WC1015 DEVELOPING EFFECTIVE METHODS FOR THE SYSTEMATIC SURVEILLANCE OF BATS IN WOODLAND HABITATS IN THE UK

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Including:

POTENTIAL DEVELOPMENT OF WOODLAND MONITORING BASED ON THE WOODLAND BAT SURVEY AND MONITORING PROTOCOL

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Executive Summary

AIMS

The aim of the project was to develop methods to sample woodland for bats using standardised and therefore repeatable acoustic surveys so that data from across the UK, collected by a large number of volunteers, could be compared and combined over many years. The data can initially be used to determine presence or absence of species to improve knowledge of species distributions. As data accumulate from year to year, they can be used to monitor national population trends and, depending upon the intensity and frequency of monitoring effort, regional and local trends. The primary purpose is not to provide site-specific data to inform management or monitor impacts at the site level, but the methods can be adapted to do so.

SOFTWARE

We built a user-friendly interface for and further developed software (that we had already produced prior to this project) that is able to automatically isolate and identify to species bat echolocation calls in WAV sound files. Under this project the software was distributed to the Bat Conservation Trust, bat-workers and consultants for testing and was refined in the light of comments received. The goal was to develop the best possible, user-friendly software that was at the same time scientifically robust.

To make the software as robust as possible against noise and misidentification we adopted two analytical approaches. The first is based on single calls and has a high probability of correctly identifying most species and is robust. The second is based on the analysis of bat passes – the sequence of calls recorded as a bat flies past the detector. This has the potential to be even more robust and identify more species with fewer errors, but we currently need more records of Bechstein's bat and Alcathoe bat to increase accuracy for these two species. We provide the software for the first approach and preliminary results on the second. With a larger call library it should be possible to increase accuracy for most species.

Our agreed brief was to develop the software for use with Pettersson D500x and D240x bat detectors (www.batsound.com). We have also done what we can to make it compatible with other brands, in particular the EcoObs Batcorder (www.ecoobs.de), Elekon Batlogger (www.elekon.ch), Batbox Griffin (www.batbox.com) and Wildlife Acoustics SM2 (www.wildlifeacoustics.com). The results have been mixed, but with further development we believe the software will work well with the Batcorder, Batlogger and the Batbox Griffin. By making the source code freely available, others have the opportunity to contribute to this development, as the University of Leeds continue developing the software beyond this project.

SURVEY PROTOCOLS

We developed a flexible protocol that we believe gives a good compromise between ease of use and effectiveness. It takes into account the varying detectability of different species (0.3-0.9, differences due primarily to the intensity and directionality of their calls). We determined the number of surveys that must be completed at a site to achieve a given level of probability of detection.

The protocol can be used at two levels:

i) Over numerous sites across the country, if sufficient surveys are done at each site (1-5 for most species, up to 9 for *Plecotus*) to ensure >95% probability of detection, then national or regional trends can be determined from the presence or absence of a particular species across a large number of sites. To detect a 50% change in occupancy 22-56 sites should be surveyed each year depending upon species (126 sites for *P. auritus*). As the number of years of continuous monitoring increases, sensitivity to population changes will increase.

ii) If site-specific trends are required a more intensive survey programme will be necessary, involving more replicates to overcome the high night to night variability in activity that is inherent in bat foraging behaviour, but that is not explained by easily measured variables such as weather.

Two survey protocols were developed: transects and area searches. They are equally likely to detect a given species' presence. The transect protocol, being highly reproducible, is better suited to long-term site-specific monitoring. Arguably it is also better suited to nationally or centrally coordinated surveys which operate over long time periods and which need to manage surveyor turn over across years. The transect protocol will also deliver data suitable for habitat suitability modelling or other studies that require precise geographical locations of the bats sampled. The area search is more straightforward and gives the surveyor greater freedom to explore a site and may prove better at retaining interest. It could also yield geo-referenced data but this would require a more diligent approach to GPS use by the surveyor. The transect protocol itself has two components, spot checks and walked sections and there is some flexibility in how these are used to deal with difficult terrain or unusual sites. The BCT, who will implement the survey, will choose which strategies it is best to adopt on practical grounds based on the proposed pilot surveys.

REPORTING

We have provided full guidelines for software use and suggestions for future development for those with the necessary skills. We also provide full transect and equal area search protocols, with a rationale, guidelines on data format, organisation and storage, instructions on how to submit data to BCT, and on analysis that contributors may wish to do for themselves. A data sheet is provided in Word and Excel format to ensure consistency in execution and recording of essential data and metadata.

