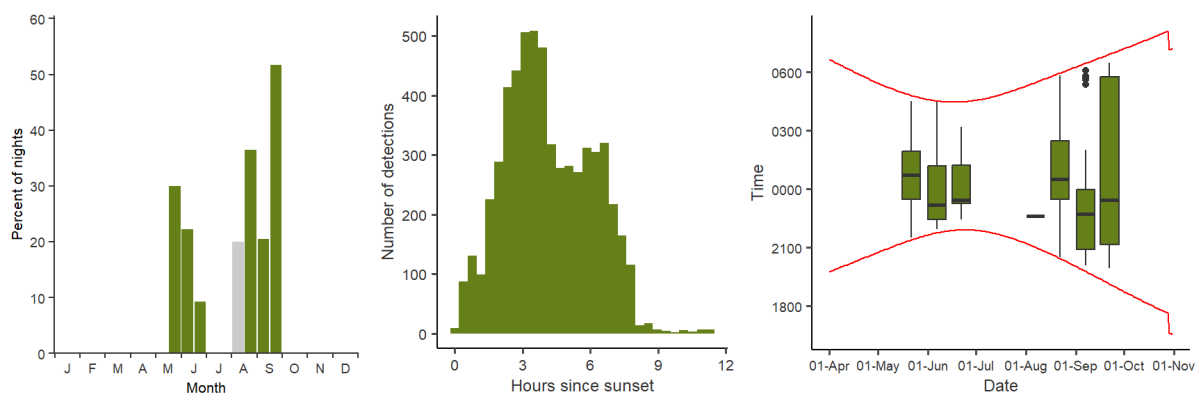
Soprano Pipistrelle social calls

Soprano Pipistrelle social calls *Pipistrellus pygmaeus* were recorded on 62 nights, from 15 locations, giving a total of 5,831 recordings.

