BTO RESEARCH REPORT 716

Improving our understanding of the distribution and status of bats within the Ryevitalise Landscape Partnership Scheme area

Newson, S.E. & Berthinussen, A.

BTO
Looking out for birds

ACKNOWLEDGEMENTS: We are grateful to Alexandra Cripps and Elizabeth Clements for setting up the project, in providing existing bat data for the area and in working with us to arrange land access permissions. Stuart Newson designed the methodology; Anna Berthinussen carried out professional fieldwork, liaised with landowners and commented on the report; Matt Baxter and Steve Pritchard set up the online sign-up map; Stuart Newson analysed the data and led on the writing of the report.

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ISBN 978-1-912642-02-1

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EXECUTIVE SUMMARY

1. This project aims to improve our understanding of the distribution and status of all species of bats within the Ryevitalise Landscape Partnership Scheme area. Specifically, the proposed work has the following objectives: (a) to work with the North York Moors National Park Authority to undertake a desk-based study to collate existing information on the distribution and activity of all species of bats within the Ryevitalise Landscape Partnership Scheme area; (b) to design and implement survey work in 2018 that provides large-scale data on bat distribution and activity in the Ryevitalise Landscape Partnership Scheme area. In addition, the report aims to address the following points: (c) to identify "hotspots" for different species of bats within the Ryevitalise Landscape Partnership Scheme area; (d) to carry out habitat analyses of bat survey data that help to inform practical conservation action and future work; (e) to suggest methods and protocols for adapting the project to run in the longer-term as a large-scale volunteer-based project.

2. Prior to the start of the fieldwork, a desk-based study was carried out to collate existing bat records for the Ryevitalise Scheme area for the period 2000 to the present. Most bat records were provided by the North Yorkshire Bat Group, with some additional records obtained from the National Biodiversity Network (NBN). Anna Berthinussen was contracted to spend 30 days between mid-April and August 2018 to survey for bats. Survey locations were chosen prior to the start of the survey season according to a systematic survey design with a random starting point, to ensure representative geographic and habitat coverage. Static bat detectors were left out to record for four consecutive nights at each location.

3. Data from 100 different 1-km squares were surveyed for bats. This sample comprised 387 complete nights of recordings. 1,133,862 triggered recordings were collected which, following analyses and verification, were found to include 276,764 recordings containing one or more species of bat. The remaining recordings were mainly of bird calls.

4. Spatial models of bat distribution and activity were produced and predictive performance evaluated for all species of bats, except Alcathoe Bat for which there were too few records to model distribution and activity. Additional analyses were carried out to assess the importance of habitat type for each bat species at local and landscape scales.

5. The current data set has been valuable in defining patterns of occurrence and activity across the Ryevitalise Landscape Partnership area. Alcathoe Bat, Noctule and Whiskered Bat / Brandt's Bat appear to be the most range restricted bat species, with the core distribution and activity of these species in the southern half of the study area. For Noctule, comparatively few 1-km squares recorded a high proportion of the total activity. Whilst Common and Soprano Pipistrelles were recorded almost everywhere where a detector was left out to record, Soprano Pipistrelle showed strong spatial clustering in activity at a small number of locations. Of eight Alcathoe Bat recordings, only three – from two locations – were typical for this species in closed habitat, where identification of this species is most straightforward.

6. Most of the relationships between bat occurrence and activity and habitat were in line with the current knowledge on the ecology of the species present.

7. Considering the results of the study, a number of recommendations for practical conservation action are proposed.

8. Beyond this study, there is the potential to continue and develop the survey work as a Citizen Science project. In the last section in the report, we draw on our experience of setting up and running similar volunteer projects in Norfolk and southern Scotland and in supporting Devon Wildlife Trust with their HLF funded Greater Horseshoe Bat project, and Bat Conservation Trust in developing national bat monitoring.

1. INTRODUCTION

The North York Moors National Park is currently developing a Heritage Lottery Fund (HLF) Landscape Partnership Scheme called Ryevitalise which is all about conserving, protecting and interpreting the cultural and natural landscape of the River Rye. Following a successful application to the HLF, the body released funds to allow for the development of the Landscape Partnership Scheme which will culminate in a final submission to the HLF for approval in October 2018. In this current development phase, a number of surveys are being commissioned to establish base line data so that towards the end of the four years of the Scheme's delivery (2019–2023) beneficial change can be measured by carrying out re-surveys. One of the main biodiversity objectives of the Partnership is to conserve and enhance the exceptional populations and assemblage of bats within this area and to understand the issues facing summer roosting and foraging sites. This includes the nationally important and only relatively recently discovered Alcathoe Bat.

1.1. AIMS AND OBJECTIVES

This project aims to improve our understanding of the distribution and status of all species of bats, including Alcathoe Bat within the Ryevitalise Landscape Partnership Scheme area.

Specifically, the work has the following objectives:

- To work with the North York Moors National Park Authority to undertake a desk-based study to collate existing information on the distribution and activity of all species of bats within the Ryevitalise Landscape Partnership area.

- To design and implement survey work in 2018 that will provide large-scale data on bat distribution and activity in the Ryevitalise Landscape Partnership area.

In addition, the report will address the following points:

- To identify "hotspots" for different species of bats within the Ryevitalise Landscape Partnership area.

- To carry out habitat analyses of bat survey data, to help inform practical conservation action and future work.

- To suggest methods and protocols for adapting the project to run in the longer-term as a large-scale volunteer-based project.

2. METHODS

2.1. DESK-BASED STUDY

Prior to the start of the fieldwork below, a desk-based study was carried out to collate existing bat records for the Ryevitalise area, specifically the 1-km squares that comprise this area to be comparable with the later fieldwork. Most bat records were provided by John Drewett Chair of North Yorkshire Bat Group and compiled from data held on the North Yorkshire Bat Group database on 7 November 2017. The data comprised records collated from published records, surveys, records obtained via enquiries from the public and data gathered by ecological consultants carrying out surveys in relation to planning applications. These data comprised information on the species where known, the number of bats, grid references, date of records and the type of record. The type of record provided additional information associated with the record, for example 'in flight' or 'roost'.

Some additional records were obtained from the National Biodiversity Network (NBN). For most NBN records, there was no associated metadata on record type. More intensive monitoring data was also provided by the North York Moors National Park for specific swarming sites, although these lay outside the boundary of the scheme area and were not included here.

From the North Yorkshire Bat Group and NBN data, we removed (a) records with no information on when they were recorded, (b) older or historic records prior to 2000, and (c) unspecific records not assigned to species, but retaining records of Whiskered / Brandt's bat, (d) removing duplicate records of the same species recorded at the same location, (e) removing records that were not recorded at a spatial scale of 1-km square or finer. To help visualise the distribution of these, maps of the distribution for each species were produced.

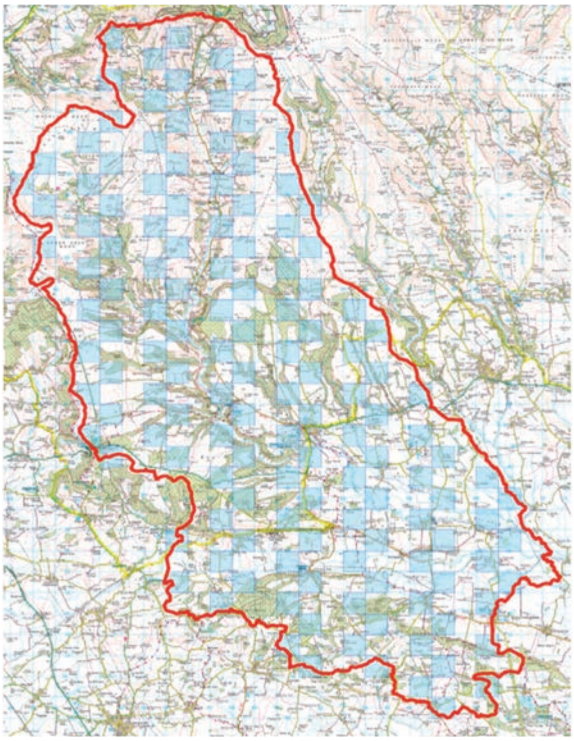
2.2. BAT SURVEY PROTOCOL

The project focusses on the Ryevitalise Landscape Partnership Scheme area, a survey area of about 470 km^2. Although there has been little in the way of extensive or systematic bat recording in this area, local studies and ad hoc recording have recorded at least nine species prior to this study. A paid fieldworker, Anna Berthinussen, was contracted to spend 30 days between mid-April and August to survey for bats. The fieldwork was designed to try and survey as many 'priority squares' as possible, 140 of which were selected according to a systematic survey design with a random starting point, prior to the start of the survey season, from all 1 km squares in the survey area (Figure 1).

With the aim of improving understanding of species distribution and activity, this project focussed on obtaining large-scale spatial coverage, detectors were left out to record for four consecutive nights at each location. This recommendation of four nights, follows analyses of bat data carried out by ourselves as part of a Defra-funded project to inform the most cost-effective sampling regime for detecting the effect of local land-use / land management (Newson *et al.* in prep). 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 equipment was purchased and is now owned by the National Park, to be used by volunteers in subsequent years.

To facilitate the monitoring of survey coverage, an online sign-up tool was set up. This system was used to 'reserve' out squares as they were surveyed (see Figure 2), and so to keep track of coverage during the field season.

Figure 1. Survey area with "priority squares" for survey by the fieldworker highlighted in blue.



The detectors were set to use a high pass filter of 1 kHz which defined the lower threshold of the frequencies of interest for the triggering mechanism. This is a lower frequency than is required for bats and, while outside the scope of the project, it provided an opportunity to incidentally collect and provide some additional data on nocturnal birds, such as Nightjar and Woodcock, which are otherwise poorly monitored and can be difficult to survey.

Recording was set to continue until no trigger was detected for a two second period. Detectors were set to record from 30 minutes before sunset until 30 minutes after sunrise the following morning. Microphones were mounted on 2 m poles to avoid ground noise and reduce recordings of reflected calls. Where possible, microphones were deployed at least 1.5 meters in any direction from vegetation, water or other obstructions. During the survey season, recordings were backed up on an external hard drive, and the original memory cards containing recordings were returned to the BTO for analyses. Given a choice, detectors were positioned as close to the centre of a 1-km square as possible, i.e. a random location.

2.3. SEMI-AUTOMATED ACOUSTIC 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. This is particularly important to consider if there is the ambition of involving volunteers in a large-scale citizen science project in the future. In this study, we used an acoustic classifier TADARIDA (a Toolbox for Animal Detection in Acoustic Recordings Integrating Discriminant Analysis, which we have been involved in helping to develop). All recordings were passed through the TADARIDA random forest classifier (Step 1). This entails extraction of 150 measures of call characteristics from each recording (Annex 1, Bas & Bas, 2016), and a comparison of these against measurements taken from an extensive reference library of manually identified ultrasound 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 (as compared with the underlying training database) on a scale of 0–1. For Common

Pipistrelle and Soprano Pipistrelle, which typically account for >95% of all bat recordings, TADARIDA identifications of these species for which the estimated probability of correct classification is high (≥ 0.8), were taken as being accurate. The call shape (similar to a hockey-stick) and frequencies of Common and Soprano Pipistrelle are sufficiently characteristic to allow reliable classification of these species by the classifier.

Manual checking (Step 2) of spectrograms using software SonoBat (http://sonobat.com/) was used as an independent check of the original species identities assigned by the TADARIDA classifier. Using the output from Step 1, manual checks were carried out on a random sample of recordings of Common and Soprano Pipistrelle, to verify that classifier identification of these species was accurate. For the other species, all recordings were inspected with SonoBat regardless of the associated probability of correct classification. Species identities were checked (and re-classified if necessary).

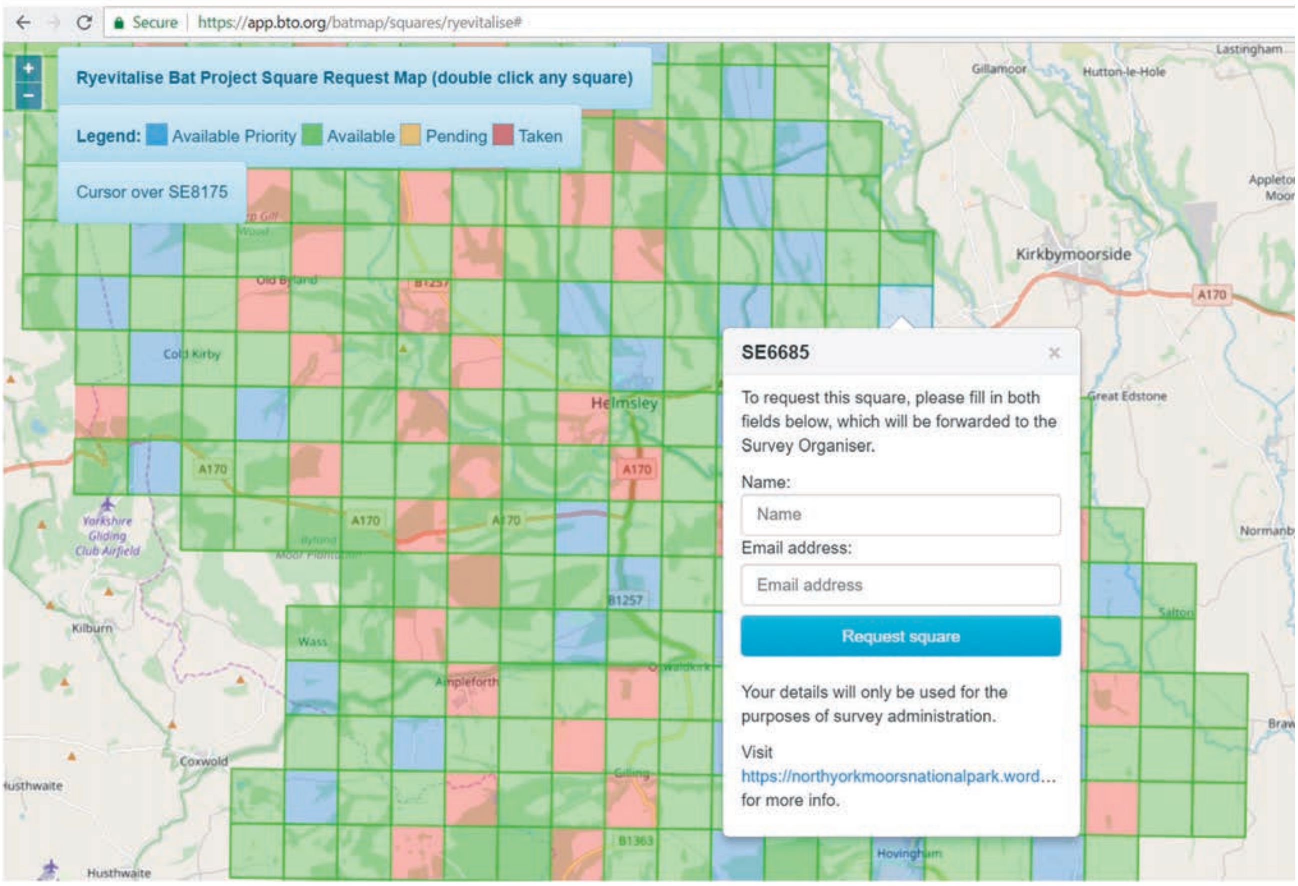
Once species identities had been checked by looking at individual recordings in isolation, calls assigned to species whose calls had the most potential to be confused with those of other species (e.g. bats in the genus *Myotis* and *Nyctalus*) were re-examined in SonoBat, comparing them to other recordings potentially of the same bat made from the same location on the same night at neighbouring points in time (Step 3). All subsequent analyses used final identities upon completion of the above inspection and (where necessary) correction steps. For a summary of the main identification characters for each species see Annexes 2 and 3.

2.4. SPATIAL MODELS OF DISTRIBUTION & ACTIVITY

All data analysis was conducted in R (R Core Team 2015). To assess the value of the data collected here for informing our understanding of bat activity and species distributions within the target area, it was necessary to consider the data in a spatial modelling framework.

We used Generalised Boosted Regression, which is an ensemble implementation of Regression Trees that estimates the form of the relationship between a response variable and its predictors without a priori specification of a data model (Elith *et al.* 2008). This technique estimates a large number of simple models, which are combined to form a final model optimized

Figure 2. To facilitate the monitoring of survey coverage, an online sign-up tool was set up. This system was used to “reserve” out squares as they were surveyed, and so keep track of coverage during the season.



for prediction, using cross-validation for model building. Models were produced using the R package gbm (Ridgeway 2013) and using the gbm.step function (Elith *et al.* 2008) to find the appropriate learning rate and number of trees for each model (see Newson *et al.* 2017). Following analyses of similar data in Newson *et al*. (2015, 2017), we used a tree complexity parameter of 10 and started with a learning rate of 0.001. We then changed the learning rate to find a value that was slow enough to result in an initial steep decline in prediction error followed by a gradual approach to the minimum, and where the number of trees at the minimum point was as close to 1000 as possible based on the rules of thumb in Elith *et al.* (2008). Models were trained with 10-fold cross-validation with a bagging fraction of 0.5 and assessed for predictive performance using either the area under the ROC curve (AUC) for occurrence models or the correlation coefficient between observed and predicted value for bat activity. For evaluation of AUC values, we used the approach recommended by Swets (1988): excellent AUC > 0.90; good 0.80–0.90; fair 0.70–0.80; poor 0.60–0.70; and fail 0.50–0.60 although we accept that these divisions are fairly arbitrary. For occurrence models we assumed a Bernoulli distribution for the response variable and for activity models, a Poisson distribution. Based on previous work which has looked at patterns in bat activity with respect to sunset time (Newson *et al.* 2015, 2017), we standardised all data by considering only bat passes up to six hours after sunset. Gini coefficients were used to assess the degree to which bat occupancy and activity across the Ryevitalise Landscape Partnership area are uniform (coefficient tends to 0) or aggregated (coefficient tends to 1) among 1 km squares. Gini coefficients were calculated using the ineq package in R (Zeileis 2014).

To generalise the recordings at sample locations to the rest of the region, it was necessary to include factors in the model that are likely to influence bat presence and activity. For this, we made use of CEH landcover map 2015 data, comprising eight broad habitats present in the survey area (Rowland *et al.* 2017, Annex 4). These include broad-leaved woodland, coniferous woodland, arable, improved grassland, semi-natural grassland, moorland heath and bog, freshwater and built-up areas and gardens (Table 1). To produce predictions at a 1-km square scale, it was necessary to have habitat data that covered the whole extent of 1 km squares in the Ryevitalise Landscape Partnership Area, i.e. for a wider area around the boundary of the Ryevitalise Landscape Partnership area. Phase 1 habitat was made available by the National Park, but because this was not available for the whole extent of 1-km squares, it was not possible to compare the predictive performance of CEH landcover map data and Phase 1 habitat data. However, additional analyses using Phase 1 habitat data are carried out below to look at habitat relationships at a finer spatial scale, relating to the habitat at the location in which bat detectors were left out to record.

Table 1. CEH Landcover data 2015 aggregate habitat classes.