The software source code has been made available (https://bitbucket.org/chrisscott/batclassify), and annotated for those who wish to develop it further. Files will also be hosted on the University of Leeds website and could also be hosted by the BCT.

A presentation & workshop will be given at the BCT 2014 conference in September 2014. The first will describe the aims of the project and basic principles of the method, the second will describe and discuss the details.

Full report
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1. Background and rationale

Council Directive 92/43/EEC on the Conservation of Natural Habitats and of Wild Fauna and Flora, known as the Habitats Directive, was adopted in 1992. The Habitats Directive requires strict protection of all species listed in Annex IV, which includes all bats found in the UK.

The Directive requires member states to undertake surveillance of species and habitats and to report on the implementation of the Directive every six years (Article 17). This report should include an assessment of the conservation status of species and habitats listed on the Annexes to the Directive.

Although the protocols presently used by the National Bat Monitoring Programme (NBMP) provide information on population trends for 11 of the 17 breeding bat species and distribution information on some additional species found in the UK, there is far less information on the distribution, conservation status and habitat requirements of many woodland bat species, particularly woodland specialists such as barbastelle and Bechstein's bat. This reflects the difficulties involved in trying to survey or study these animals in structurally complex habitats using existing methods, such as roost emergence counts, simple bat detectors or standard capture techniques.

In addition to the need for better information on woodland bats to inform Habitats Directive reporting, access to improved methods for woodland bat survey would allow for further research on the impacts of woodland management, which is critical to refine woodland policy.

The aims of the project, as set out by Defra were to develop, test, critically assess, refine, document and publish new survey methods for rapid and systematic monitoring of bats in woodland habitats. The project was to focus on the *Myotis* species: Alcathoe, Bechstein's, Brandt's, Natterer's and whiskered bats, along with brown long-eared bats and barbastelles, as they forage in woodland habitats across the U.K. Since many long-term species surveillance schemes in the UK are funded by JNCC or the Country Agencies, in collaboration with the voluntary sector, the methods had to be appropriate for use by trained volunteers.

The project was carried out by a team from the University of Leeds, in collaboration with the Bat Conservation Trust.

The UK's rarest bats are all woodland species, reflecting the degradation, fragmentation and loss of our woodlands over recent centuries. The need for landscape scale conservation efforts, to increase habitat connectivity and improve climate change resilience, requires the development of reliable survey and long term monitoring methods. These methods must:

1) Reliably detect all or most of the bats present in the surveyed area of woodland
2) Reliably identify them to species
3) Be capable of being applied by relatively inexperienced fieldworkers
4) Facilitate rapid data analysis
5) Have the potential to be used in predictive modelling of bat distributions to maximise the utility of the data and facilitate targeted survey work

Surveys involving bat capture is in most circumstances likely to be too time-consuming and qualitative – too few bats are caught to reliably assess abundance and species composition and possibly even presence. Capture is also biased, since it is effective only in certain habitats and locations. Finally, capture requires highly trained and licenced volunteers. The most practical and quantitative methods available to a large, volunteer-based survey programme are likely to be based on echolocation call recording and analysis. Recent work has provided important methodological advances that overcome the major barriers to using this approach.

Two main factors have limited the breadth and scale of acoustic monitoring: the high labour costs involved in analysing large volumes of data and the difficulty in detecting bats and identifying calls reliably to species. To address these issues we developed an Open Source software application, for the automated extraction and classification of echolocation calls from time expanded and direct sampling recordings. The software reliably extracts all but the weakest calls and identifies most woodland species with high accuracy, using Pettersson detectors. Free Open Source software with a user-friendly interface could bring accurate species identification to the bat research and conservation community. By making the source code available for further development we hope that some of the problems we have been unable to solve in the time available can be tackled by the wider community and the software can also be adapted for bats in other parts of the world.

Designing an efficient monitoring programme must weigh the power to detect meaningful changes in a population against the cost of data collection. An essential component in determining the number of surveys needed to give acceptable statistical power to a proposed monitoring programme's survey design is establishing the probability of detecting a species given its presence at a site (termed the 'probability of detection'). Only once the probability of detection is known can the effects of survey design and sampling effort be explored to estimate power. We have surveyed sites multiple times to estimate the probability of detection for each species, and modelled statistical power to evaluate the most suitable survey design and monitoring protocol in light of sampling costs.