Spatial pattern of activity



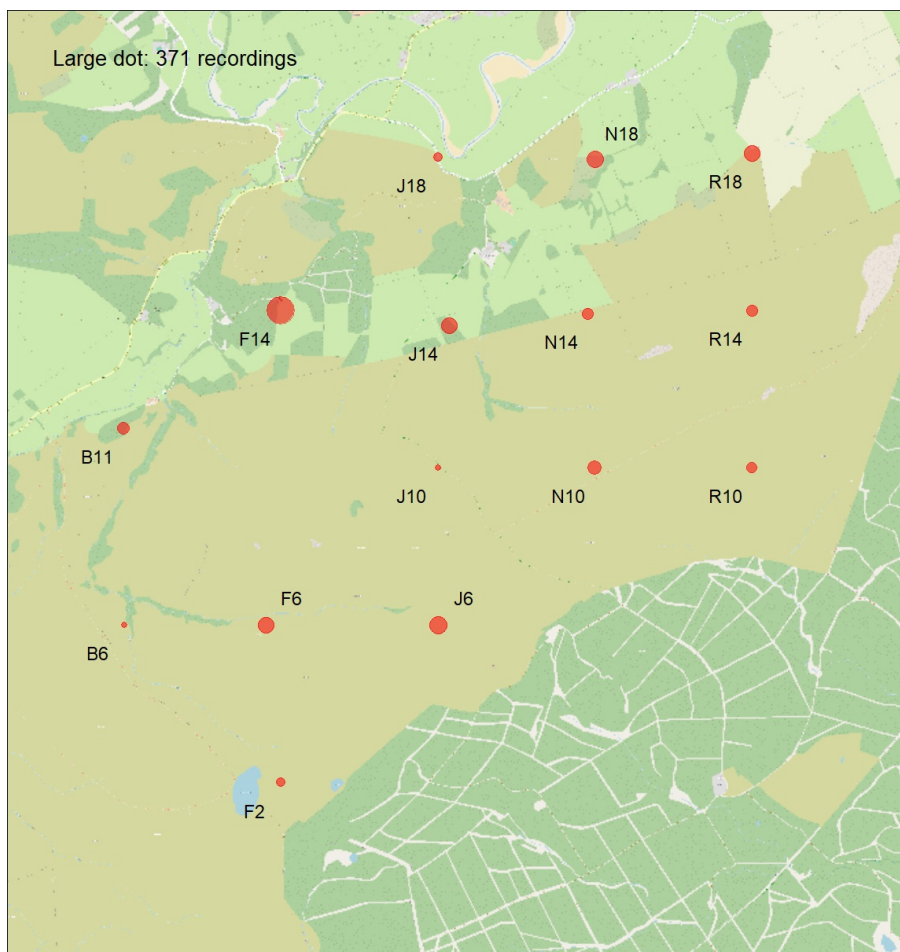
Seasonal and nightly activity



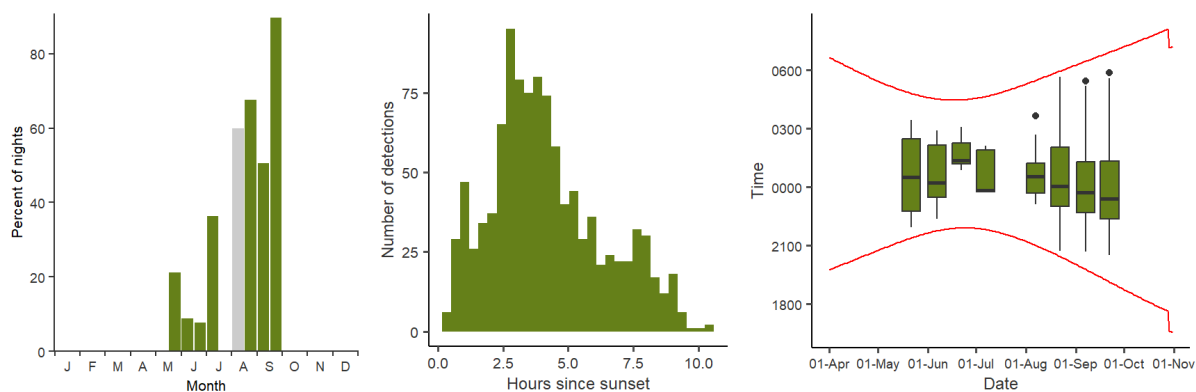
Brown Long-eared Bat echolocation calls

Brown Long-eared Bat echolocation calls *Plecotus auritus* was recorded on 56 nights, from 15 locations, giving a total of 1,062 recordings.