HABITAT CLASS	RYEVITALISE PARTNERSHIP SCHEME AREA KM^2 (% OF TOTAL)	SQUARES SURVEYED AREA KM^2 (% OF TOTAL)
Broad-leaved woodland	51.36 (10.66)	7.06 (14.40)
Coniferous woodland	38.25 (7.94)	7.93 (16.17)
Arable	154.69 (32.11)	12.98 (26.47)
Improved grassland	117.98 (24.49)	13.01 (26.53)
Semi-natural grassland	3.7 (0.77)	0.65 (1.33)
Mountain, heath and bog	110.19 (22.87)	6.71 (13.68)
Freshwater	0.37 (0.08)	0.03 (0.06)
Built-up area and gardens	5.2 (1.08)	0.67 (1.37)

We focus here on eight species of bat, including Whiskered Bat and Brandt's Bat, which are difficult to distinguish acoustically and are treated together here as a species pair. See Table 2 for the scientific names of these and all species referred to in this paper. Once models had been trained, mid-season (corresponding to the 20th week of the year) predictions of occurrence probability and activity (pass frequency) were made for each species in every 1 km square, using habitat data for each square. All probability of occurrence maps used the same colour scale, ranging from >0 to 1 in increments of 0.1. Bat activity maps use a 10-colour scale, where grid cells are placed into bands according to the 10 equal divisions of predicted activity.

2.5. IDENTIFYING IMPORTANT LOCAL BAT ASSEMBLAGES

A map showing the combined distributions of all bats species was produced to highlight areas with noteworthy local bat species assemblages. The approach taken here was to sum the estimates of probability of occurrence for each 1 km square in the Ryevitalise Landscape Partnership scheme area. High probability of occurrence and many species contribute to make an area being more important in terms of its species assemblage.

2.6. HABITAT RELATIONSHIPS

For each survey location, bat activity (the total number of passes for each bat species recorded during the night) was determined as a measure of relative abundance. In addition, these data were simplified to presence / absence per night as a measure of bat occurrence. As above we standardised all data by considering only bat passes and presence / absence up to six hours after sunset.

Eight broad habitat variables at a 1 km square scale were included in the models as above and taken from Landcover Map 2015 (broad-scale analyses). In addition, we carried out additional analyses using Phase 1 habitat data at a finer spatial scale (fine-scale analyses), relating to the habitat at the location at which bat detectors were left out to record. The Phase 1 habitat comprised 43 habitat types within the Ryevitalise Landscape Partnership scheme area (Table 2). Many of these habitats made up less than 1 km^2 of the scheme area. For the purposes of habitat modelling, it was necessary to reduce the number of habitat types. As a rule of thumb it is recommended that there should not be more than one predictor variable, habitat in this case, for each data point. This was done by grouping Phase 1 habitats into 10 broad classes (Table 2). These included fresh water, heathland and bog, arable, built-up areas and gardens, coniferous woodland, mixed woodland, broad-leaved woodland, unimproved / semi-natural grassland, improved grassland and miscellaneous habitat, the latter comprising mainly scarce habitats which could not easily be combined with other broad habitat classes. As above we focus on eight species of bat, including Whiskered Bat and Brandt's Bat, which were treated together here as a species pair.

For all species, occurrence was modelled using a binomial Generalized Linear Model (GLM) using the lme4 package (Bates *et al.* 2015). Before analysis, the bat data were aggregated across multiple visits to the same sampling point for each species to calculate the number of events and trials and mean activity (average number of recordings). Habitat variables were centred and standardised before implementing the model. Bat activity was modelled with a quasi-Poisson GLM, which we chose in preference to Poisson because it was deemed better able to account for some over-dispersion in the data. Habitat variables were considered significant if $p < 0.05$.

3. RESULTS

3.1. DESK-BASED STUDY

From the National Biodiversity Network, 139 bat records for the target area were extracted. After filtering these to remove records which: (a) did not have a date, (b) were from before 2000, (c) were not recorded at the species level, (d) were duplicate species presence records for the same location, and (e) were not available at a 1-km square resolution or finer, only 8 bat records remained (Table 3). Of 694 bat records provided by the North Yorkshire Bat Group for the Ryevitalise Partnership scheme area, 231 records remained following filtering (Table 3, Annex 5).

3.2. FIELDWORK SURVEY COVERAGE

Data from 100 different 1 km squares were surveyed for bats and sent back to the BTO for processing. This sample comprised 387 complete nights of recording. Whilst the spatial coverage is less than projected due to the timing of securing land access permission, the survey effort far exceeded the 160 nights of recording proposed in the original tender document. 1,133,862 recordings were collected which, following analyses and validation, were found to include 276,764 recordings containing one or more species of bat. Table 4 provides

Table 2. Bat records made available via the National Biodiversity Network and North Yorkshire Bat Group.

(a) Number of records

FILTERING RECORDS	NBN	NORTH YORKSHIRE BAT GROUP
All records	139	694
STEP 1 – remove records without a date	57	694
STEP 2 – remove records before 2000	37	549
STEP 3 – remove records not at species level	25	439
STEP 4 – remove duplicate records	9	231
STEP 5 – remove records with low spatial resolution	8	231

(b) Breakdown of records by record type

SPECIES	IN FLIGHT	ROOST	OTHER	TOTAL
Daubenton's Bat *Myotis daubentonii*	11	0	3	14
Whiskered Bat *Myotis mystacinus*	3	2	3	8
Brandt's Bat *Myotis brandtii*	3	1	1	5
Whiskered or Brandt's Bats *M. mystacinus / M. brandtii*	9	2	3	14
Alcathoe Bat *Myotis alcathoe*	0	2	1	3
Natterer's Bat *Myotis nattereri*	8	6	4	18
Noctule *Nyctalus noctule*	12	0	1	13
Common Pipistrelle *Pipistrellus pipistrellus*	42	37	8	87
Soprano Pipistrelle *Pipistrellus pygmaeus*	14	7	4	25
Brown Long-eared Bat *Plecotus auritus*	16	19	17	52

a breakdown of recordings by species, where a single recording (triggered wav file) may contain more than one bat species.

The remaining recordings mainly comprised recordings of birds (Annex 6 for selected species). Maps of bat activity showing the average number of recordings of each species per night are presented in Annex 7. Manual checking of 500 randomly selected recordings each of Common and Soprano Pipistrelle suggested that less than 1% of recordings were incorrectly assigned (in most of these cases to the other species) which was deemed an acceptable error rate for these highly abundant and geographically widespread species.

3.3. SPATIAL PATTERNS OF DISTRIBUTION AND ACTIVITY

Models of bat distribution and activity were produced for all species (Fig. 3), expect Alcathoe Bat for which there were too few records to model distribution and activity. The learning rate used for each model, number of trees on which the final model was based and model performance statistics (AUC values for distribution modelling and correlation coefficient between observed

Table 3. Phase 1 habitat and broad grouped habitat classes.

PHASE 1 HABITAT	AREA (KM^2)	BROAD HABITAT
Standing water	2.64	Freshwater
Running water	0.38	Freshwater
Dry heath / dwarf shrub heath	4.20	Heathland and bog
Acid dry / dwarf shrub heath	79.03	Heathland and bog
Wet dwarf shrub heath	1.27	Heathland and bog
Wet heath / acid grassland mosaic	0.08	Heathland and bog
Valley mire	0.06	Heathland and bog
Dry modified bog	2.52	Heathland and bog
Acid neutral flush	1.10	Heathland and bog
Basic flush	0.03	Heathland and bog
Basin mire	0.01	Heathland and bog
Arable	103.93	Arable
Urban	0.36	Built-up areas and gardens
Planted coniferous woodland	45.75	Coniferous woodland
Recently felled coniferous woodland	0.19	Coniferous woodland
Parkland scattered coniferous trees	0.01	Coniferous woodland
Planted mixed woodland	11.44	Mixed woodland
Planted scattered mixed trees	0.01	Mixed woodland
Semi-natural mixed woodland	0.02	Mixed woodland
Broad-leaved semi-natural woodland	25.04	Broad-leaved woodland
Parkland scattered broad-leaved trees	0.66	Broad-leaved woodland
Recently felled broad-leaved woodland	0.09	Broad-leaved woodland
Marshy grassland	1.91	Unimproved / semi-improved grassland
Unimproved calcareous grassland	0.96	Unimproved / semi-improved grassland
Unimproved acid grassland	4.77	Unimproved / semi-improved grassland
Unimproved neutral grassland	4.91	Unimproved / semi-improved grassland
Poor semi-improved grassland	10.02	Unimproved / semi-improved grassland
Semi-improved neutral grassland	9.10	Unimproved / semi-improved grassland
Semi-improved calcareous grassland	0.08	Unimproved / semi-improved grassland
Semi-improved acid grassland	1.87	Unimproved / semi-improved grassland
Improved grassland	90.33	Improved grassland
Amenity grassland	1.62	Improved grassland
Bare ground	0.63	Miscellaneous
Ephemeral short perennial	0.05	Miscellaneous
Quarry	0.08	Miscellaneous
Acid inland cliff	0.02	Miscellaneous
Spoil	0.19	Miscellaneous
Dense continuous scrub	3.11	Miscellaneous
Scattered scrub	0.35	Miscellaneous
Continuous bracken	11.83	Miscellaneous
Tall ruderal	2.69	Miscellaneous
Scattered bracken	0.01	Miscellaneous

and predicted values for bat activity) are shown in Table 4. Models validated using occurrence data showed excellent (>0.90) or good AUC values (0.80–0.90), with Common Pipistrelle fair (0.73). For bat activity, the correlation coefficients averaged 0.74, and ranged from 0.57 for Natterer's Bat to 0.93 for Noctule. These values are higher than published elsewhere for other analyses of abundance type information (e.g. Johnston *et al.* 2013, Newson 2015, 2017).

Using Gini coefficients to assess the degree to which numbers of recordings were uniform or aggregated, Whiskered Bat / Brandt's Bat, Natterer's Bat, Daubenton's Bat and Noctule had the highest Gini coefficients for distribution of 0.37 or more reflecting their more restricted ranges. Gini coefficients of activity were highest for the same species highlighting that comparatively few 1km squares contribute a large proportion of the recorded activity (Table 4).

Common Pipistrelle, Soprano Pipistrelle and Brown Long-eared Bat showed lower Gini coefficients for distribution of 0.03–0.25 (Table 4), with those of Common Pipistrelle and, to a lesser degree, for Soprano Pipistrelle close to zero reflecting their widespread distribution. Whilst Common and Soprano Pipistrelle are widespread in distribution terms, there were some differences in spatial patterns of activity, with Soprano Pipistrelle having a comparatively high Gini coefficient for activity of 0.72, highlighting spatial clustering in activity (Table 4, Annex 7).

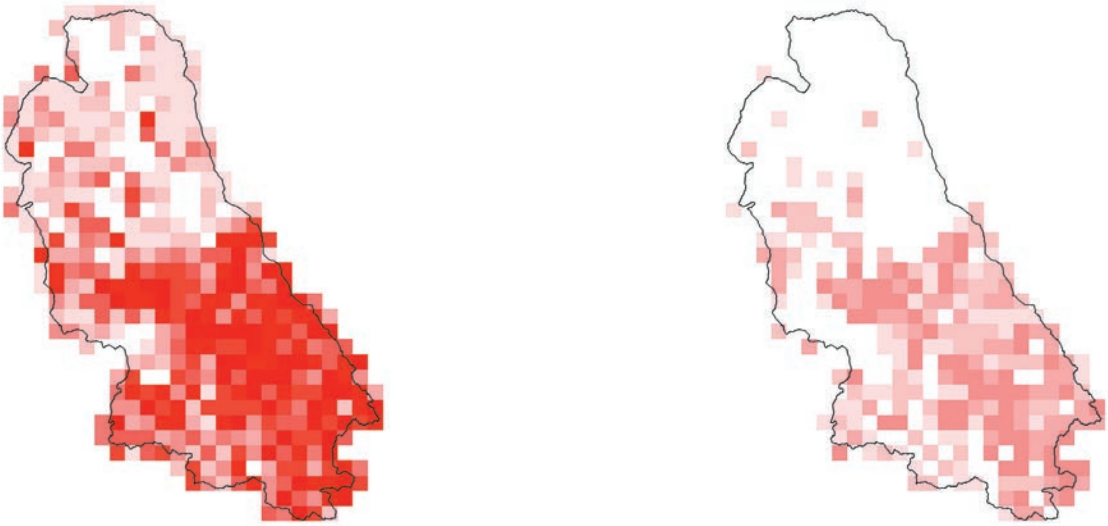
Table 4. Bat species detected by the Ryevitalise Bat Survey, number of recordings of each species following validation and a summary of the scale of recording.

SPECIES	SPECIES CODE	NO. RECORDINGS FOLLOWING VALIDATION	NO. DIFFERENT 1-KM SQUARES (% OF TOTAL)
Daubenton's Bat, *Myotis daubentonii*	Mdau	62,420	97 (97%)
Whiskered/Brandt's Bats, *Myotis mystacinus / Myotis brandtii*	Mmys/Mbra	7,971	74 (74%)
Alcathoe Bat, *Myotis alcathoe*	Malc	8*	6 (6%)
Natterer's Bat, *Myotis nattereri*	Mnat	6,644	95 (95%)
Noctule, *Nyctalus noctula*	Mnoc	6,281	74 (74%)
Common Pipistrelle, *Pipistrellus pipistrellus*	Ppip	120,123	100 (100%)
Soprano Pipistrelle, *Pipistrellus pygmaeus*	Ppyg	56,249	88 (88%)
Brown Long-eared Bat, *Plecotus auritus*	Paur	1,393	80 (80%)
Unidentified *Myotis* species	Myotis	17,716	95 (95%)
Unidentified *Pipistrellus* species	Pipspp	56,029	100 (100%)
Unidentified *Nyctalus* species	Noclei	1,393	59 (59%)

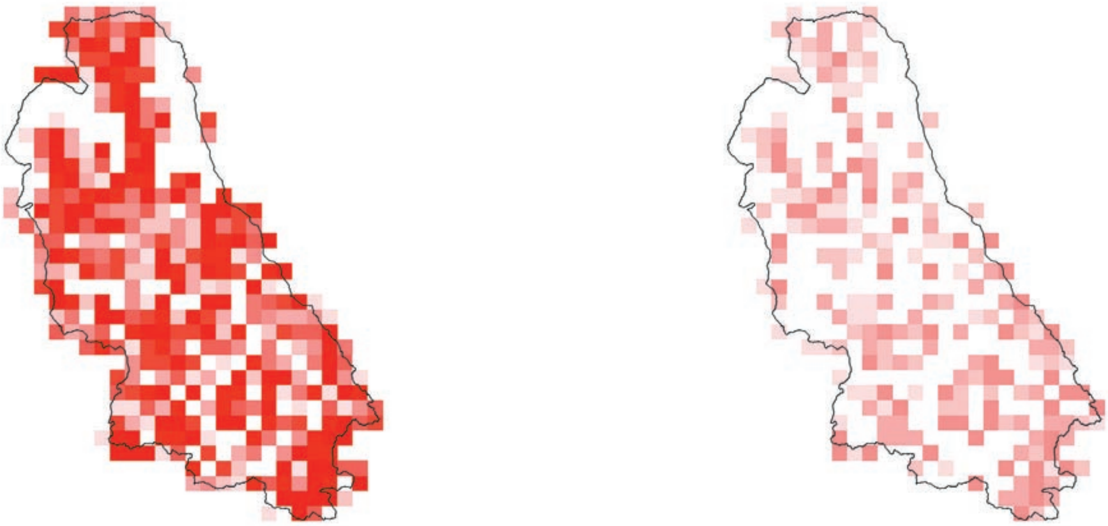
* Note of the eight Alcathoe recordings, only three recordings from two locations were typical recordings of this species in closed habitat where identification of this species is most straightforward. We suspect that the remaining recordings are Alcathoe Bat, but we present these with the caveat that the calls are from open habitat (see Annex 3) where there is more overlap with Whiskered Bat / Brandt's Bat. In addition, we cannot exclude the possibility that some additional recordings of Alcathoe Bat have been assigned to unidentified *Myotis* species.

Figure 3. Maps of predicted occurrence probability (left) and predicted activity (right; a proxy for abundance) for bats in the Ryevitalise Landscape Partnership Scheme area. Darker tones indicate higher probability of occurrence or higher activity. Occurrence maps share the same scale (probability in increments of 0.1 from 0 to 1). The scale for activity maps varies among species although in each case the darkest colour represents the top 10% of locations for that species.

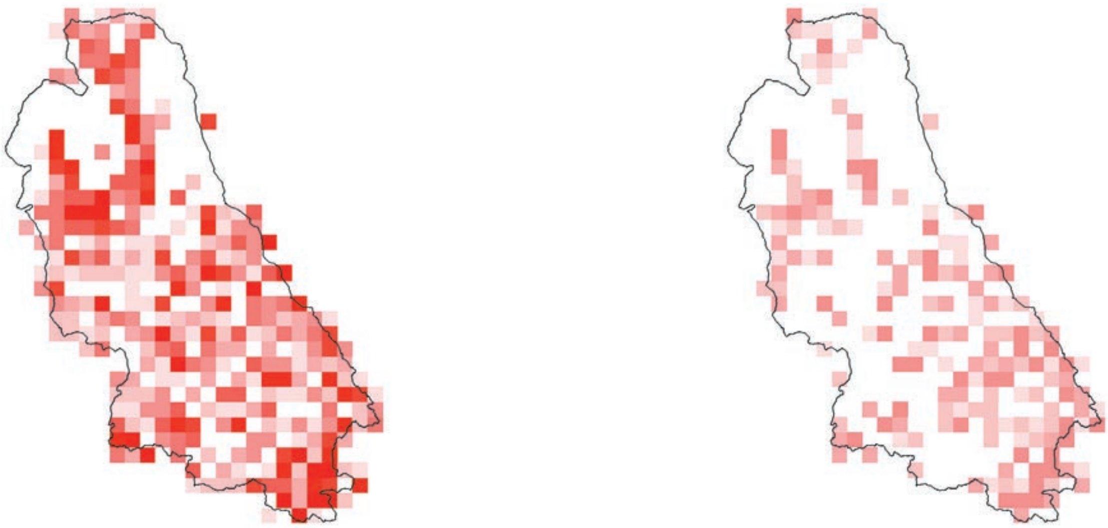
Noctule *Nyctalus noctula*



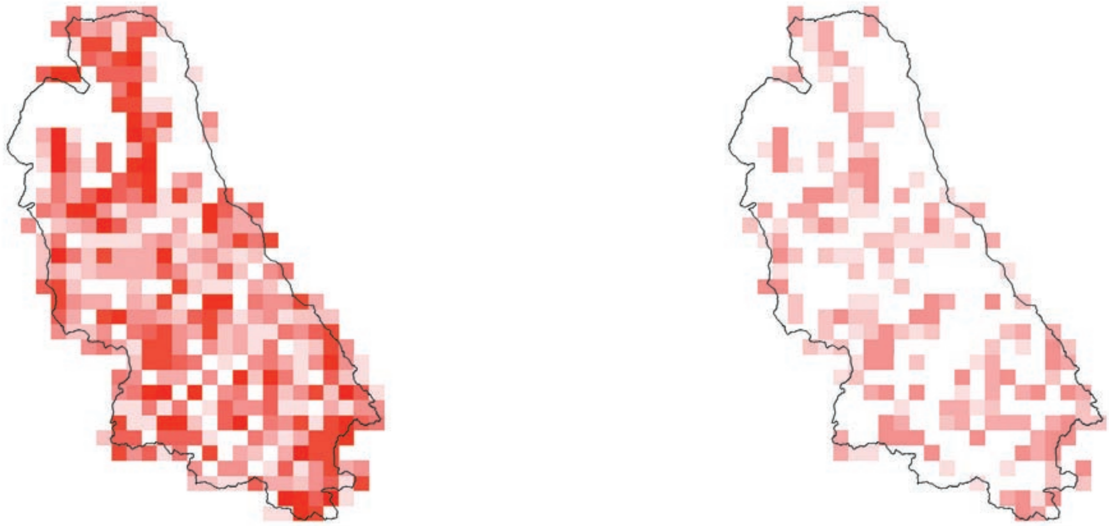
Daubenton's Bat *Myotis daubentonii*



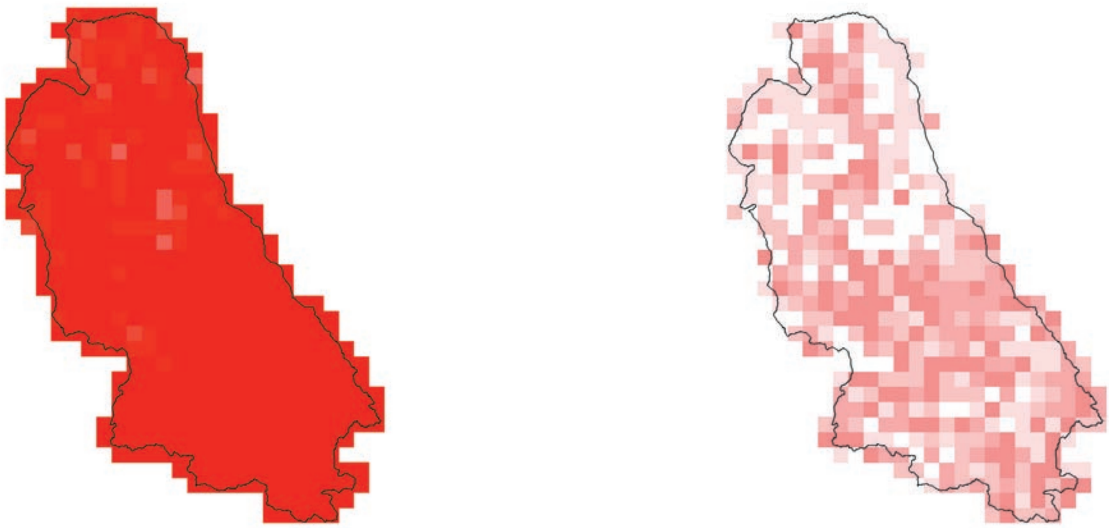
Whiskered / Brandt's Bat *M. mystacinus / brandtii*