2. Bat detectors

The two main types of bat detector suitable for the detailed call analysis required by this project are time-expansion (TE) and direct sampling (DS). Other detectors (e.g. heterodyne and frequency division) are not suitable since they preserve too little of the detail of the bats' calls. TE detectors make short, high sample rate recordings and play them back to the user at a slower rate, bringing the ultrasonic calls of bats into the audible range. A separate audio recorder must be used in combination with a TE detector in order to save the audio for later analysis. During playback of the time-expanded audio, the detector is temporarily unable to sample. DS detectors omit the playback step used by TE detectors, and simply record the high sample rate audio directly to on-board memory. For the purposes of analysis, the difference between detector types is not necessarily one of recording quality, simply the number of calls available for identification – overall and for each bat detected. The Pettersson D240X TE and D500X DS detectors we used in the study have the same microphone, and produce high quality recordings suitable for identification, but the D240X cannot sample continuously and therefore potentially misses calls during playback periods.

TE detectors include settings for variable sampling times and trigger thresholds, with different settings influencing the resulting recordings. Longer sample times capture longer sequences of calls than shorter sample times, but remain inactive for longer periods during playback, increasing the probability of missing bats. To investigate these effects we wrote a script for converting continuous D500X recordings into pseudo-time-expansion recordings, with settings to emulate the behaviour of typical detectors. This facilitated the processing of continuous recordings to recreate the downtime experienced by TE detectors, enabling the effect of detector settings to be directly analysed in terms of calls sampled relative to the ground truth recorded by the direct sampling detector.

During initial field trials we made recordings using the D500X at 12 woodlands. The ability of the D500X to make continuous recordings enabled full call sequences to be captured. Monte-Carlo simulation with 10,000 iterations was employed to assess the impact of the reduced sampling capabilities of TE detectors on survey results. Simulation is appropriate in this situation as any number of detector settings can be investigated, and the inherent randomness in when the detector triggers relative to a bat pass can be modelled. With each iteration the trigger time was randomly shifted relative to the sampling time under investigation. To illustrate, a D240X sampling for 0.1 s is inactive for 1 s during playback/recording. Set to trigger continuously, the detector samples short windows of 0.1 s, each separated by 1 s silent regions. Depending on precisely when the detector is 'listening' relative to a passing bat, the resulting recording may contain all, none or a subset of the sequence of calls recorded by a DS detector. To simulate this variation, at each iteration the trigger time was shifted backwards in time up to 1 s from the start of the DS recording, allowing the short sampling windows to overlay different regions. The number of sequences and calls per sequence was recorded for each iteration and averaged to provide a robust estimate of the sampling capability of TE detectors relative to DS.

D240x detectors have three preset sampling periods, 0.1, 1.7 and 3.4 s. Excluding the numerous pipistrelle passes and concentrating on the rarer species, a simulated D240X survey sampling for

3.4 s completely missed 87% of all bat passes, but recorded an average of 12.7 calls from each captured sequence. Using a 1.7 s sampling period 83.2% of sequences were missed, and an average of 9.9 calls were recorded per captured sequence. At the 0.1 s sample time setting, only 2.6% of sequences were missed, but on average only 1.6 calls per sequence were recorded. There is a clear trade-off between longer sample times missing a larger proportion of total bat passes, but obtaining longer call sequences from those bats that are sampled, relative to shorter sample times. For a detector setup to trigger continuously (the only way to standardise time-expansion detector surveys), the 0.1 s sample time is the most efficient setting, capturing the most bat passes. However, with an average of fewer than two calls recorded in each bat pass, recordings will rarely capture the highest quality calls obtained by direct sampling detectors. Moreover, where only single or small numbers of calls are available, it is difficult for machine-classified calls to be verified by human experts.

Using detectors set to trigger continuously is the only way of ensuring consistency between detectors. This standardised approach was adopted by the ***iBats*** programme (http://www.ibats.org.uk/).

Direct sampling detectors are more expensive (~£1,600) than time-expansion detectors (~£1,100), but this is clearly the direction in which technology is going and the price gap is already closing. Time-expansion detectors are currently in more widespread use, but represent a compromise both on the number of bats recorded during surveys and the number of calls available for analysis, and on the ability to design an effective standardised survey methodology.

Detectors from other manufacturers could be used in surveys. However, sampling rate, microphone characteristic and other factors make their suitability for analysis with our software variable. We have worked with users of other detector brands to evaluate the performance of our software on calls recorded from Elekon, EcoObs, Batbox, and Wildlife Acoustics detectors (see below).