Spatial pattern of activity



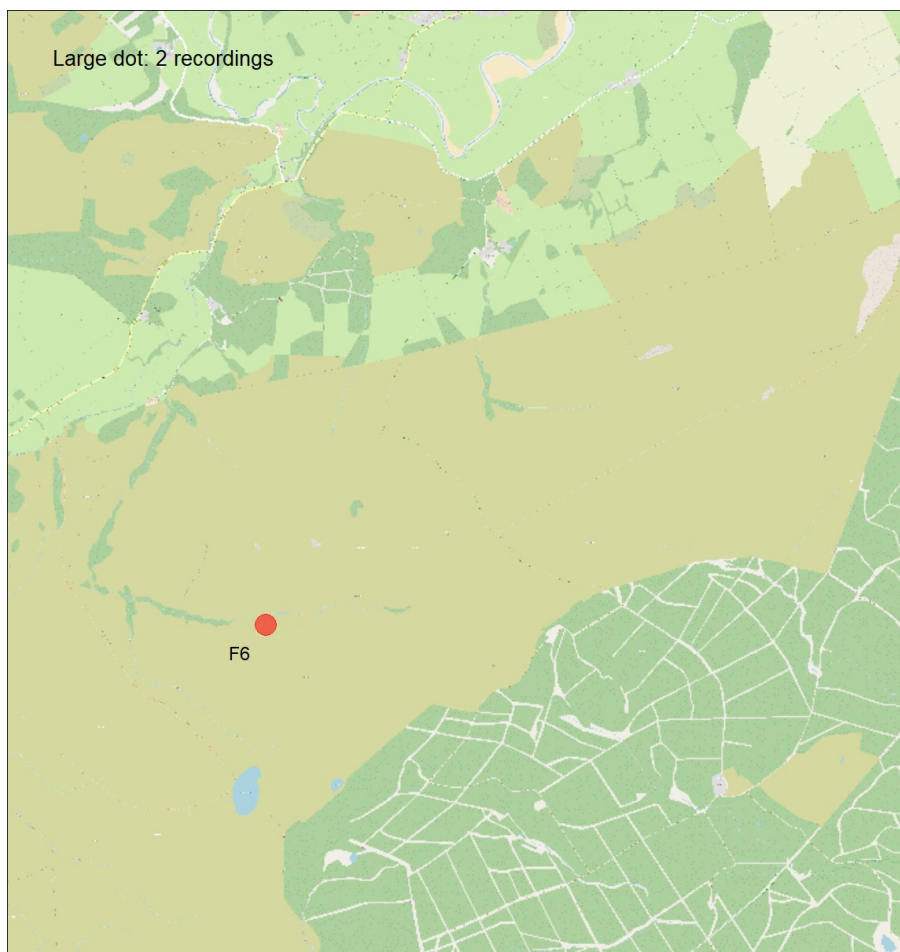
Seasonal and nightly activity



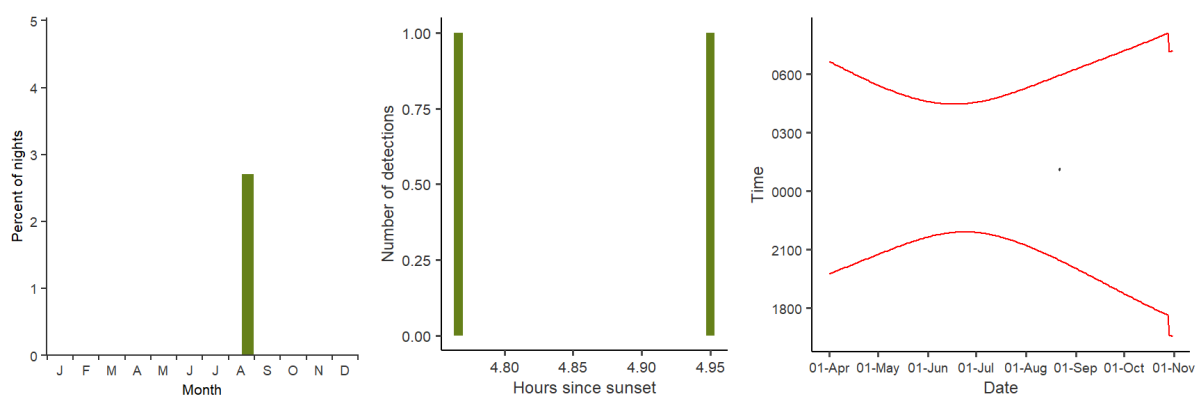
Brown Long-eared Bat social calls

Brown Long-eared Bat social calls *Plecotus auritus* were recorded on two nights, from 1 location, giving a total of 2 recordings.