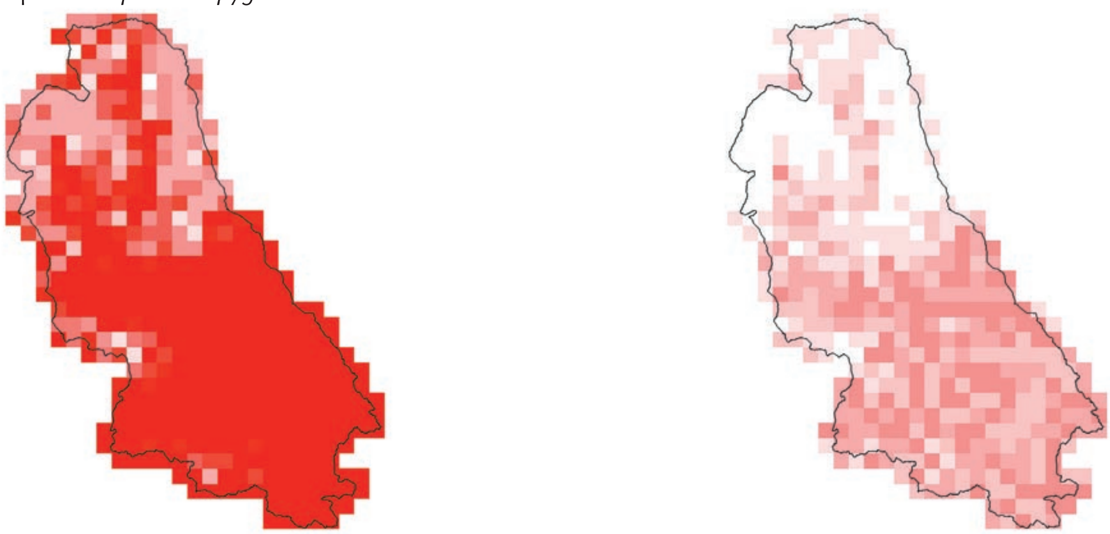
Natterer's Bat *Myotis nattereri*



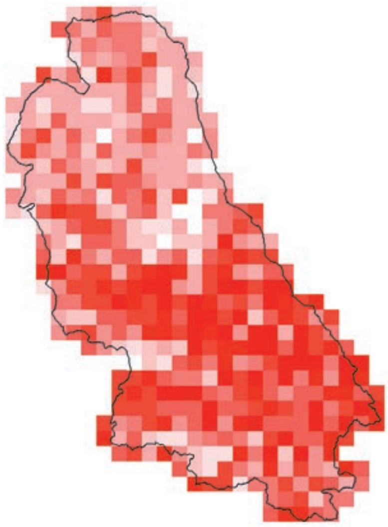
Common Pipistrelle *Pipistrellus pipistrellus*



Soprano Pipistrelle *Pipistrellus pygmaeus*



Brown Long-eared Bat *Plecotus auritus*



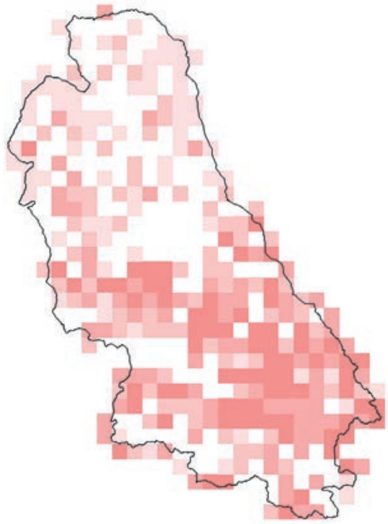


Table 5. Results of generalised boosted regression models to predict patterns of bat occurrence and activity. lr is the learning rate used for each model and nt is the number of trees on which the final model was based. Model performance was assessed by cross-validation and quantified using area under the receiver-operator curve (AUC) for occurrence models and the correlation coefficient between observed and predicted values for relative abundance. Gini coefficients measure the level of aggregation in predicted occurrence or activity.

	PREDICTED OCCURRENCE				PREDICTED ACTIVITY			
SPECIES	lr	nt	AUC	Gini	lr	nt	r	Gini
Daubenton's Bat	0.0018	1,000	0.93	0.41	0.012	1,000	0.93	0.90
Whiskered/Brandt's Bat	0.0034	950	09.1	0.51	0.0145	1,150	0.76	0.83
Natterer's Bat	0.0015	1,110	0.86	0.44	0.0082	1,100	0.57	0.77
Noctule	0.004	950	0.86	0.37	0.0055	1,250	0.74	0.85
Common Pipistrelle	0.001	1,100	0.73	0.03	0.016	970	0.67	0.48
Soprano Pipistrelle	0.009	1,310	0.91	0.16	0.0036	950	0.73	0.72
Brown Long-eared Bat	0.0035	1,050	0.83	0.25	0.035	900	0.76	0.58

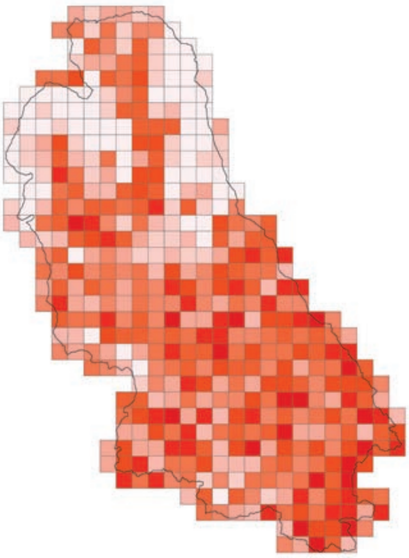
3.4 IDENTIFYING NOTEWORTHY LOCAL BAT ASSEMBLAGES

By combining model predictions of occurrence across all bat species, it is possible to look at the relative importance of different areas in terms of its species assemblage. Through Fig. 4, individual species are allowed to contribute equally to the production of a species assemblage map. This highlights broader species assemblages in the southern half of the study area, away from large areas of open moorland areas.

3.5. HABITAT RELATIONSHIPS

Common Pipistrelle, Soprano Pipistrelle, Natterer's Bat and Daubenton's Bat were the most widely recorded species in the study area, recorded from 88% or more of survey points (Table 4). This was followed by Brown Long-eared Bat (80% of survey points) and Whiskered Bat / Brandt's Bat and Noctule which were both recorded from 74% of survey locations. Because of the small number of locations from which Alcathoe Bat was identified or suspected, it was not possible to formally model habitat associations for this species, but we provide further information on each of the locations that this species was recorded from below.

Figure 4. Map showing spatial variation in the importance of different areas for its bat assemblage. High probability of occurrence and many species contribute to make an area more important in terms of its species assemblage. The darkest colour represents the top 10% of locations.



3.5.1. BROAD-SCALE HABITAT ASSOCIATIONS

A significant positive association between bat occurrence and broad-leaved woodland at a 1km scale was found for five of seven species of bat (Table 6). Positive associations between bat occurrence and built-up areas and between bat occurrence and arable, were also found for five of seven species, although the strength of the positive relationship for arable was weak compared with broad-leaved woodland and built-up areas.

Two species, Noctule and Whiskered Bat / Brandt's Bat were significantly less likely to be recorded in moorland, heath and bog, whilst Common Pipistrelle was the only species that was positively associated with moorland, heath and bog. Noctule and Brown Long-eared Bat were significantly less likely to be recorded in coniferous woodland, and Noctule significantly less likely to be recorded in improved grassland. No significant relationships between bat activity and habitat were identified at this spatial scale (Table 7).

3.5.2. FINE-SCALE HABITAT ASSOCIATIONS

Phase 1 habitat data were used to look at the importance of habitat for different species of bats using habitat associations based on point location at which the bat detector was left out to record.

A significant positive association between bat occurrence and arable was found for four of seven species of bats, including Daubenton's Bat, Natterer's Bat, Noctule and Soprano Pipistrelle (Table 8). Positive associations between bat occurrence and broad-leaved woodland were found for two species, Daubenton's Bat and Soprano Pipistrelle, for semi-natural grassland (Soprano Pipistrelle and Daubenton's Bat), for moorland heath and bog (Natterer's Bat and Whiskered Bat / Brandt's Bat), for freshwater (Daubenton's Bat) and for built-up areas and gardens (Whiskered Bat / Brandt's Bat).

Looking at the importance of habitat in relation to bat activity (number of bat recordings) as a proxy for abundance, revealed that there was higher activity of Brown Long-eared Bat in broad-leaved woodland (Table 9). There was significantly lower activity of Noctule in coniferous woodland, and significantly greater activity of Soprano Pipistrelle in arable habitat. Perhaps surprisingly there was significantly higher activity of Natterer's Bat, Common Pipistrelle and Brown Long-eared Bats in moorland, heath and bog, but at the fine spatial scale considered here, this may relate to moorland, heath and bog that is adjacent to other habitats of importance and reflects the spatial scale of these analyses. Lastly activity of Common Pipistrelle, Soprano Pipistrelle and Daubenton's Bat were significantly greater in built-up areas and gardens, whilst the activity of Brown Long-eared Bat was significantly lower in built-up areas and gardens.

3.5.3. HABITAT AND ALCATHOE BAT

In Figure 5 we provide a photo, a map and a description of the habitat recorded in the field at each of six locations where we recorded Alcathoe Bat (SE5240990608 and SE6769870407), or where we suspect that Alcathoe Bat was recorded (SE5446989366, SE6032587132, SE6475576550, SE6696379608). Whilst all locations are associated in some way with broad-leaved or coniferous woodland, most comprise small patches of woodland within a mosaic of other habitats. The exception is SE5240990608, which comprised recordings from within an area of predominantly mature wet broad-leaved woodland.

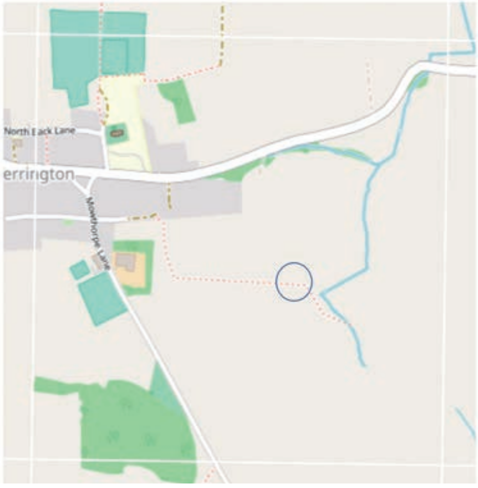
Figure 5. Photo, map and description of habitat recorded at locations where Alcathoe Bat was recorded or suspected to be present.

SE5240990608 (Alcathoe recordings)

Habitat description: edge of pond surrounded by mature broad-leaved trees and boggy grassland.

SE6769870407 (Alcathoe recording)

Habitat description: corner of open pasture next to shrubby treeline and small conifer plantation.



SE5446989366 (suspected Alcathoe recording)

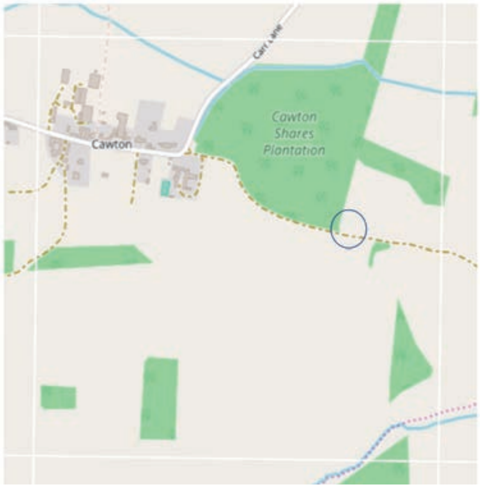
Habitat description: edge of grazed pasture lined with broad-leaved trees, next to small stream.

SE6032587132 (suspected Alcathoe recording)

Habitat description: grassy ride through strip of conifer plantation surrounded by arable fields.

SE6475576550 (suspected Alcathoe recording)

Habitat description: edge of mixed woodland and grazed pasture.



SE6696379608 (suspected Alcathoe recording)

Habitat description: grass strip through small patch of broad-leaved woodland.

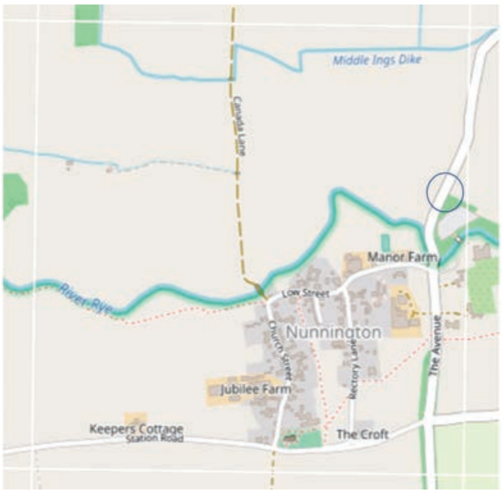


Table 6. Relationship between bat occurrence and habitat variables (CEH landcover map 2015). P-values are: *<0.05, **<0.01, *<0.001. Significant results are further highlighted in bold. Columns are estimated coefficients for the predictors, and their standard errors.**

SPECIES	BROAD-LEAVED WOODLAND	CONIFEROUS WOODLAND	ARABLE	IMPROVED GRASSLAND	SEMI-NATURAL GRASSLAND	MOORLAND, HEATH AND BOG	FRESHWATER	BUILT-UP AREA/ GARDENS
Daubenton's Bat	**0.09 (0.02)***	0 (0.01)	**0.01 (0.1)***	0(0.01)	-0.07 (0.04)	0.01 (0.01)	**0.12 (0.3)***	**0.06 (0.02)***
Whiskered / Brandt's Bat	**0.03 (0.01)***	-0.02 (0.01)	**0.01 (0)***	-0.01 (0.01)	-0.03 (0.04)	**-0.03 (0.01)****	0.32 (0.39)	**0.02 (0.01)***
Natterer's Bat	0.01 (0.01)	0 (0.02)	**0.01 (0)****	0 (0.01)	0 (0.04)	0.01 (0.02)	6.29 (8.23)	0 (0.01)
Noctule	0.02 (0.01)	**-0.04 (0.01)*****	**0.02 (0)****	**-0.02 (0.01)***	-0.04 (0.05)	**-0.02 (0.01)***	**5.86 (2.23)****	0.03 (0.01)
Common Pipistrelle	**0.08 (0.03)****	0.02 (0.01)	**0.03 (0.01)****	0.01 (0.01)	0 (0.05)	**0.02 (0.01)***	5.22 (18.3)	**0.07 (0.03)****
Soprano Pipistrelle	**0.07 (0.02)****	0 (0.01)	**0.03 (0.01)****	0.01 (0.01)	-0.08 (0.04)	0.01 (0.01)	5.17 (16.91)	**0.06 (0.02)****
Brown Long-eared Bat	**0.02 (0.01)***	**-0.04 (0.01)*****	0 (0)	0 (0.01)	-0.04 (0.04)	-0.01 (0.01)	5.8 (26.92)	**0.02 (0.01)***

Table 7. Relationship between bat activity as a proxy for abundance and habitat variables (CEH landcover map 2015). P-values are: *<0.05, **<0.01, *<0.001. Significant results are further highlighted in bold. Columns are estimated coefficients for the predictors, and their standard errors.**

SPECIES	BROAD-LEAVED WOODLAND	CONIFEROUS WOODLAND	ARABLE	IMPROVED GRASSLAND	SEMI-NATURAL GRASSLAND	MOORLAND, HEATH AND BOG	FRESHWATER	BUILT-UP AREA/ GARDENS
Daubenton's Bat	2.15 (3.12)	-9.56 (6.96)	6.9 (4.29)	-4.45 (9.43)	5.88 (3.21)	0.45 (4.7)	-6.36 (4.24)	2.12 (4.19)
Whiskered / Brandt's Bat	2.1 (6.23)	-15.73 (9.37)	10.43 (6.21)	-7.90 (13.31)	8.35 (5.45)	-2.55 (6.57)	-14.41 (5.48)	2.3 (5.13)
Natterer's Bat	3.28 (6.31)	-20.72 (13.11)	13.41 (7.81)	-6.60 (21.78)	11.54 (7.17)	2.54 (10.13)	-13.24 (7.25)	4.70 (4.13)
Noctule	2.70 (6.21)	-15.14 (7.52)	8.29 (6.42)	-5.89 (12.43)	8.72 (4.65)	0.12 (5.64)	-11.64 (7.92)	3.01 (4.04)
Common Pipistrelle	0.06 (1.63)	-3.92 (4.52)	1.38 (1.56)	-3.72 (5.52)	1.29 (1.11)	-3.21 (1.87)	-2.7 (2.42)	0.02 (1.43)
Soprano Pipistrelle	3.08 (7.89)	-12.27 (9.4)	9.56 (7.69)	-6.36 (14.12)	8.78 (5.54)	-2.27 (4.32)	-11.12 (5.72)	3.12 (7.90)
Brown Long-eared Bat	-0.19 (0.32)	-0.21 (0.24)	0.21 (0.26)	-0.13 (0.4)	0.12 (0.4)	-0.16 (0.42)	0 (0.4)	-0.43 (0.49)

Table 8. Relationship between bat occurrence and habitat variables (Phase 1 habitat data). P-values are: *<0.05, **<0.01, *<0.001. Significant results are further highlighted in bold. Columns are estimated coefficients for the predictors, and their standard errors**