Spatial pattern of activity



Seasonal and nightly activity



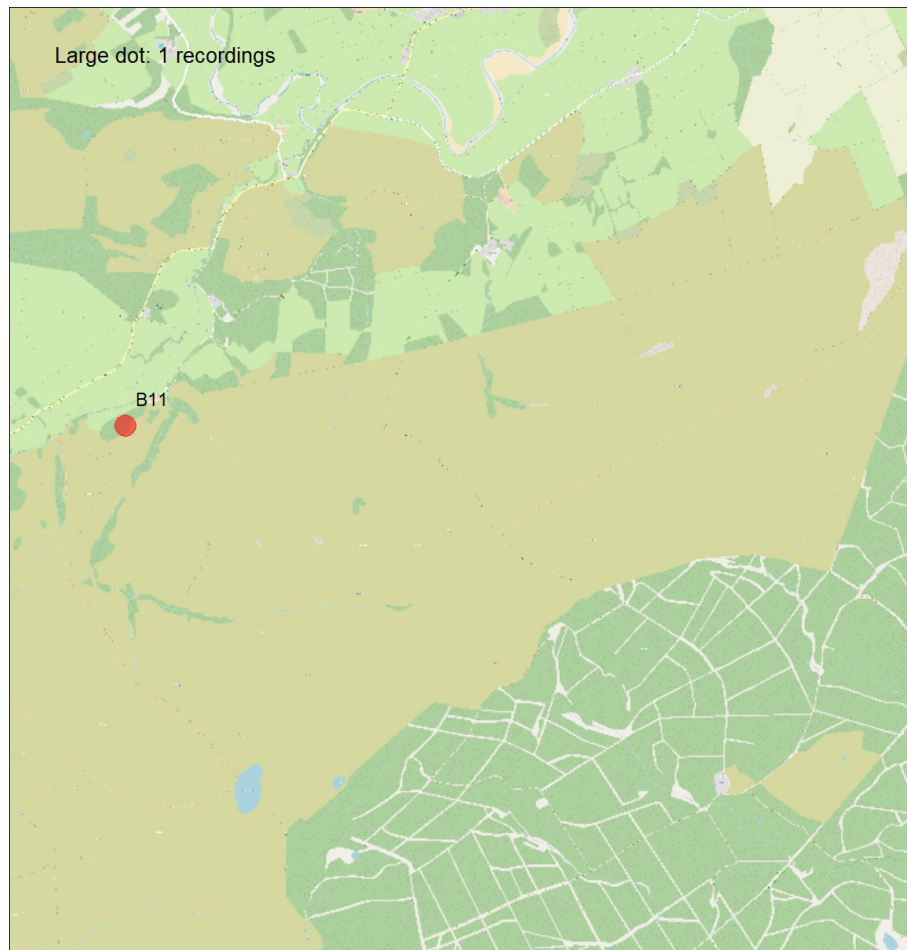
4.4.2 Small terrestrial mammal species

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

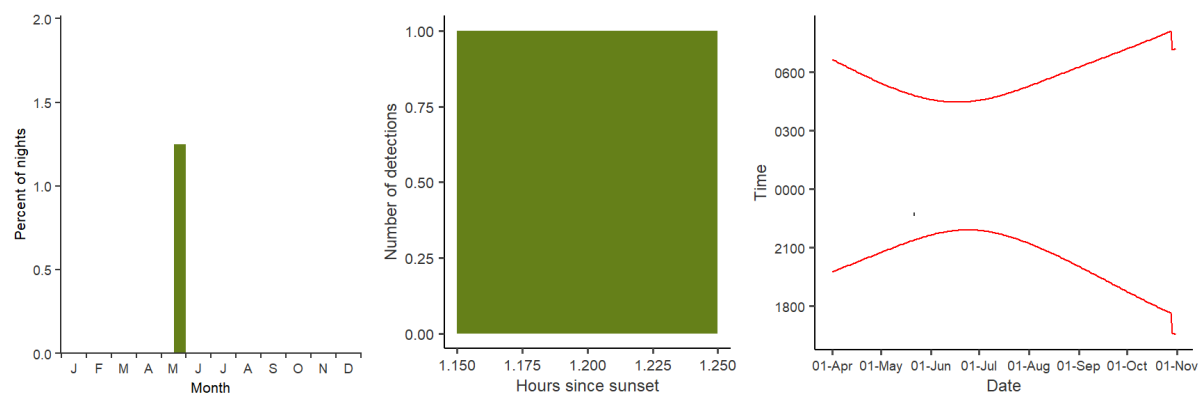
Wood Mouse

Wood Mouse *Apodemus sylvaticus* was recorded on one night, from 1 location, giving a total of 1 recording.