SPECIES	BROAD-LEAVED WOODLAND	CONIFEROUS WOODLAND	ARABLE	IMPROVED GRASSLAND	SEMI-NATURAL GRASSLAND	MOORLAND, HEATH AND BOG	FRESHWATER	BUILT-UP AREA/ GARDENS
Daubenton's Bat	**2.11 (0.75)****	1.18 (0.66)	**3.49 (1.17)****	0.36 (0.65)	**2.11 (0.94)***	18.23 (1882.92)	**2.4 (0.94)***	18.23 (1304.53)
Whiskered / Brandt's Bat	0.69 (0.64)	0.34 (0.63)	1.3 (0.67)	-1.27 (0.68)	1.28 (0.74)	**2.73 (1.2)***	0.17 (0.71)	**1.49 (0.75)***
Natterer's Bat	1.08 (0.65)	0.57 (0.63)	**1.58 (0.7)***	0.48 (0.64)	0.75 (0.72)	**2.4 (1.19)**	1 (0.77)	0.94 (0.73)
Noctule	0.24 (0.64)	-0.23 (0.63)	**1.65 (0.69)***	-0.95 (0.66)	0.26 (0.71)	1.03 (0.85)	0 (0.72)	17.9 (791.2)
Common Pipistrelle	1.35 (0.81)	0.08 (0.72)	1.28 (0.85)	-1.23 (0.72)	0.89 (0.91)	0.51 (1.02)	-0.76 (0.78)	16.47 (791.24)
Soprano Pipistrelle	**1.32 (0.67)***	0.24 (0.66)	**2.82 (0.77)*****	-0.59 (0.69)	**2.69 (0.87)****	1.03 (0.85)	1.03 (0.74)	1.45 (0.75)
Brown Long-eared Bat	0.6 (1.2)	0.2 (1.14)	17.17 (1568.63)	-0.79 (1.1)	0.78 (1.46)	17.17 (3104.42)	-0.45 (1.21)	17.17 (2150.8)

Table 9. Relationship between bat activity as a proxy for abundance and habitat variables (Phase 1 habitat data). P-values are: *<0.05, **<0.01, *<0.001. Significant results are further highlighted in bold. Columns are estimated coefficients for the predictors, and their standard errors.**

SPECIES	BROAD-LEAVED WOODLAND	CONIFEROUS WOODLAND	ARABLE	IMPROVED GRASSLAND	SEMI-NATURAL GRASSLAND	MOORLAND, HEATH AND BOG	FRESHWATER	BUILT-UP AREA/ GARDENS
Daubenton's Bat	3.34 (2.2)	2.05 (2.22)	3.2 (2.21)	1.94 (2.23)	3.05 (2.22)	2.12 (2.33)	3.16 (2.22)	**5.85 (2.2)****
Whiskered / Brandt's Bat	1.22 (0.74)	-0.56 (0.81)	1.14 (0.74)	-1.84 (1.08)	0.77 (0.79)	1 (0.84)	-0.02 (0.88)	0.42 (0.82)
Natterer's Bat	0.62 (0.76)	0.16 (0.77)	-0.34 (0.85)	0.05 (0.79)	1.25 (0.77)	**1.61 (0.79)***	-0.18 (0.92)	1.02 (0.79)
Noctule	0.49 (0.63)	**-2.22 (0.95)***	-0.85 (0.76)	-4.18 (2.24)	-1.13 (0.94)	-0.77 (1.06)	-1.01 (0.92)	0.88 (0.66)
Common Pipistrelle	1.42 (0.81)	-0.01 (0.86)	1.35 (0.82)	-2.82 (1.66)	-0.17 (1)	**1.9 (0.85)***	0.74 (0.88)	**3.26 (0.8)*****
Soprano Pipistrelle	1.47 (0.78)	0.29 (0.81)	**1.77 (0.78)***	-0.76 (0.92)	**2.12 (0.79)****	0.08 (1.06)	1.42 (0.81)	**2.25 (0.79)****
Brown Long-eared Bat	**1.64 (0.59)****	0.39 (0.61)	0.95 (0.61)	-0.24 (0.65)	0.28 (0.68)	**1.3 (0.65)***	0.61 (0.65)	**-1.43 (0.61)***

4. DISCUSSION

4.1. DESK-BASED STUDY

The desk-based study collated existing bat records for the period 2000 to the present. Most records were provided by the North Yorkshire Bat Group, supplemented with a small number of additional records from the National Biodiversity Network (NBN). Such opportunistic bat recording forms the basis of local recording, and it is normally the best information that is available for bats for an area. However, such data are very limited in their ability to describe large-scale bat distribution and activity.

The main problems are that the data were not collected according to a standardised survey protocol and there is no information on survey effort, making a valid comparison between sites impossible. In addition, recording is likely to be biased geographically and by habitat. These both introduce biases which are difficult to control for. For example, records obtained from the public and associated with planning applications are likely to be biased towards areas and habitats where there are more people, rather than reflecting the true distribution of bats. In addition, bat workers typically focus their survey effort on sites and habitats which they perceive to be of greater value for bats. This is useful if you are interested in the bats present at target sites, but not if you are interested in landscape patterns of distribution and activity, or wish to interpret the importance of sites in a wider regional context. Whilst beyond the scope of this report, there are steps that can be taken to improve the value of biological recording, such as simple effort recording, but the current value of the existing data for informing our understanding of bat distribution and activity is limited.

4.2. IDENTIFYING "HOTSPOTS" FOR BATS

The current dataset of over 270,000 bat recordings has been valuable in defining patterns of occurrence and activity across the Ryevitalise Landscape Partnership area.

Alcathoe Bat, Noctule and Whiskered / Brandt's Bat appear to be the most range restricted bat species, with the core distribution and activity of these species in the southern half of the study area. The latter can be viewed as a proxy for abundance, with high levels of activity typically occurring where a species is most abundant. For Noctule, comparatively few 1 km squares recorded a high proportion of the total activity. Whilst Common and Soprano Pipistrelles were recorded almost everywhere where a detector was left out to record, Soprano Pipistrelle showed strong spatial clustering in activity at a small number of locations. Of eight Alcathoe Bat recordings, only three recordings from two locations were typical for this species in closed habitat, where identification of this species is most straightforward. We suspect that the remaining five recordings are Alcathoe Bat, but we present these with the caveat that the calls are of a type recorded in open habitat (see Annex 3), where there is some overlap with Whiskered Bat / Brandt's Bat. In additional we cannot exclude the possibility that some additional recordings of Alcathoe Bat were not identified and are currently assigned to unidentified *Myotis* species.

4.3. IMPORTANCE OF HABITAT

Most of the relationships between bat occurrence and activity and habitat are in line with the current knowledge on the ecology of the species present (e.g. Bellamy *et al.* 2013). We have considered habitat associations at two spatial scales, but it is important to acknowledge that we cannot exclude the possibility of there being important habitat associations at a larger spatial scale than we have considered.

Common and Soprano Pipistrelle are the most common and widespread of all British bat species (Bat Conservation Trust 2018). Whilst Common Pipistrelle is more of a generalist, foraging in a wider range of habitats, Soprano Pipistrelle is more strongly dependent on riparian habitats, foraging mainly on lakes and rivers and in woodlands (Vaughan *et al.* 1997, Russ & Montgomery 2002, Nicholls & Racey 2006). In line with this, broad-leaved woodland was one of the most important habitats for Soprano Pipistrelle in the present study. There was some evidence for an association for Soprano Pipistrelle with freshwater, although the strength of the relationship was low. Broad-leaved woodland is known to provide valuable foraging and roosting opportunities for Common and Soprano Pipistrelle, but a strong positive association with built-up areas and gardens, suggests that human habitation is important, presumably in providing valuable roosting opportunities.

Daubenton's Bat is known to be strongly dependent on lakes, rivers and woodland edge for foraging (Siivonen & Wermundsen 2008). Results of the present study confirmed these preferences with a positive association with freshwater and broad-leaved woodland. Whilst previous studies have shown that Daubenton's Bat avoids bigger towns and cities, linked to disturbance resulting from the greater presence of streetlights

(Aughney *et al*. 2012), the positive association here with built-up areas and gardens relates to small inhabited areas and isolated houses, where it may be may be making use of houses for roosting.

The two cryptic species Whiskered Bat and Brandt's Bat, treated as a pair in the present study, are believed to be widespread in England, but large-scale data for these two species are generally very limited. They are both linked to broad-leaved woodland, woodland edge and parks which are selected as the core foraging areas (Russ 2012, Buckley *et al.* 2013). Results of this study confirmed this selection. They roost in trees and also in buildings (Berge 2007), the importance of which are highlighted in there being significant positive associations with broad-leaved woodland and with built-up areas / gardens. Like Daubenton's Bat, this is a species which avoids larger areas of conurbation, which are not present in the study area.

For Alcathoe Bat, only a small number of recordings of this species were identified from six locations, of which recordings from only two locations were typical recordings of this species where identification of this species is most straightforward. Whilst all of the locations were associated with broad-leaved or coniferous woodland, most comprised small patches of woodland within a mosaic of other habitats. The exception was one of the two locations from which we are most confident that Alcathoe Bat was recorded, which comprised mature wet broad-leaved woodland. On the continent, the habitat of Alcathoe Bat is generally described as consisting of moist, deciduous, mature forest close to streams (Niermann *et al.* 2007).

Natterer's Bat is another *Myotis* species which is often associated with broad-leaved woodland for roosting and foraging (Swift 1997, Vaughan *et al.* 1997, Smith & Racey 2008). This species is also known to make use of old and historic buildings (Jones & Altringham 1996) including churches. In this study, we found few strong and consistent habitat associations for this species, although as noted above, we cannot exclude the possibility of there being important habitat associations for this species at a larger spatial scale.

The fast flying Noctule is able to exploit a range of habitats, as long as they have sufficient trees for roosting and a high density of high-flying insects (Dietz & Kiefer 2016). This presumably explains the distribution of species, which appears to be much more widespread and abundant away from larger areas of moorland, heath and bog where there are fewer trees. Noctule is primarily a tree-dwelling species, particularly preferring woodpecker cavities over natural cavities (Boonman 2000). Together with freshwater, woodland is thought to be important for this species, but this species can commute long distance to foraging sites. In this study we did not find a significant association with broad-leaved woodland, but this species was significantly more likely to be present in areas where there was water in the 1-km square. Although not recorded previously, there was no evidence from this study that the closely related Leisler's Bat was present in the study area.

The Brown Long-eared Bat is also predominantly a tree-dwelling bat, but this species is also often recorded roosting in loft spaces of old houses, barns and churches, although the presence of woodland within a radius of 0.5 km from the roost seems to be required (Entwistle *et al.* 1997). In this study there was a significant association with broad-leaved woodland, but no strong association with built up areas and gardens for this species.

4.4. RECOMMENDATIONS FOR PRACTICAL CONSERVATION ACTION

Woodland needs to be managed in such a way that minimises disturbance and impacts to bats. In particular, a lot of tree felling is being carried out in the study area, which could impact on bats. Within these areas, there is a clear need to identify and protect roost trees, and to minimise impacts where possible, for example by carrying out felling in the winter. Where there are young plantations, these can be hard for bats to exploit. The maintenance of some unmanaged patches with mature trees may encourage a greater presence of bats in these areas. In addition, of primary importance should be the preservation of veteran trees, which are more likely to have cavities and splits providing roosting opportunities for bat species. However small trees with appropriate features are also frequently used by bats for roosting and should not be overlooked (see http://battreehabitatkey.co.uk).

Arable farmland comprises about a third of the Ryevitalise Landscape Partnership area, and as such it is important to encourage farming practices that are likely to benefit bats. It is important to consider landscape scale conservation, which maintains a mosaic of different habitats and connectivity across the landscape. This includes maintaining and potentially extending the network of hedgerows and tree lines. Because freshwater is important for several species of bats, it also important to ensure that the quality of riparian habitats for bats, including water quality is maintained.

There is good evidence from this study that small villages and isolated houses are likely to present important roosting opportunities for several bat species, including Whiskered Bat / Brandt's Bat. For these, the goal should be to encourage bat awareness and education among householders, to minimise bat sensitive development and, where useful, to replace or enrich areas with trees and hedgerows to facilitate the connectivity of woodland patches in the landscape. Related to roosting opportunities, the restoration or renovation of old or historical buildings, farms, barns and churches should ensure the preservation of existing roost sites. In practice, the renovation of buildings where there are bat roosts often has negative consequences for bats (Stone *et al.* 2013). In areas where there are people, the levels and use of artificial lighting should be minimised as far as possible. This could include restricting unnecessary lighting installations and considering turning off lights in areas commonly used by light-adverse bat species at key times of year, such as when breeding (Jones 2000). Where lighting cannot be avoided, intelligent lighting schemes should be considered, including the use of motion sensors which permit lights to remain switched off unless needed (Royal Commission on Environmental Pollution 2009).

4.5. DEVELOPING THE SURVEY INTO A LARGE-SCALE CITIZEN SCIENCE PROJECT

Beyond this season there is the potential to continue and develop the survey work as a Citizen Science project. In the following we draw on our experience of setting up and running similar volunteer projects in Norfolk and southern Scotland (www.batsurvey.org, Newson *et al.* 2015, 2017). We have also develop tools to help support Devon Wildlife Trust with their HLF funded Greater Horseshoe Bat project, and are involved in a NERC funded project with the Bat Conservation Trust, University College London and Oxford University to develop some of the tools and infrastructure needed to run a large-scale passive detector survey, the British Bat Survey as part of the National Bat Monitoring Programme.

Through these we have developed or are developing tools to help with the running of large-scale acoustic projects like this, which with funding could be adapted for use here.

Whilst the size of the Ryevitalise Partnership Scheme area is small in comparison, assessing season wide status of bat species across a large region like Norfolk or southern Scotland, is something that is only realistically achievable on this scale by working with members of the public. Both these surveys were set up to enable members of the public to have access to passive real-time bat detectors, comparable to those used here, which they could place in a location of their choice to automatically trigger and record the calls to a memory card every time a bat passes throughout a night. The Norfolk Bat Survey data set now contains over two million bat recordings, making this one of the most extensive high-quality data sets for bats.

Through all of our volunteer bat projects, we have collaborated with a number of organisations and local libraries to set up "Bat Monitoring Centres" at existing locations used by the public, from which anyone could borrow a bat detector for a short period. The idea of doing this was to make the equipment as accessible to as many people as possible over a large survey area, but also to take advantage of the interest and pool of volunteers provided by working with a range of organisations, each with its own community of supporters and volunteers. For the North York Moors National Park, the survey area over which volunteers need to travel to pick up a bat detector may be sufficiently small that the park headquarters could act as a single hosting centre, but there are advantages of making the equipment more widely available and involving other organisations. In particular, another hosting centre in the north of the study area could be useful, for example at Chop Gate. If this is considered, there are a number of requirements of the hosting centres, which are worth considering and are likely to influence the level of volunteer uptake.

1. Bat Monitoring Centres that are evenly spaced so that as many people as possible will be within a close distance to a hosting centre. Also close to main roads, and areas with people / potential volunteers.

2. Ideally centres hosting a detector should be open to the public six or seven days a week with good opening hours. Priority was given to centres where staff, volunteers or members would be interested in using the equipment themselves or in promoting the project, and ideally include a range of organisations and local libraries if present.

To give an idea of the maximum target level of uptake possible, if a detector were to be fully booked out from a centre across a long survey season (May to September), and recording for four days at a time with an additional day between to allow for return and pick up on different days which is advised, it should be possible to survey about 30 1 km squares. With six detectors, the maximum survey coverage would be about 180 1 km squares (720 nights of bat recording). If there was an interest in surveying specific sites, repeat visits to the same sites throughout the season or a wish to boost survey coverage, it would be good to consider employing a paid fieldworker. We have used this approach in southern Scotland, to work concurrently with volunteers and a paid fieldworker who worked to ensure representative geographic and habitat coverage (Newson *et al.* 2017).

No prior experience or training on using the bat equipment is needed, but instead volunteers follow provided instructions and guidance on setting and placement of the detector and microphone. A quick start guide on using the bat equipment has already been written and provided with each detector kit.

Through our bat surveys memory cards containing recordings have been returned to the BTO for analyses in a supplied freepost envelope, along with a completed recording form giving the dates and grid reference at which the detector was used. If distributing equipment across hosting centres, a similar system could be used, or alternatively if all the equipment is hosted at the National Park offices, the used SD card/s could be returned with the equipment to the park offices. Where the SD cards are returned to will depend on who and where the data will be processed, and whether there is the ambition to provide a first feedback of results quite quickly to volunteers. This has the advantage of enthusing volunteers to do more or enlist others, but this can be extremely time consuming and may require some specialist knowledge.

In terms of processing bat recordings, there are a couple of options which the BTO could help support.

1. The first would be to provide a copy of some software and scripts for the National Park to carry out a first analysis of recordings themselves and to leave this to the National Park to administer. The data volume would be less for the Ryevitalise area than for Norfolk, but with 20 bat detectors in Norfolk, we normally need in the region of about 55 days of staff time / administration with a survey organiser to deal with emails, problems with bat equipment, downloading and processing recordings, and returning feedback as data is received. To do this would require some information systems expertise at the national park to install, and a computer literate survey organiser who is able to use bespoke software and to use existing scripts written in R. This would also require a computer with a minimum of 16 GB of ram of memory and somewhere to store a large volume of recordings. Related to the processing, this season, we have set the detectors to record birds in addition to bats. The cost of doing this, is that the memory cards will fill up more quickly, potentially a 32 GB card in under four nights (although a 64 GB card could be used instead). With this there is an additional cost in storage and time to download and copy recordings, and there will be a significant additional computational cost and time to process recordings.

2. The second option, would be for the BTO to set up an automated pipeline for getting the raw recordings from volunteers, for processing recordings and returning results to the volunteer. This would be a significant piece of work to put in place (about 50 days of work, plus cost of storage of large sound files), but would result in a more engaging user experience, and a significant saving in staff time / administration in the longer-term.

The system we would propose would start with the volunteer making use of software currently in development at the BTO, through which they would be able to upload their bat recordings directly to a central computer (potentially on the cloud) for processing (Fig. 6), along with associated metadata (name and contact details of volunteer, system for recording where the detector was left out to record etc). Doing this would reduce the amount of time needed for administering the survey and data. The recordings would then be processed as a first analysis and results made available / returned to the volunteer. Using this method, members of the public would be given an opportunity to participate in bat surveys, to take advantage of bat recording technology that would not normally be available to them, and to be engaged in the results as soon as possible after taking part. Such an approach provides significant added value in terms of public engagement.

In Norfolk we have developed online interactive results pages, which could form part of the pipeline to automatically make results available to volunteers once the sound files have been processed. As an example public results pages for the Norfolk Bat Survey can be viewed at https://app.bto.org/bat-vis/NorfolkBatSurvey/ (Fig. 7) Online results pages are also produced to provide the volunteer with their site-level results, which are accessible to volunteers through a private URL (although which can be shared by the volunteer) which could be set to automatically be emailed out to the volunteer once the data has processed.

In terms of the infrastructure, we already have existing web systems through which volunteers can sign up to take part (https://app.bto.org/batmap/squares/ryevitalise) and for coordinating the booking out of detectors. The following example was set up to help support the HLF funded Devon Wildlife Trust Greater Horseshoe Bat Project https://app.bto.org/batmap/batcentres/devon, Fig. 8). These would require some funding for development and maintenance, but much of the core development work has already been carried out.

Through our past projects, we have used publicity to direct people to the online sign-up map, showing survey coverage, available squares, and enabling volunteers to sign up. If there are areas where uptake is slow before the field season begins, it gives the National Park the opportunity to see these and to target further promotion to these areas. The survey map is updated during the season; and potentially data analysed and feedback given to volunteers during the project rather than at the end of the season. This means that it is possible to pick up any problems at hosting centres if used or with volunteer uptake at an early stage. The sign-up map is linked to the online booking system, to help coordinate the booking out of detectors, and so that volunteers are automatically emailed the web link to reserve out a detector once they have reserved a 1 km square for survey.