Spatial pattern of activity



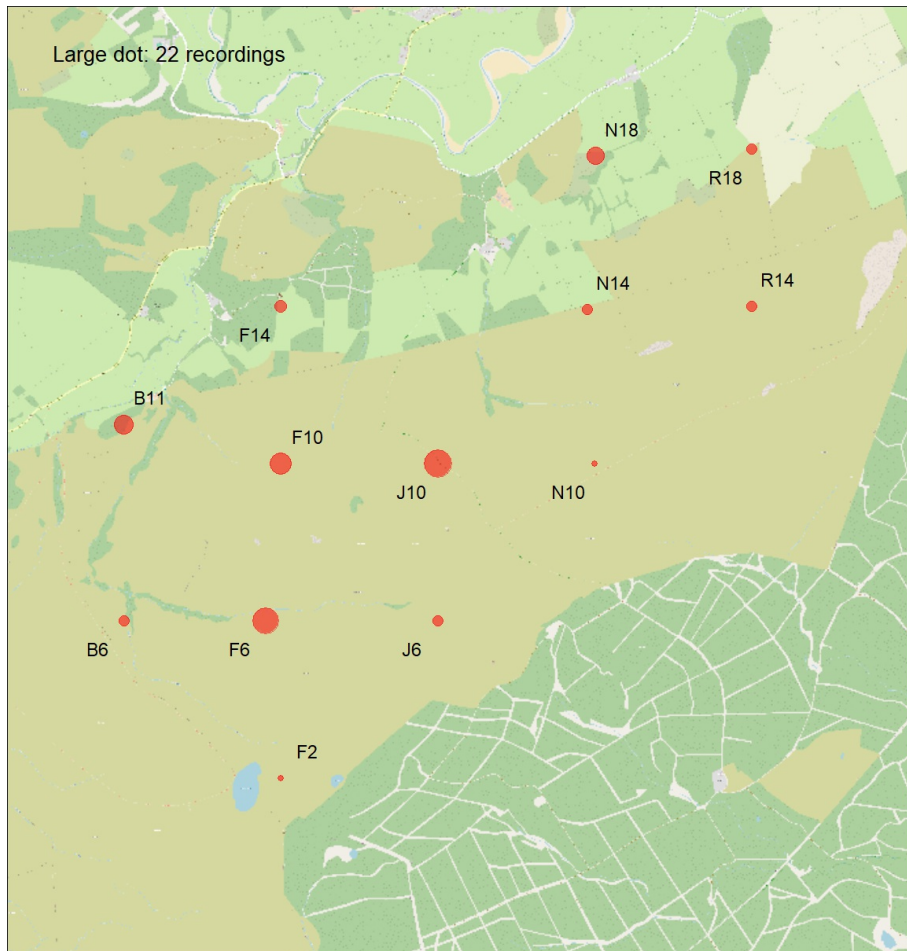
Seasonal and nightly activity



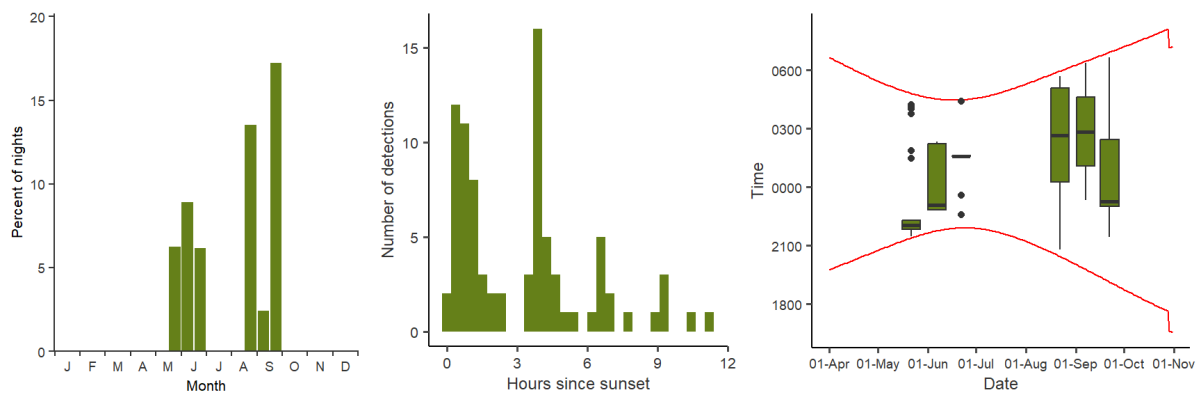
Eurasian Pygmy Shrew

Eurasian Pygmy Shrew *Sorex minutus* was recorded on 23 nights, from 13 locations, giving a total of 84 recordings.