In terms of the survey design for ongoing volunteer surveys, it is worth considering what the most important longer-term outputs would be. If the ambition is to be able to monitor change in bat populations over time, it would be best to focus on making repeat visits to as many of the same sites surveyed this season as possible, which would enable the detection of change in bat populations, which in turn would feed into an ongoing assessment and conservation priorities for this taxon. If the main interest is in describing species distribution and activity, it would be better to focus on improving spatial coverage of the Ryevitalise Partnership scheme area, so to focus on surveying new 1 km squares. These are not mutually exclusive, but regardless of the main aim, it would be valuable to continue to encourage volunteers to achieve as representative geographic and habitat coverage as possible. A simple option would be to highlight "priority" squares for survey in blue on the online sign-up map as done this year. Depending on the approach

Figure 6. BTO software in development through which volunteers can upload their recordings, along with associated metadata (volunteer name and contact details and recording location) to a central place for processing.

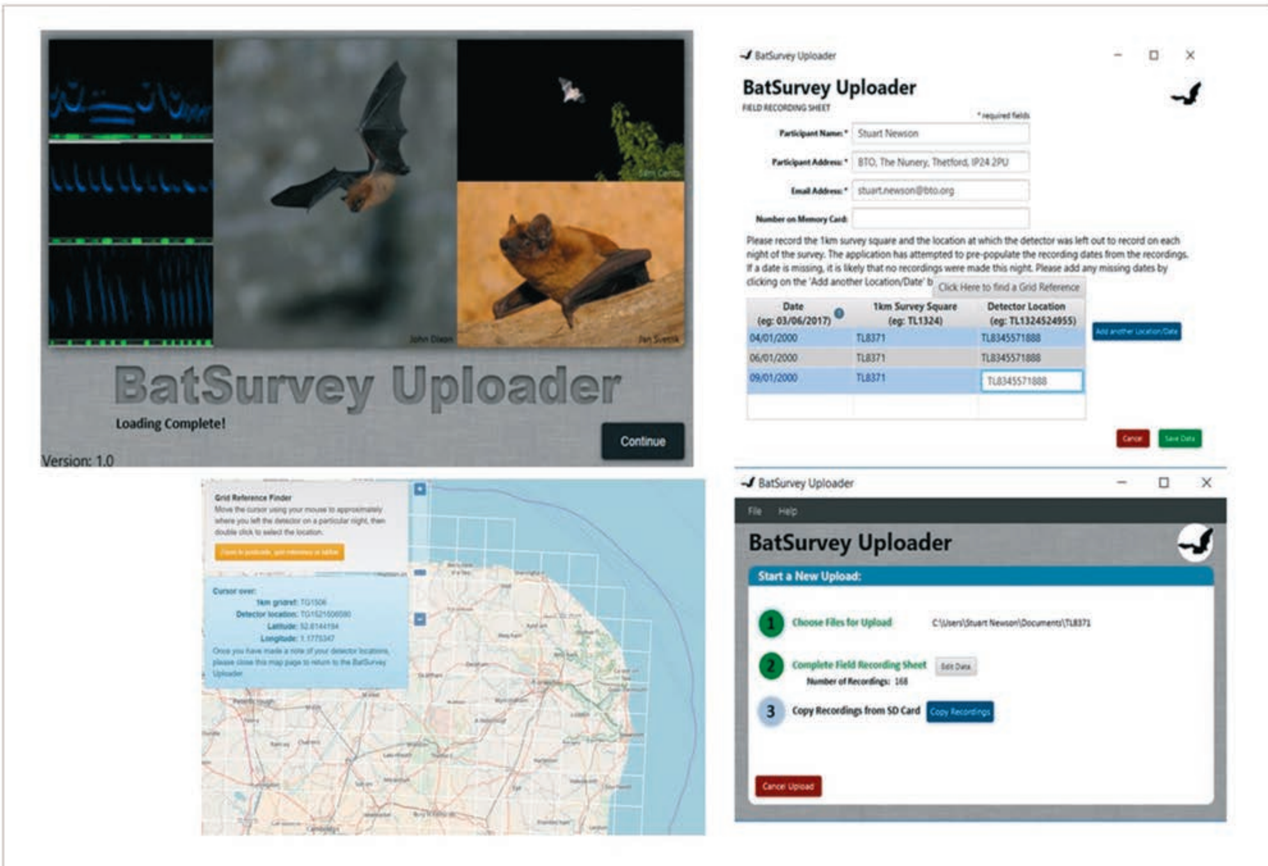


Figure 7. Interactive online results pages shown here for the Norfolk Bat Survey. A similar system could be set up to present and return results to volunteers for the Ryevitalise Landscape Partnership Area. See https://app.bto.org/bat-vis/NorfolkBatSurvey/

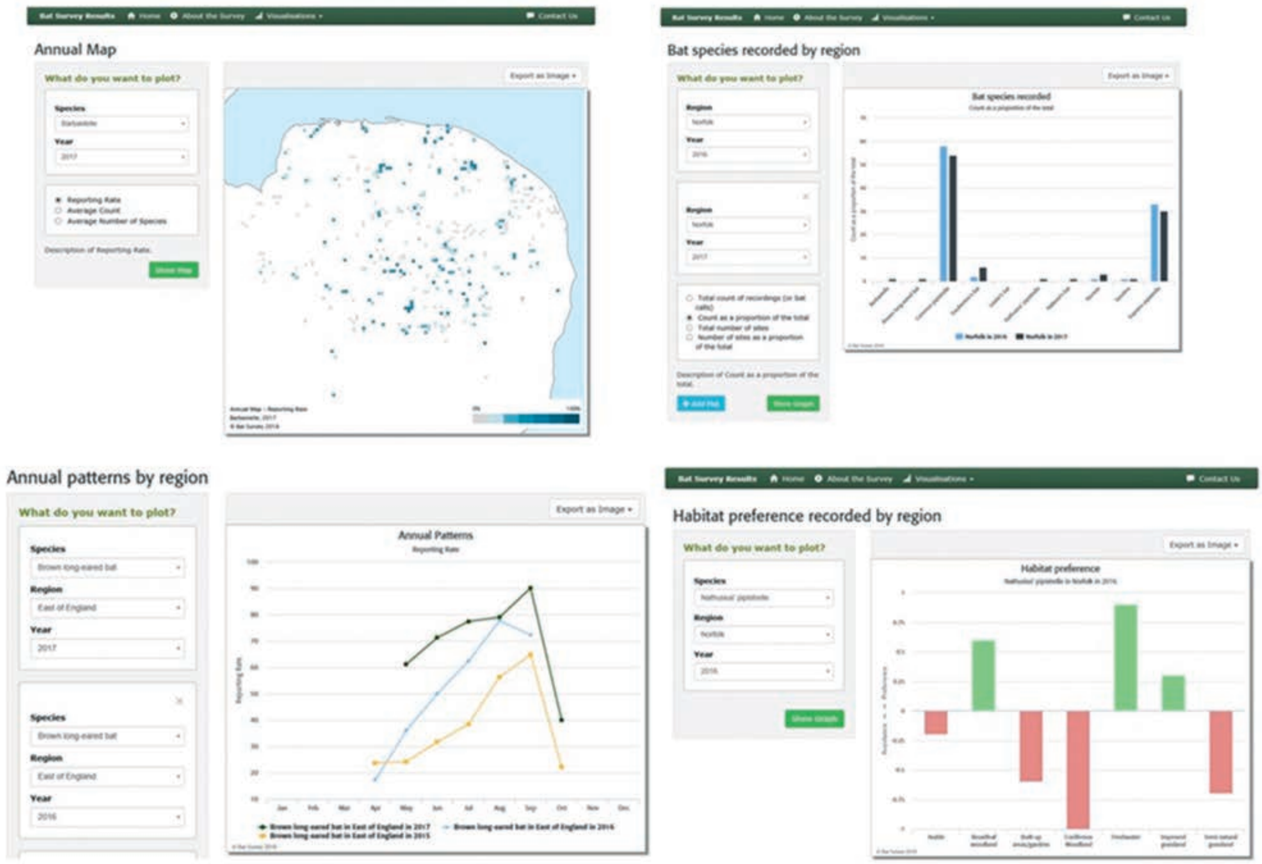
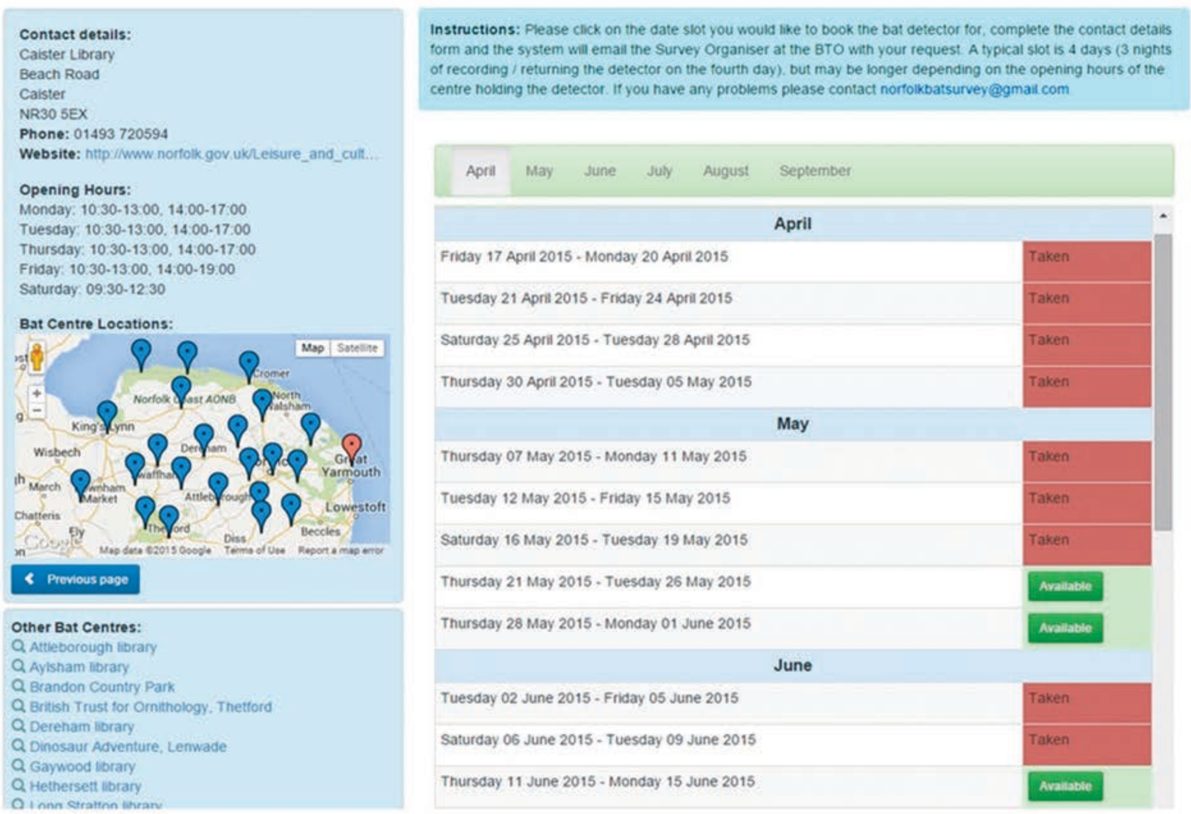


Figure 8. An interactive online booking system for members of the public to request a detector for a few days is already operational for the Norfolk Bat Survey shown here; with minor modification this could be extended to the Ryevitalise Landscape Partnership Area.



(repeat visits of the same sites, or increasing spatial coverage) to either retain the same priority squares, or to shift these. Working with volunteers, it would then be good to encourage volunteers to survey a random priority square if they are able to but, to obtain high volunteer uptake, to have some flexibility to survey at other locations if this is not possible. This approach was successfully used in our southern Scotland bat survey (Newson *et al.* 2017).

If the future priority is to focus effort on habitats, such as broad-leaved woodland, which have been shown here to be particularly important for bats, including Alcathoe Bat, it is important to ensure that the survey design is representative of the habitat or area of interest. This could be done according to a stratified random survey design, by dividing the Ryevitalise Landscape Partnership areas into two strata, inside and outside the habitat of interest, and to then randomly select locations for survey within the habitat of interest. Within these more focused acoustic surveys and trapping could be carried out to confirm the presence of Alcathoe Bat.

Whilst the focus of this study has been to provide baseline information on bats in the Ryevitalise Landscape Partnership area, there is clearly an opportunity to maintain and develop the infrastructure and volunteer-base either within or beyond the Ryevitalise Landscape Partnership area. This would make a substantial and cost-effective contribution to long-term, large-scale bat monitoring and understanding of bats in the area, with the potential to put these data to a wider range of uses than the survey was designed to address. Similar data have been used to describe ecological patterns for a number of bat species and at a variety of spatial scales, including studies of spatial variation in relative abundance, habitat selection, phenology of seasonal and nocturnal activity (e.g. Azam *et al.* 2015; Millon *et al.* 2015; Newson *et al.* 2015; Border *et al.* 2017).

4.6. CONCLUSIONS

As well as contributing to our understanding of bat distribution and activity in the Ryevitalise Landscape Partnership area, this study illustrates that it is possible to collect presence-absence data at a large spatial scale to provide large-scale representative data to be used for spatial modelling. Increased reliance on presence-absence and information on bat activity as a proxy for abundance generated by this kind of sampling will lead to an improvement in the quality of bat data, and in the reliability of the conclusions drawn from them. This is particularly important when these conclusions feed into conservation management and regulation, as these can impact not only on the conservation status of bats but also on decisions made about economic development and the attitude of society towards conservation.

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ANNEX 1: BAT CALL MEASUREMENTS

Call measurements extracted and used by the random forest classifier in Step 1 of the recording validation process are shown below. Measurements with the prefix CM, CS, CN, CO and CO2 relate to linear descriptors of each detected sound event (DSE), and correspond to the elements that contain the maximum amplitude within each time window, the starting edge of the DSE, the upper frequency edge of the DSE, the lower frequency edge of the DSE and the first elements forming a local amplitude maximum on each frequency band respectively. The call measurements are described in more detail in Bas & Bas (2016) Tadarida-L GitHub repository https://github.com/YvesBas/Tadarida-L/blob/master/Manual_Tadarida-L.odt.

MEASUREMENT	DESCRIPTION OF CALL MEASUREMENT
Amp1	Average amplitude among time windows within 1st quarter of DSE
Amp2	Average amplitude among time windows within 2nd quarter of DSE
Amp3	Average amplitude among time windows within 3rd quarter of DSE
Amp4	Average amplitude among time windows within last quarter of DSE
BW	Maximum frequency - minimum frequency
CM_5dBBW	Frequency of farthest point before frequency of maximum amplitude and less than 5 dB below peak amplitude
CM_5dBDur	Time difference between 5dBBF point and 5dBAF point
CM_ELB2POS	The same as ELBPOS, but bend id determined by global slopes before and after bend
CM_ELB2SB	Slope of the part of the line ending at the first bend identified by global slopes (ELB2POS)
CM_ELBPOS	Duration of line to the point where the line makes a “bend” divided by the duration of the line before the first eventual ascent of the line. A “bend” is defined as the first element x where the slope ratio between three elements before and three elements after x is under 0.6
CM_ELBSB	Slope of the part of the line ending at the first bend determined by local slopes (ELBPOS)
CM_EnSl	End Slope
CM_FlF	Frequency of the flattest part of the line (calculated on five consecutive time windows). If several frequencies get a 0 slope, FlF takes the value of longest null slope
CM_FISl	Slope at the FIF point
CM_LoSl	Slope of the lower part of the line (below HCF - frequency of the point of maximum change of slope before frequency of flattest part of the line)
CM_RAFE	Ratio of time windows average frequency before the master point and after + ratio of the time windows average amplitude before master point and after
CM_RAFP3	Ratio of the sums of time windows average amplitude weighted by amplitude (of the point of the line), before and after master point
CM_SAMP	Slope between the master point and the end of the line
CM_SBAR	SBMP/SAMP
CM_SBMP	Slope between the beginning of the line and the master point

CM_SDCL	Cumulated changes in frequency slope of the part of the line before the first eventual ascent succeeding the master point
CM_SDCLOP	Cumulated changes in frequency slope of the "main slope" of line. The "main slope" is defined as the part of the line which contains the master point and has no change of slope direction
CM_SDCLR_DNP	SDCL divided by the number of changes of direction of the line (positive / negative) / Dur
CM_SDCLROP	SDCLOP / Dur
CM_SDCLRWB	SDCLWB / Dur
CM_SDCLRXYOPWB	SDCLWB divided (a second time) by duration
CM_SDCR	Cumulated changes in frequency slope / Dur
CM_SDCRXY	(SDCR / BW) / Dur
CM_Slope	Modulation Slope
CM_StSl	Start Slope
CM_THCF	Time of the point which gave "HCF", where HCF is the frequency of the point of maximum change of slope over/before FIF (in fraction of line duration)
CM_UpSl	Slope of the upper part of the line (over HCF)
CN_EnSl	End Slope
CN_FlF	Frequency of the flattest part of the line (calculated on five consecutive time windows). If several frequencies get a 0 slope, FlF takes the value of longest null slope
CN_FPSl	Slope at the point of maximum amplitude
CN_LoSl	Slope of the lower part of the line (below HCF)
CN_SDCR	SDC / Dur
CN_Slope	Modulation Slope
CN_StSl	Start Slope
CN_THCF	Time of the point which gives "HCF" (in fraction of line duration)
CN_UpSl	Slope of the upper part of the line (over HCF)
CO_EnSl	End Slope
CO_FPSl	Slope at the point of maximum amplitude
CO_LoSl	Slope of the lower part of the line (below HCF)
CO_SDCR	SDC / Dur

CO_Slope	Modulation Slope
CO_StSl	Start Slope
CO_THCF	Time of the point which gaves "HCF" (in fraction of line duration)
CO_UpSl	Slope of the upper part of the line (over HCF)
CO2_5dBBW	Difference between 5dBBF and 5dBAF
CO2_5dBDur	Time difference between 5dBBF point and 5dBAF point
CO2_EnSl	End Slope
CO2_FISl	Slope at the FIF point
CO2_FPkD	Difference of _FPk with previous detected sound event
CO2_ISlope	1/Slope
CO2_LoSl	Slope of the lower part of the line (below HCF)
CO2_SDCR	SDC / Dur
CO2_Slope	Modulation Slope
CO2_StSl	Start Slope
CO2_THCF	Time of the point which gaves "HCF" (in fraction of line duration)
CO2_TPk	Time of amplitude peak (in fraction of line duration)
CO2_UpSl	Slope of the upper part of the line (over HCF)
CS_ELB2POS	The same as ELBPOS, but the bend id determined by the global slopes before and after the bend
CS_ELB2SB	Slope of the part of the line ending at the first bend identified by global slopes (ELB2POS)
CS_ELBPOS	Duration of line to the moment where the line makes a "bend" divided by the duration of the line before the first eventual ascent of the line. A "bend" is defined as the first element x where the slope ratio between three elements before and three elements after x is under 0.6
CS_ELBSB	Slope of the part of the line ending at the first bend determined by local slopes (ELBPOS)
CS_EnSl	End Slope
CS_FIF	Frequency of the flattest part of the line (calculated on 5 consecutive time windows). If several frequencies get a 0 slope, FIF takes the value of longest null slope
CS_FPSl	Slope at the point of maximum amplitude
CS_LoSl	Slope of the lower part of the line (below HCF)

CS_SDCLOP	Cumulated changes in frequency slope of the "main slope" of the line. The "main slope" is defined as the part of the line which contains the master point and has no change of slope direction
CS_SDCLR_DNP	SDCL_DNP / Dur
CS_SDCLROP	SDCLOP / Dur
CS_SDCLRY_DNP	SDCLR_DNP divided by frequency amplitude
CS_SDCLRYOP	SDCLOP divided by frequency amplitude of the pan
CS_SDCLWB	Cumulated changes in frequency slope of the part of the line between the middle between start and master point and the first eventual ascent after master point
CS_SDCR	SDC / Dur
CS_SDCRXY	SDCRY / Dur
CS_Slope	Modulation Slope
CS_StSl	Start Slope
CS_THCF	Time of the point which gaves "HCF" (in fraction of line duration)
CS_UpSl	Slope of the upper part of the line (over HCF)
CVAmp	Coefficient of variation of Amp1, Amp2, Amp3 and Amp4.
Dbl8	Amplitude difference between the detected sound event and low-frequency noise (=everything below 8kHz)
Dur	detected sound event duration
EnStabLg	Average change of amplitude between adjacent elements on a square of 21 x 21 elements around the master point (~6 ms - ~11kHz)
EnStabSm	Average change of amplitude between adjacent elements on a square of 7 x 7 elements around the master point (~2 ms - ~5kHz)
FileDur	File duration
FMin	Minimum frequency
HeiEM	Number of time windows within the detected sound event, whose mean amplitude exceeds 80% of the mean amplitude of the master point time window
HeiEMT	Number of time windows, after master point and within the detected sound event, whose mean amplitude exceeds 80% of the mean amplitude of the master point time window
HeiET	Number of time windows within the detected sound event, whose cumulated amplitude exceeds 80% of the cumulated amplitude of the master point time window

HeiRM	HeiEM divided by total number of time windows
HeiRMT	HeiEMT divided by total number of time windows
HeiRT	HeiET divided by total number of time windows
HeiRTT	HeiETT divided by total number of time windows
HetCMC	Proportion of consecutive time windows where average amplitude slope changes
HetCMD	Average difference of average amplitude between each pair of consecutive time windows
HetCMfP	Density of local average amplitude maxima among time windows
HetCTC	Proportion of consecutive time windows where cumulated amplitude slope changes
HetCTD	Average difference of cumulated amplitude between each pair of consecutive time windows
HetCTfP	Density of local cumulated amplitude maxima among time windows
HetPicsMABD	3rd quartile of intervals between local average amplitude maxima among time windows
HetPicsMALD	1st quartile of intervals between local average amplitude maxima among time windows
HetPicsMRBLD	HetPicsMABD / HetPicsMALD
HetPicsTABD	3rd quartile of intervals between local cumulated amplitude maxima among time windows
HetPicsTRLBD	HetPicsTABD / HetPicsTALD
HetX	Proportion of change of amplitude slope, among each set of three consecutive elements along the time axis
HetYr	Idem HetY but restricted to the seven time windows around the master point
Hlo_Ampdif	
Hlo_PosEn	Same parameters for potential lower harmonic
Hup_AmpDif	Amplitude difference between the detected sound event and its potential upper harmonic
Hup_RFMP	Ratio of FreqMP between "potential harmonic" (see definition above) and the detected sound event
Int25	1st quartile of intervals between detected sound events of similar frequency bands (i.e. whose master point is within +/- 2 frequency bands around the current detected sound event master point, corresponding to an approx. 3 kHz interval)
Int75	3rd quartile of intervals between detected sound events of similar frequency bands (i.e. whose master point is within +/- 2 frequency bands around the current detected sound event master point, corresponding to an approx. 3 kHz interval)
LgIntDev	Median deviation from Int75 among the half largest "similar frequency" (see Int75) intervals

NextMP1	Time difference between master points of the detected sound event and the next one
NextMP2	Time difference between master points of the detected sound event and the next one whose master point is between FMax and FMin, and conversely its FMin-FMax interval contains FreqMP of the current detected sound event
NoiseDown	Average amplitude among the elements neighbouring the detected sound event on the top on a 3-element width (approx. 2 kHz above)
NoiseNext	Average amplitude among the elements neighbouring the detected sound event on the right on a 3-element width (approx. 1 ms after)
NoisePrev	Average amplitude among the elements neighbouring the detected sound event on the left on a 3-element width (approx. 1 ms before)
NoiseUp	Average energy among the elements neighbouring the detected sound event on the bottom on a 3-element width (approx. 2 kHz below)
PosMP	Time Position of the master point (in fraction of the detected sound event duration)
PrevMP1	Time difference between master points of the detected sound event and the previous one
PrevMP2	Time difference between master points of the detected sound event and the previous one whose master point is between FMax and FMin, and conversely its FMin-FMax interval contains FreqMP of the current detected sound event
PrevSt	Time difference between starts of the detected sound event and the previous one
RAHE4	Ratio of average amplitude between the first quarter of the detected sound event and the following. The first six time windows are more weighted. For the second part, only the part not exceeding the quarter of the length of the first part after master point is counted
Ramp_1_2	The same for half frequency
Ramp_2_1	Ratio of average amplitude between the elements whose frequency is twice that of the detected sound event and those of the current detected sound event
Ramp_2_3	The same for frequency multiplied by 2/3
Ramp_3_1	The same for triple frequency
Ramp_3_2	The same for frequency multiplied by 1.5
RAN_1_2	The same for half frequency
RAN_2_1	Ratio of cumulated energy between the elements surrounding (3 elements width) those whose
RAN_2_3	The same for frequency multiplied by 2/3
RAN_3_1	The same for frequency multiplied by 3
RAN_3_2	The same for frequency multiplied by 1.5

RAN_4_3	The same for frequency multiplied by 4/3
RInt1	Int75 / Int25
RIntDev1	LgIntDev/SmIntDev
SmIntDev	Median deviation from Int25 among the half smallest "similar frequency" (see Int25 above) intervals
Stab	An index of amplitude stability around the master point: average amplitude change between neighbouring elements within the detected sound event, inversely weighted by distance from Master Point
StTime	Start time of the detected sound event (detected sound event)
VarInt	IntDev/MedInt
VarLgInt	LgIntDev/Int75
VarSmInt	SmIntDev/Int25
VBDPPicsM	VBDPicsM / HetPicsMABD
VBDPPicsT	VBDPicsM / HetPicsMABD
VLDPPicsM	VLDPicsM / HetPicsMALD
VLDPPicsT	VLDPicsT / HetPicsMALD

ANNEX 2: VALIDATION OF BAT RECORDINGS

Important call parameters used in Step 3 of the recording validation process to manually check species identity based on call parameters in Russ (2012) and Barataud (2015) and adapted from Newson *et al.* (2015). For some species (e.g. Brown Long-eared Bat) identification is more straightforward, whilst for other species, (e.g. the *Myotis* bats), there is overlap, such that a high proportion of recordings are assigned to genus only. Common and Soprano Pipistrelles are not included in this table as their calls are diagnostic (see text).

SPECIES	SPECIES CODE	MAIN CONFUSION SPECIES	MOST IMPORTANT CALL PARAMETERS FOR SPECIES IDENTIFICATION.[1]
Dabenton's Bat *Myotis daubentonii*	Mdau	Mmys/Mbra (Mnat)	Calls often sigmoidal in shape; Start frequency (rarely) >100 kHz End frequency (typically) about 25 kHz; Often slight kink or bend at heel of call at about 40 kHz.
Alcathoe Bat *Myotis alcathoe*	Malc	Mmys/Mbra	Start frequency (commonly) >100 kHz; End frequency very high normally > 40 kHz Typical calls steep, with an end shaped like a golf driver.
Whiskered Bat /Brandt's Bat *Myotis mystacinus/M.brandtii*	Mmys/Mbra	Mdau (and Mnat)	Start frequency (commonly) >100 kHz; End frequency (typically) > 30 kHz Sometimes slight kink at knee of call at >35 kHz; In open areas calls can be similar to Mdau.
Natterer's Bat *Myotis nattereri*	Mnat	Other *Myotis* bats	Most distinctive *Myotis* in study area; Very high bandwidth; End frequency (often) <20 kHz Short duration calls – (often) over 100 kHz change in frequency over 1 ms; No kink at knee or heel of call in closed or semi-closed habitat is distinctive.
Noctule *Nyctalus noctule*	Nnoc	Nlei (and Eser)	Two main call types: an FM / qCF[2] call and qCF call; Call types (often) produced alternatively; FM / qCF call peak frequency of about 24 kHz, call duration about 14 ms; qCF call peak frequency of about 19 kHz, call duration about 22 ms.
Leisler's Bat *Nyctalus leisleri*	Nlei	Nnoc (and Eser)	As noctule two main call types; Calls types (often) produced alternatively FM / qCF call peak frequency of about 27 kHz, call duration about 8 ms qCF call peak frequency of about 23 kHz, call duration about 17 ms
Nathusius' Pipistrelle *Pipistrellus nathusii*	Pnat	Ppip	Typical hockey-stick shaped *Pipistrellus* call; End frequency of all calls <40 kHz.
Brown Long-eared Bat *Plecotus auritus*	Paur	None (*Pipistrellus* social calls - but not regular series of calls)	Normally distinctive with two harmonics, the first starts around 55 kHz and ends about 24 kHz and second starts around 73 kHz and ends about 33 kHz.

[1] See Russ (2012) and Barataud (2015) for a more detailed description and comparison of call parameters.
[2] FM = frequency modulated, qCF quasi-constant frequency (see Russ 2012, section 2.3.3 for a full description of call types)

ANNEX 3. SOUND IDENTIFICATION OF BATS

Adapted from Toms & Newson (2018).
FM = frequency modulated, qCF quasi-constant frequency (see Russ 2012, section 2.3.3 for a full description of call types)

NOCTULE *Nyctalus noctula*

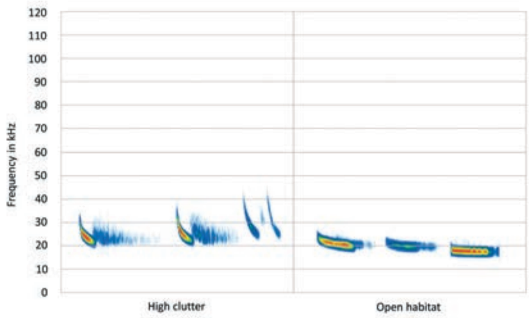
Echolocation

Two main call types:

- FM/qCF call loudest at about 24 kHz, call duration about 15 ms
- qCF call loudest at about 19 kHz, call duration about 22 ms

Call types (often) produced alternately

Main confusion species: Leisler's Bat and Serotine (very similar in clutter).



SEROTINE *Eptesicus serotinus*

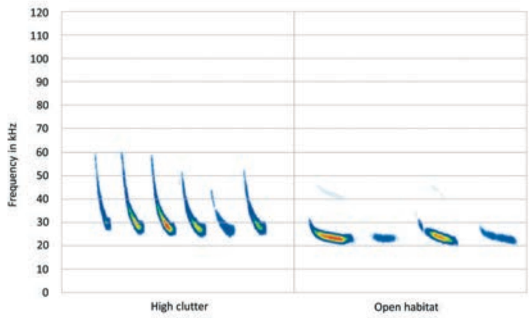
Echolocation

Produces FM / qCF calls only

- In open habitat, calls loudest at about 25 kHz, call duration about 13 ms
- In clutter, calls loudest at about 27 kHz, call duration about 8 ms

Irregular rhythm to call sequence

Main confusion species: Noctule and Leisler's Bat (very similar in high clutter).



LEISLER'S BAT *Nyctalus leisleri*

Echolocation

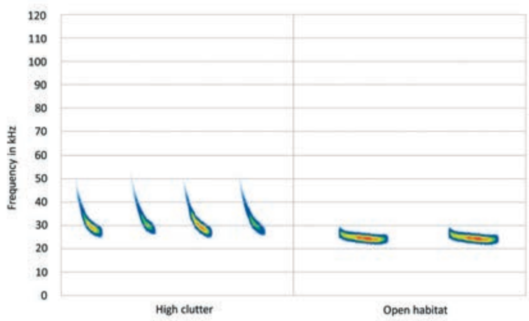
Two main call types:

- FM / qCF call loudest at about 27 kHz, call duration about 8 ms
- qCF call loudest at about 23 kHz, call duration about 17 ms

Calls types (often) produced alternatively

Can show sharp frequency change (> 2kHz) more often than Serotine

Main confusion species: Noctule and Serotine (very similar in high clutter), but note Brown Rat can produce visually similar CF calls at about 21 kHz.



BROWN LONG-EARED BAT *Plecotus auritus*

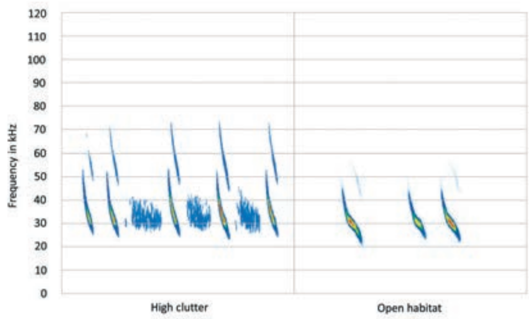
Echolocation

Two harmonics:

- first starts around 55 kHz and ends about 24 kHz
- second weaker harmonic starts around 73 kHz, ends about 33 kHz (can be lost)

In open habitat, call duration becomes longer and calls drop to about 20 kHz

Main confusion species: Normally distinctive (but possible confusion with Barbastelle in clutter, Serotine, Noctule or Leisler's Bat in clutter if missing second harmonic, or social calls of Common and Soprano Pipistrelle).



BARBASTELLE *Barbastella barbastellus*

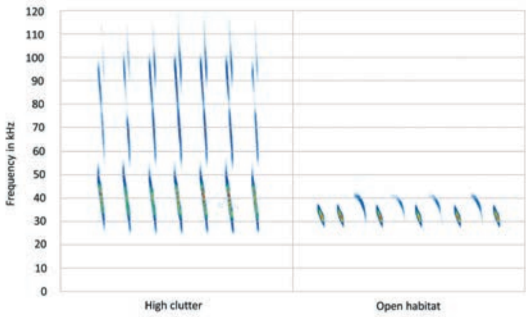
Echolocation

Two main call types:

- loudest at about 33 or 42 kHz in open habitat
- either call type can be omitted

In clutter, steep FM calls emitted, starting at about 50 kHz, ending about 27 kHz

Main confusion species: normally distinctive, but confusion most likely with Brown Long-eared Bat and *Myotis* species. Note also that Speckled Bush-cricket often produces short calls (between about 26 and 36 kHz)



ALCATHOE BAT *Myotis alcathoe*

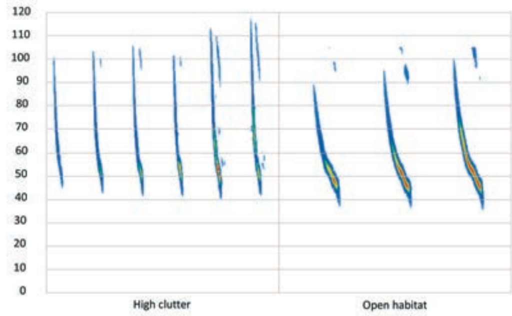
Echolocation

Start frequency (commonly) >100 kHz

End frequency very high (typically) > 40 kHz

In clutter, calls steep with golf driver-like end

Main confusion species: Whiskered Bat / Brandt's Bat.



DAUBENTON'S BAT *Myotis daubentonii*

Echolocation

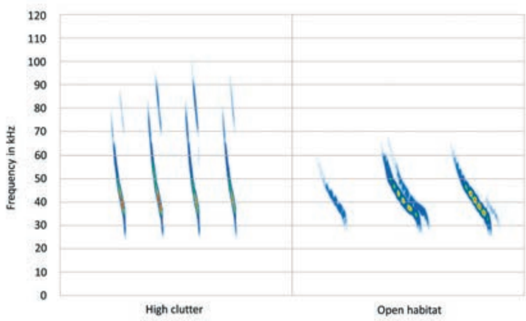
Calls often sigmoidal in shape

Start frequency (rarely) >100 kHz

End frequency (typically) about 25 kHz

Often slight kink or bend at heel of call at about 40 kHz

Main confusion species: Whiskered Bat / Brandt's Bat, and Natterer's Bat (in open habitat).



WHISKERED/BRANDT'S BAT *Myotis mystacinus/ M.brandtii*

Echolocation

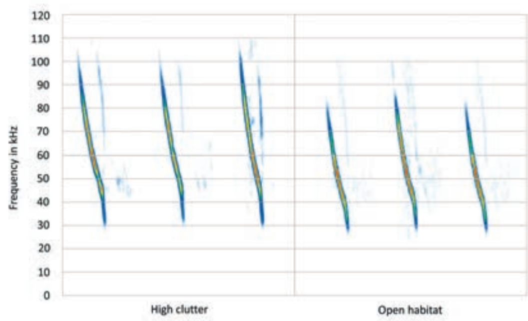
Start frequency (commonly) >100 kHz

End frequency (typically) > 30 kHz

Sometimes slight kink at knee of call at >35 kHz

In open areas calls, very similar to Daubenton's Bat

Main confusion species: Daubenton's and Natterer's Bat



NATTERER'S BAT *Myotis nattereri*

Echolocation

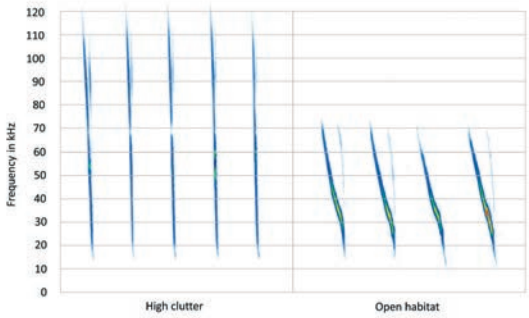
Very high bandwidth

End frequency (often) <20 kHz

Short duration calls (often) over 100 kHz change in frequency over 1 ms

No kink at knee or heel of call in clutter when calls most distinctive

Main confusion species: Whiskered Bat / Brandt's Bat and Daubenton's Bat.



SOPRANO PIPISTRELLE *Pipistrellus pygmaeus*

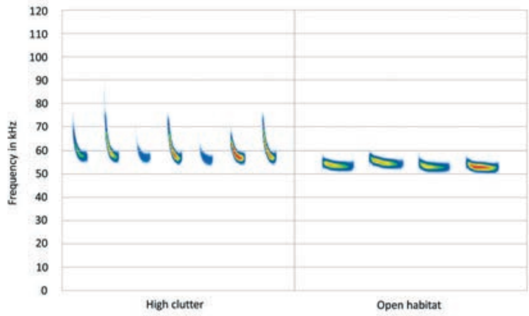
Echolocation

FM/qCF calls that sweep down from about 80 kHz to about 53 kHz, calls loudest at about 55 kHz. Mean call duration about 6 ms

In open habitat, calls become longer, calls drop to 52 kHz or lower

In clutter, call duration longer, and calls loudest at 55 kHz or more.

Main confusion species: Common Pipistrelle (open habitat), *Myotis* (extreme clutter).