Spatial pattern of activity



Seasonal and nightly activity

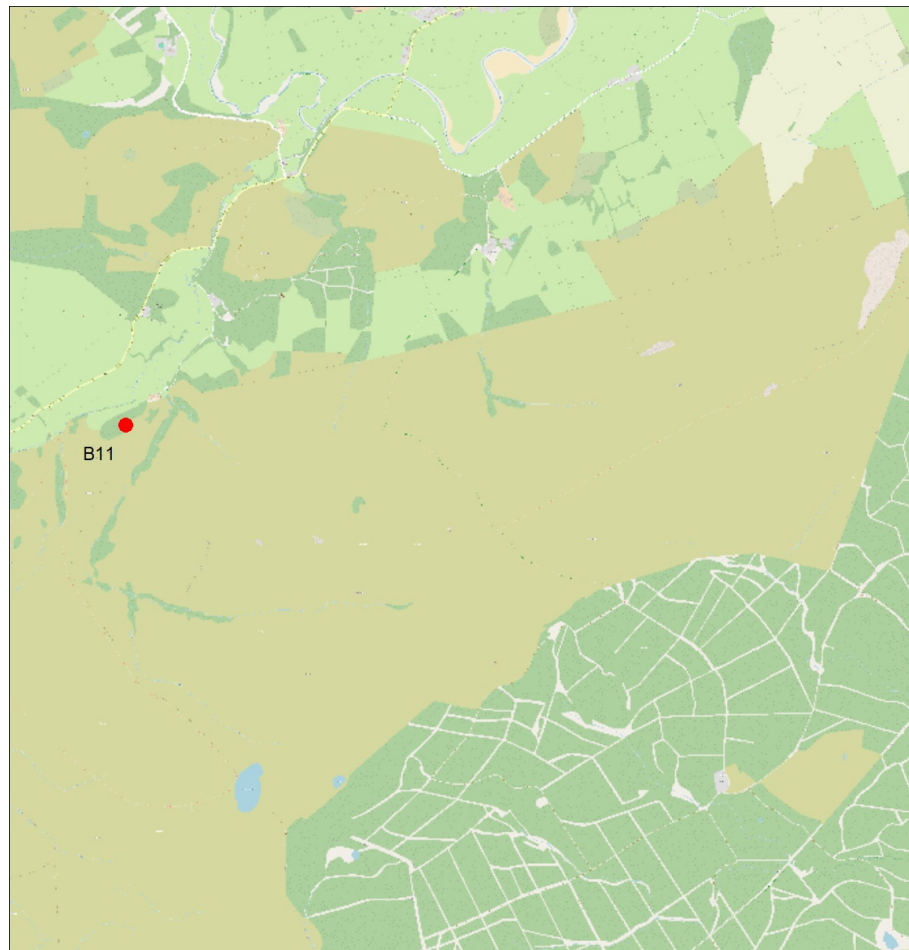


4.4.3 Audible moth species

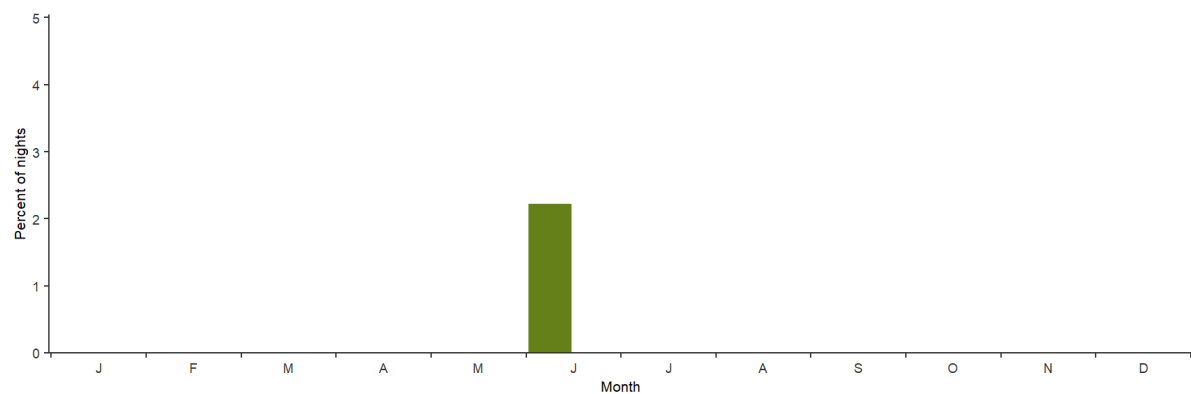
Green Silver-lines

Green Silver-lines *Pseudopsis prasinana* was recorded on one night, from one location.

Spatial pattern of detections



Seasonality



5. CONCLUDING REMARKS

In this report we demonstrate how PAM can be used to collect data over multiple taxonomic groups, including for bats and birds which are key indicators on the Rewilding Monitoring Framework.

If carried out at regular intervals, in the future, these data can be valuable to measure changes in species presence and activity for these taxonomic groups during the rewilding process.

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Images: Common Pipistrelle, by John Black; Cuckoo, by Edmund Fellowes / BTO; Natterer's Bat, by Chris Damant, Bernwood Ecology; Long-tailed Tit, by John Proudlock / BTO.
Cover image: Curlew, by Liz Cutting / BTO.

Passive acoustic monitoring on the Hepple Estate, 2024 – piloting the rewilding monitoring framework

This report presents the main findings from survey work delivered using passive acoustic monitoring devices deployed across the Hepple Estate in 2024. Through the surveys that we support we aim to improve knowledge and understanding of species distribution and activity, covering a range of taxonomic groups, including birds, bats, small terrestrial mammals and insects. Through the approach we provide robust datasets that can be used to inform better decision-making processes.

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

Ashton-Butt, A., Gough, M., Higgins, S.L., Wetherhill, A. & Newson, S.E 2025. Passive acoustic monitoring on the Hepple Estate, 2024 – piloting the rewilding monitoring framework. *BTO Research Report 782*, BTO, Thetford, UK.

ISBN 978-1-912642-79-3



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