COMMON PIPISTRELLE *Pipistrellus pipistrellus*

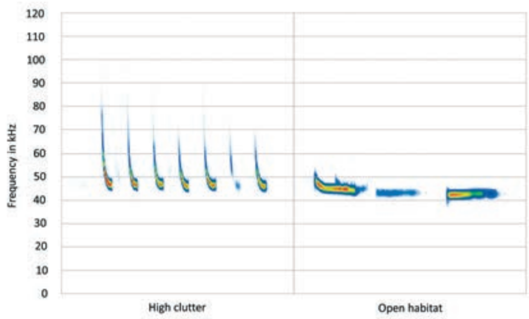
Echolocation

FM/qCF calls that sweep down from about 70 kHz to about 43 kHz, calls loudest at about 46 kHz. Mean call duration about 6 ms

In open habitat, calls become longer, calls drop to 43 kHz or lower

In clutter, call duration longer and calls loudest at 48 kHz or more.

Main confusion species: Nathusius' Pipistrelle (in open habitat) and Soprano Pipistrelle (in clutter), *Myotis* (extreme clutter).



NATHUSIUS' PIPISTRELLE *Pipistrellus nathusii*

no existing records, or evidence so far from this study that this species is present, but potential migrant.

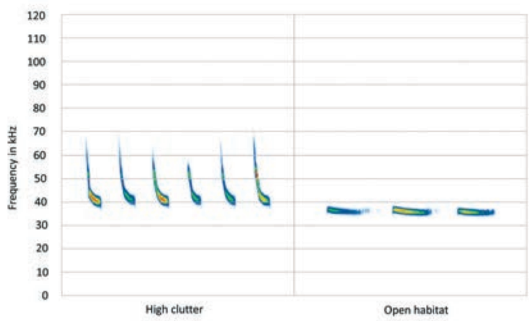
Echolocation

FM/qCF calls that sweep down from about 51 kHz to about 36 kHz, calls loudest at about 39 kHz. Mean call duration about 6 ms

In open habitat, calls become longer, calls drop to 37 kHz or lower

In clutter, call duration shorter, and calls loudest at 39 kHz (up to about 42 kHz)

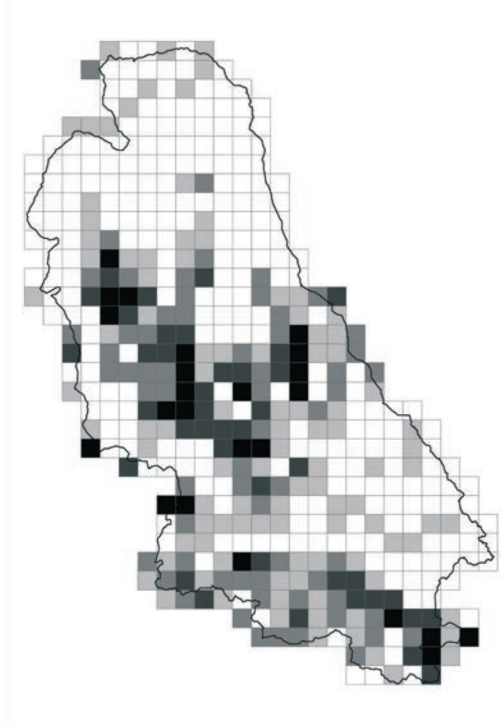
Main confusion species: Common Pipistrelle (open habitat), *Myotis* (extreme clutter)



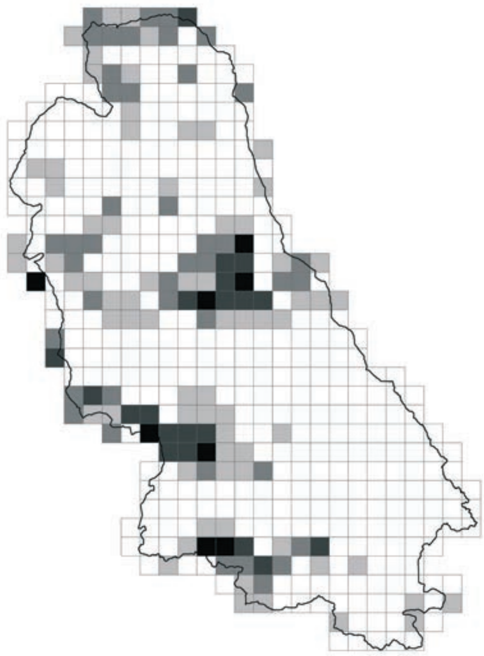
ANNEX 4. CEH LANDCOVER DATA

The maps here show the % of each habitat split into five equal bands. In the case of freshwater, it was necessary to visualise the data as two bands of 0% and 1% or greater.

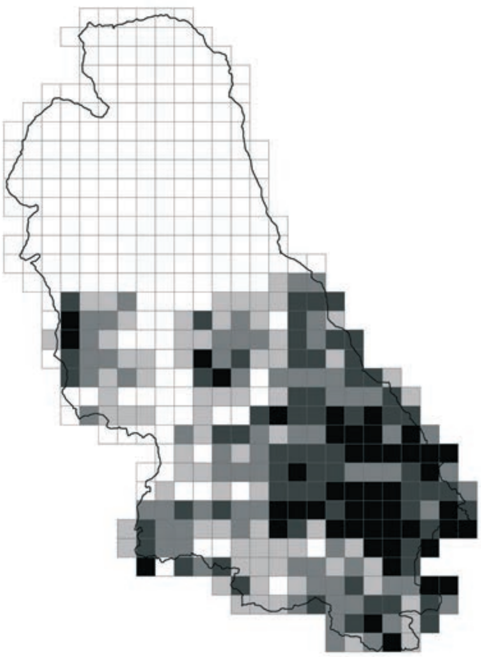
Broad-leaved woodland



Coniferous woodland

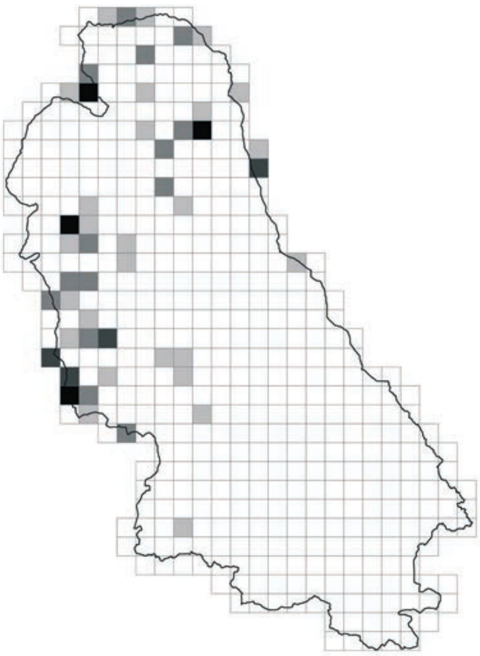


Arable

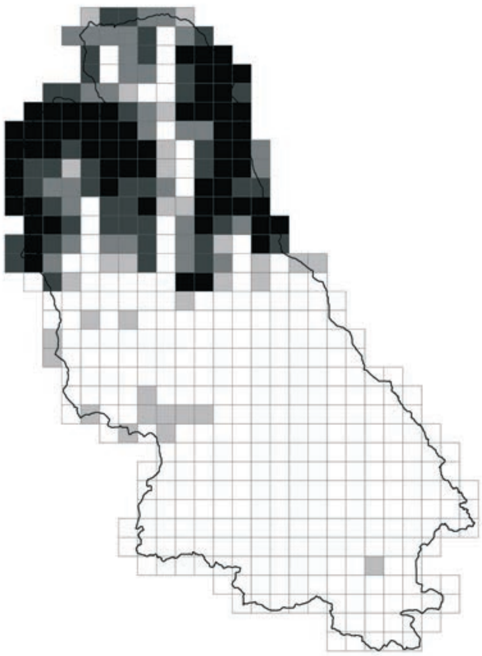


Improved grassland

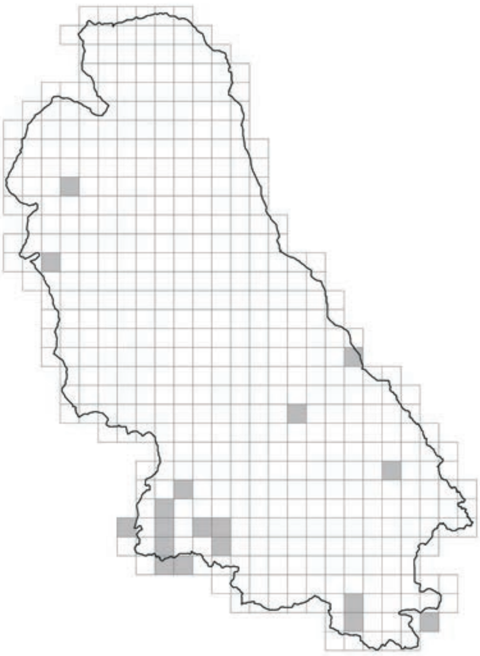
Semi-natural grassland



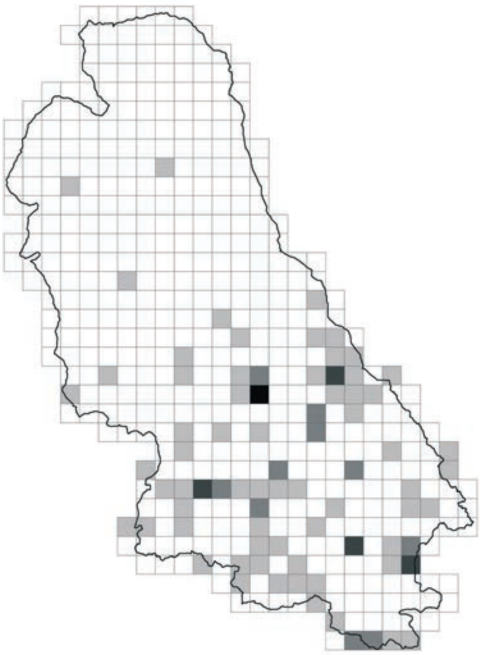
Mountain, heath and bog



Freshwater



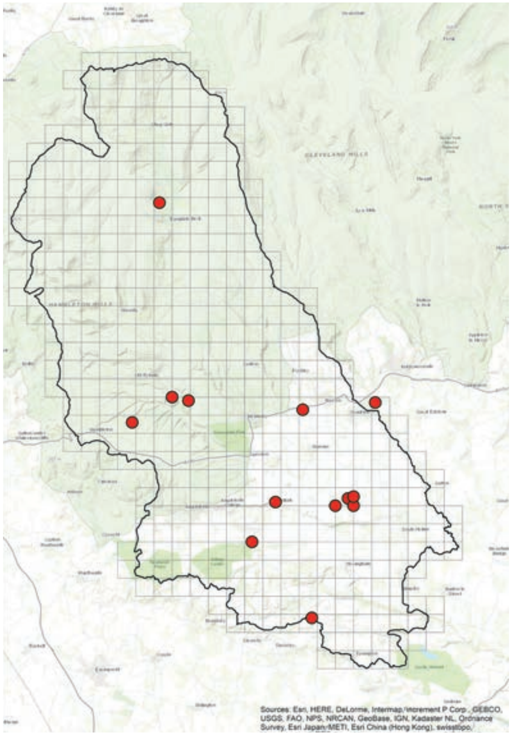
Built-up areas / gardens



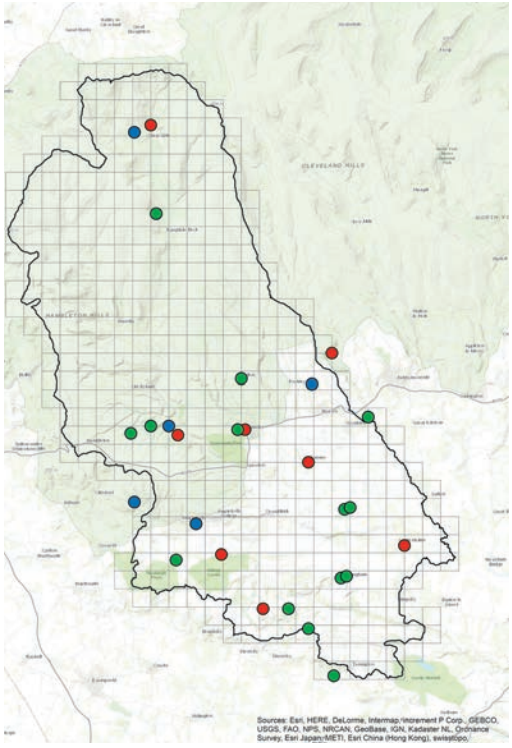
ANNEX 5. DESK-BASED STUDY

Collation of existing bat records. For Whiskered Bat and Brandt's Bat: red = Whiskered Bat, blue = Brandt's Bat and green = Whiskered Bat or Brandt's Bat.

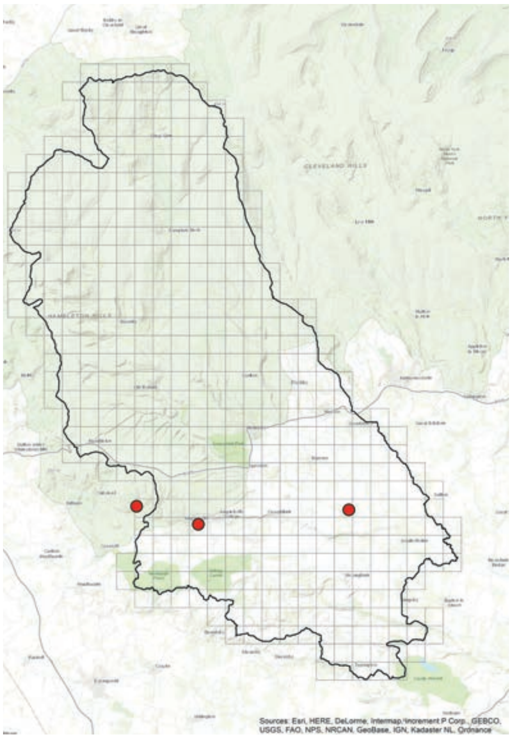
Daubenton's Bat *Myotis daubentonii*



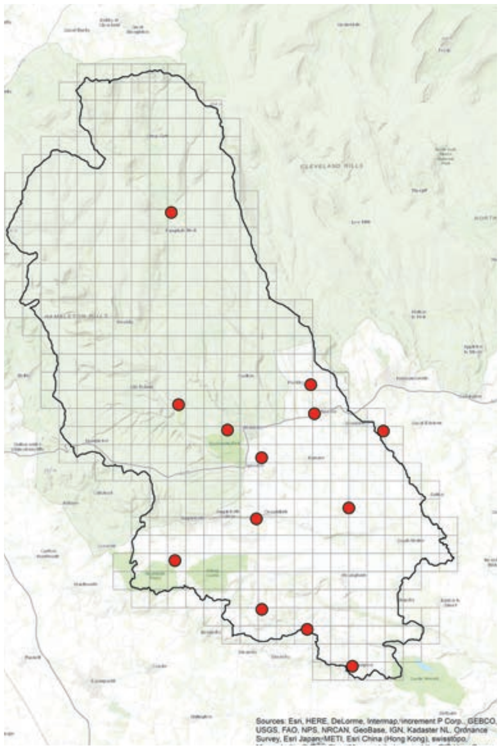
Whiskered Bat / Brandt's Bat *M. mystacinus* / *M. brandtii*



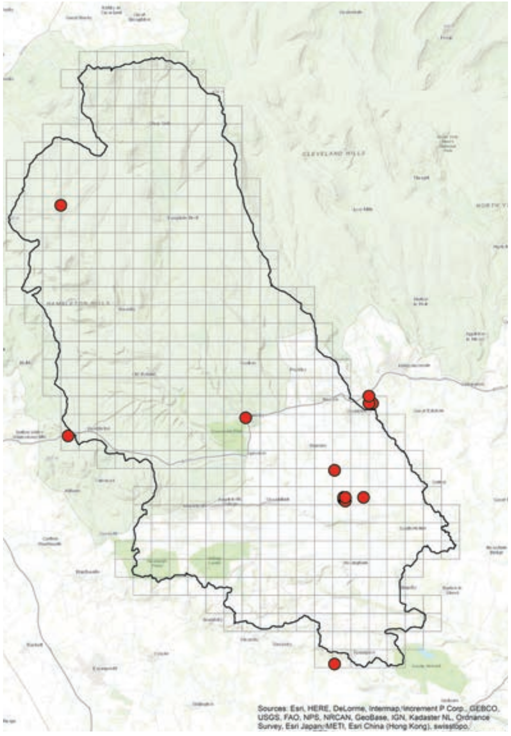
Alcathoe Bat *Myotis alcathoe*



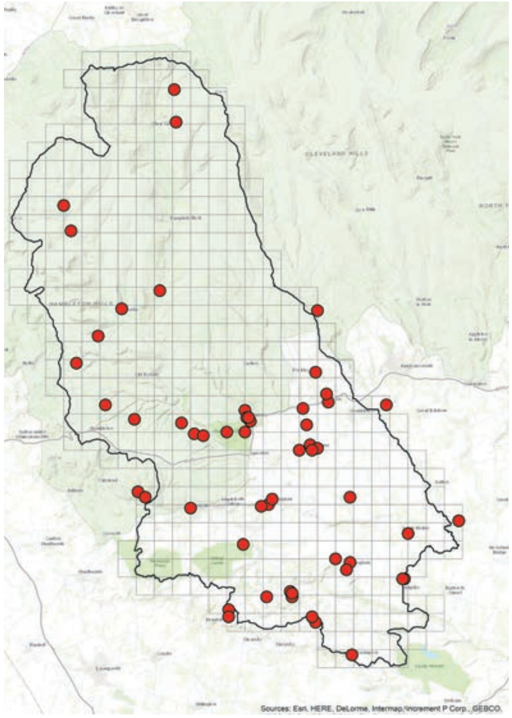
Natterer's Bat *Myotis nattereri*



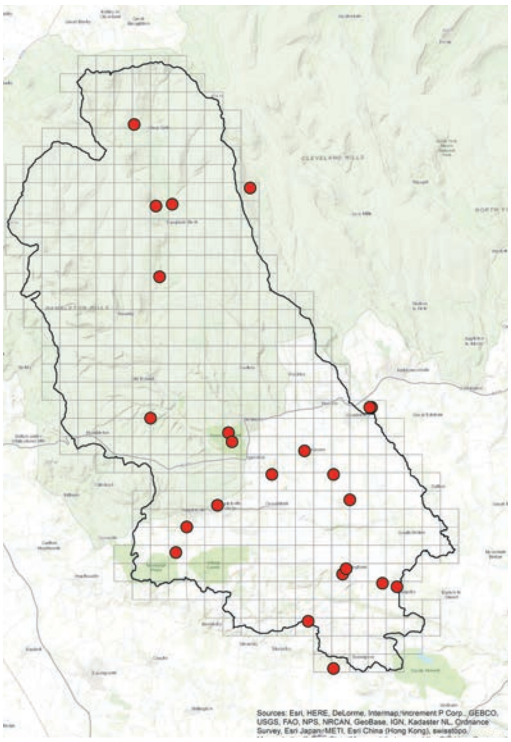
Noctule *Nyctalus noctula*



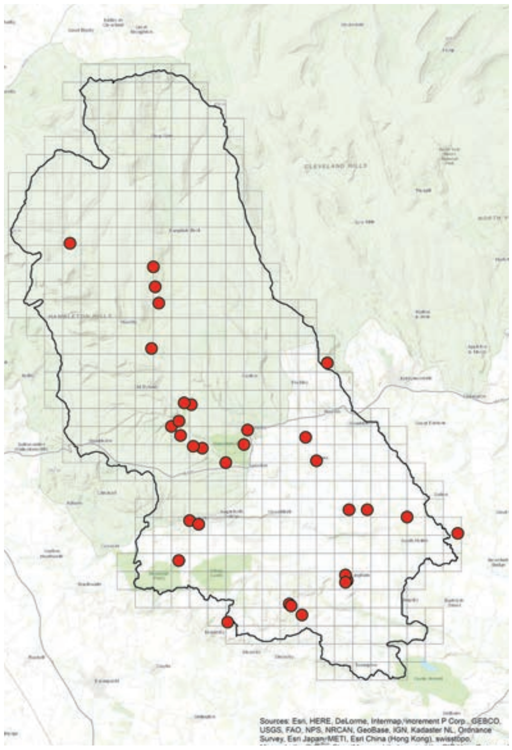
Common Pipistrelle *Pipistrellus pipistrellus*



Soprano Pipistrelle *Pipistrellus pygmaeus*



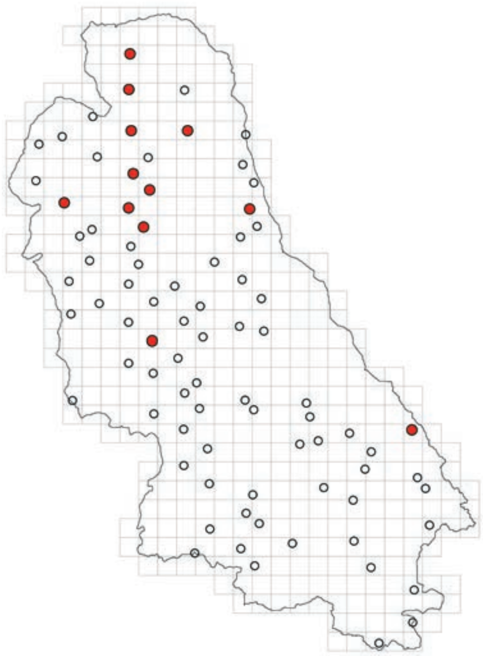
Brown Long-eared Bat *Plecotus auritus*



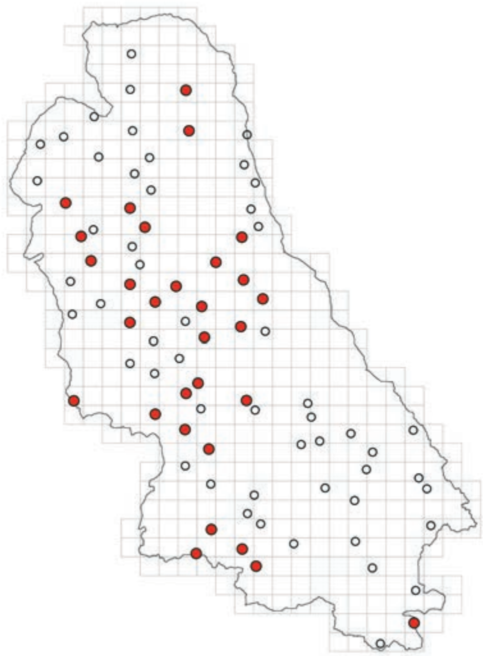
ANNEX 6. MAPS OF BIRD OCCURRENCE

Presence of selected (mainly nocturnal) bird species. Red circles = species recorded, open circles = species not recorded.

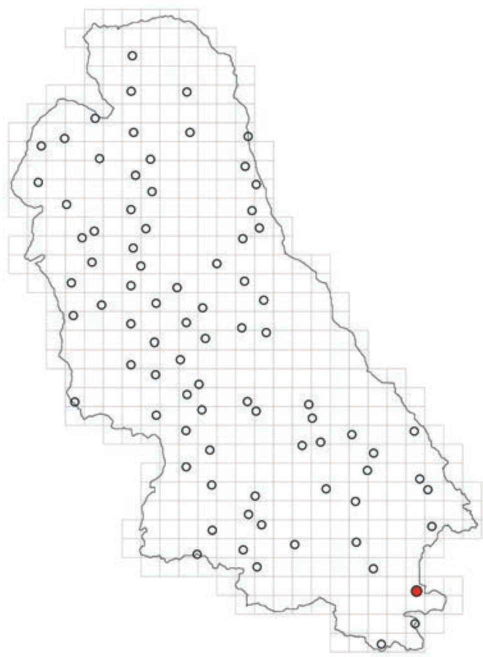
Eurasian Curlew *Numenius arquata*



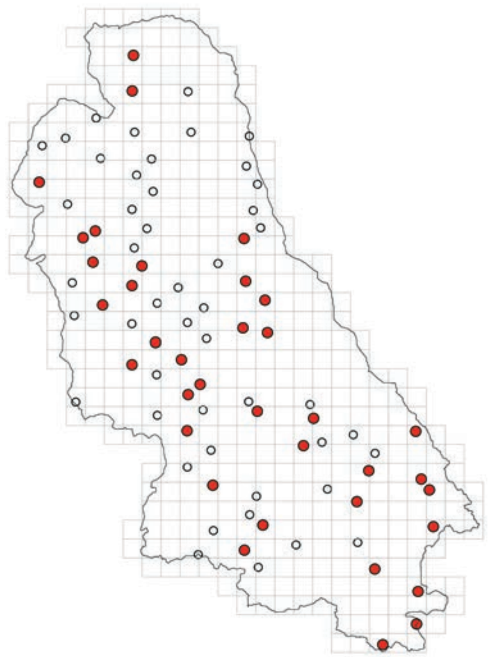
Eurasian Woodcock *Scolopax rusticola*



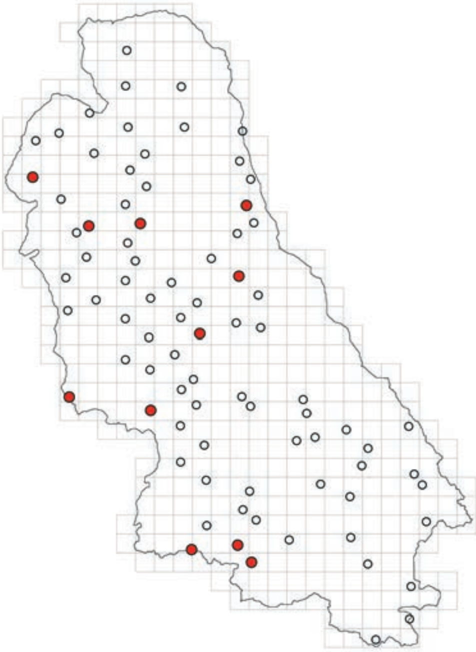
Common Cuckoo *Cuculus canorus*



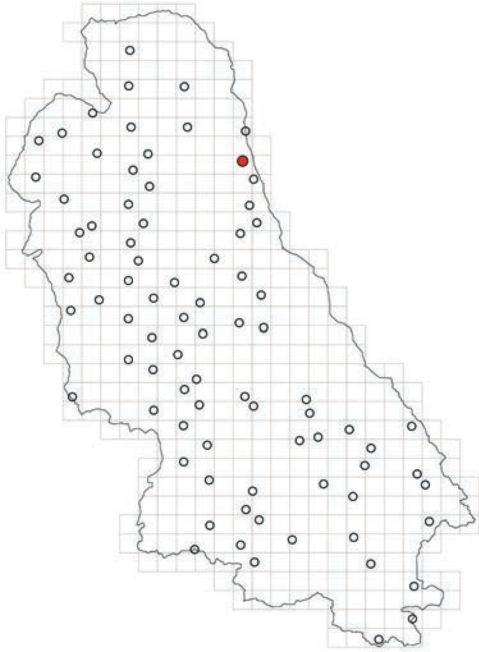
Tawny Owl *Strix aluco*



European Nightjar *Caprimulgus europaeus*



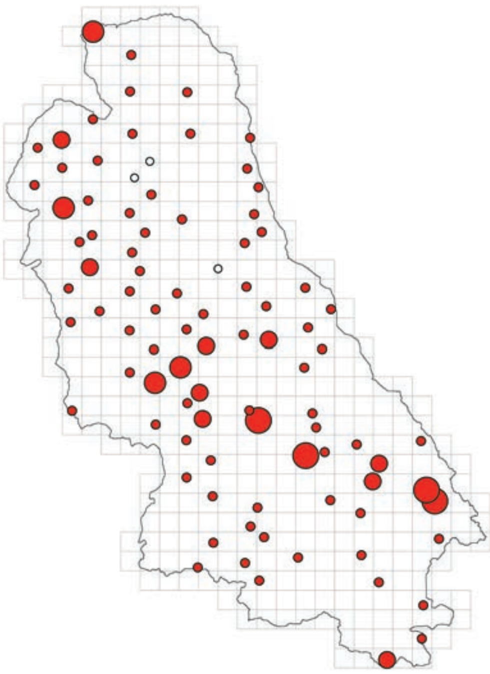
Grasshopper Warbler *Locustella naevia*



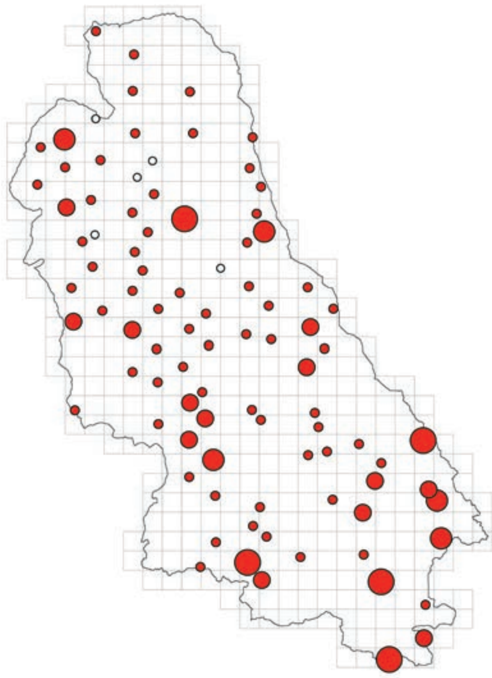
ANNEX 7. MAPS OF BAT ACTIVITY

Average number of recordings / night) as a proxy for abundance. Open circles = species not recorded, closed circles = species recorded, where larger the circle more recordings. For Alcathoe Bat, four sites where we suspect Alcathoe Bat was recorded are shown in grey.

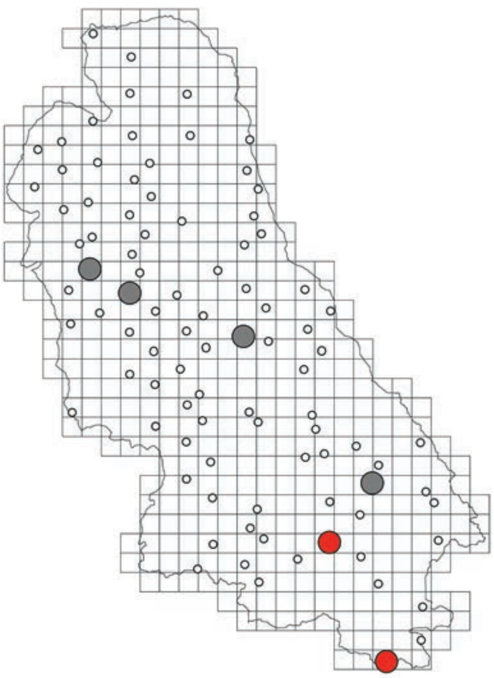
Daubenton's Bat *Myotis daubentonii*



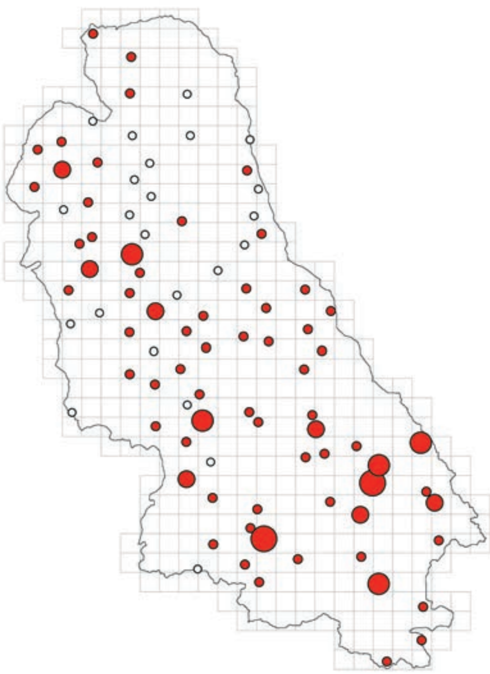
Whiskered / Brandt's Bats *M. mystacinus* / *M. brandtii*



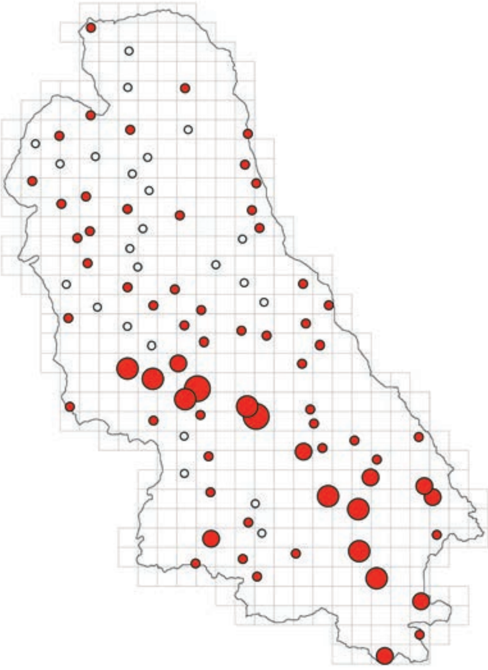
Alcathoe Bat *Myotis alcathoe*



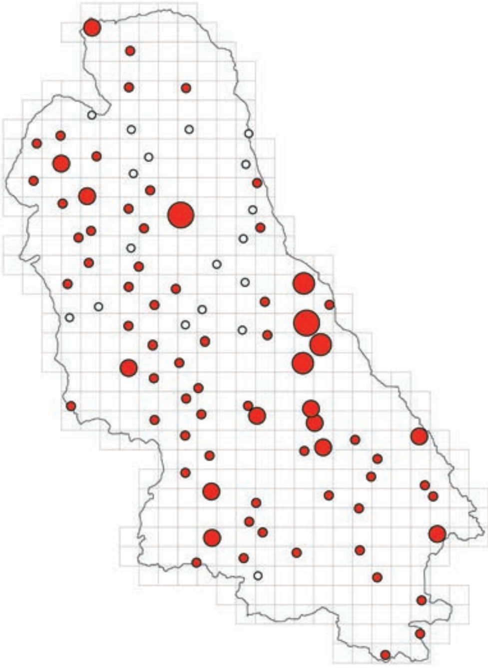
Natterer's Bat *Myotis nattereri*



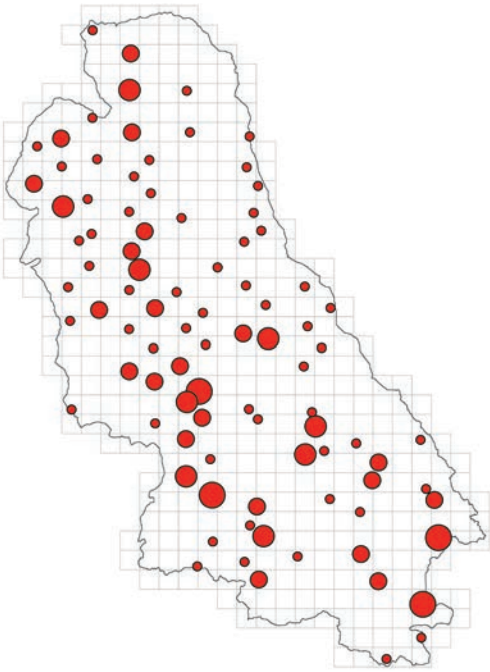
Noctule *Nyctalus noctula*



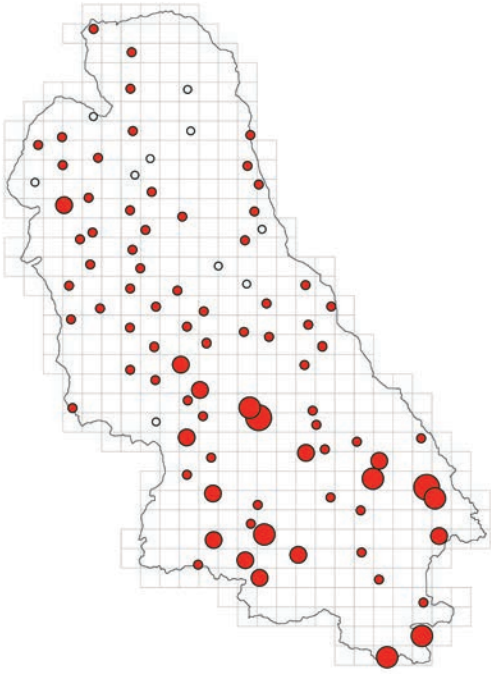
Common Pipistrelle *Pipistrellus pipistrellus*

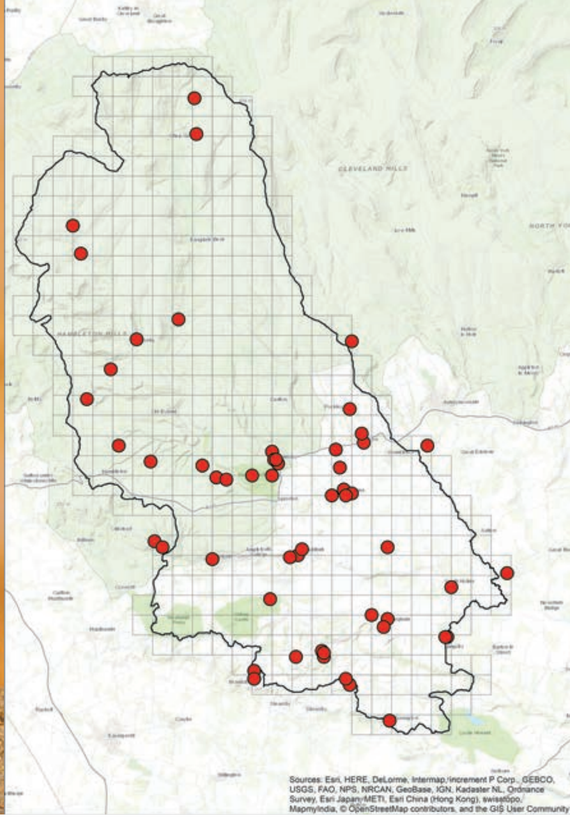


Soprano Pipistrelle *Pipistrellus pygmaeus*



Brown Long-eared Bat *Plecotus auritus*



Images: Ján Svetlik / BTO / Ján Svetlik. Cover image: Ján Svetlik

Improving our understanding of the distribution and status of bats within the Ryevitalise Landscape Partnership Scheme area

The North York Moors National Park has been involved in developing a Heritage Lottery Fund (HLF) Landscape Partnership Scheme called Ryevitalise which is all about conserving, protecting and interpreting the cultural and natural landscape of the River Rye. As part of a first development phase, a number of surveys, including of bats presented here, were commissioned to establish base line data so that towards the end of the four years of the Scheme's delivery (2019–2023) beneficial change can be measured by carrying out re-surveys.

In this report we present the results of a desk-based study and fieldwork carried out in 2018, to improve our understanding of the distribution and status of all species of bats, including Alcathoe Bat within the Ryevitalise Landscape Partnership Scheme area.

Newson, S.E. & Berthinussen, A. (2018). Improving our understanding of the distribution and status of bats within the Ryevitalise Landscape Partnership Scheme area. North York Moors National Park. BTO Research Report 716, British Trust for Ornithology, Thetford.

ISBN 978-1-912642-02-1

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