Adams *et al.* (2012) have tested the sensitivity and directionality of a number of detectors, but not Pettersson models. They found the Wildlife Acoustics SM2 and EcoObs Batcorder to be much less sensitive than the Avisoft UltraSoundGate and the Elekon Batlogger. This is likely to lead to differences in species detectability and detector type will have to be taken into account in large-scale analysis. Since models are in continuous development no information is given here on current sensitivities, but any analysis of results should include detector brand and model as a variable.

An important recent development is the release of low cost (<£500), high specification USB ultrasonic microphones that can be connected to a laptop, tablet or smart phone to directly record bat calls. This represents a relatively inexpensive way of equipping for DS survey work, especially if you already have a windows-based tablet (Pettersson M500 microphone, identical to that in D240x and D500x) or iPad/iPhone (Wildlife Acoustics Echo Meter Touch). These have yet to be evaluated with our software.

Recommendations. We would recommend the use of direct sampling bat detectors. First choice would be the Pettersson D500X, since our software has been most thoroughly tested on this.

The Batlogger and Batcorder work well (see Appendix B) but the software needs additional testing and development. Wildlife Acoustics detectors need further testing.

Commercial software is available that classifies woodland species, but few manufacturers give data on accuracy and the source code is not always available for modification. Geographical variation in call structure is well-documented, so software developed in other countries may not be reliable in the UK. Free identification software is available through the iBats programme, but it requires the commercial software Sonobat to function. It was designed to work with a wide range of detectors and identifies many species with high confidence, but is poor at identifying many woodland species.

The time-expansion detector Pettersson D240x can be used but has significant disadvantages and we advocate using the Pettersson D500x only. It may be possible to use other DS detectors after further development of the software.

3. Software

3.1 How it works

This section describes the latest version of the software, which provides a single estimate of the probability of occurrence for each species, for each sound file analysed, independent of the duration of the recording (see 'Classification'). However, we recommend that direct sampling files are short (1-3s). The program identifies each call and calculates the overall probability of each species' presence based on all calls analysed ('call-averaging'). An earlier version did a 'call-by-call' analysis and identification and in addition to identifying the species for each call with a given probability, the output included a sonogram and some key call parameters. This software is described in Appendix B. A third approach, still in development, which analyses whole call sequences, is also described below. The software has been modified so that analysis is still done by providing a single estimate for each species for a sound file (call-averaging), but sonograms can now be viewed.

The technical difficulty of this task is considerable – no software yet produced, freely or commercially available, can extract all calls capable of being identified, eliminate all non-bat calls, or correctly identify all bats to species. Although the software described here works better than other available programs, there is of course room for improvement in terms of performance, ease of use and in the 'feedback' it gives to the user. We will continue to make these improvements.

Pre-processing and Segmentation

Locating and extracting echolocation calls is a major stage of an automated system. Audio files are resampled to 500 kHz and a spectrogram created by applying a STFT (short-time Fourier Transform) using a window length of 512 samples and 75% overlap. The spectrogram is log transformed to compress the dynamic range. Background noise is then removed from the spectrogram by subtracting a running average of pixel intensity, calculated independently for each row (frequency) in the image. Regions of interest are then segmented from the spectrogram using a connected component labelling algorithm (Fu Chang *et al*. 2004). The result is a series of spectrogram segments that represent sounds above the level of the background noise. This method allows segments that overlap in time (but not frequency) to be extracted.

Feature Extraction

For each extracted segment a series of features summarising the spectral and temporal content are measured. These features include the spectral and temporal moments (mean, variance, skewness and kurtosis), calculated from the power spectrum and amplitude envelope respectively (https://bitbucket.org/chrisscott/batclassify for further details).

Classification

Calls are classified using extremely randomized trees (Geurts et al. 2005), a tree-based ensemble method. Unlike support vector machines (SVMs) they naturally handle multiple classes. Empirical class posterior distributions are stored in the leaf nodes and averaged over all trees in the ensemble to give probability estimates to classified calls. Each segment extracted from a recording is classified in turn, and the maximum posterior probability stored over all segments. This results in a single estimate per species of presence, regardless of recording duration. Classification results for each recording analysed are written in the widely supported CSV format, so that spreadsheet or statistical software (e.g. Excel and R) can be used for organisation and analysis of survey data. The output file provides an estimate of the probability of occurrence in each file of each species. Probability ranges from 0 to 1. The user need only set an acceptable threshold to decide whether or not to score a species as present. For rarer species, or when unexpected results are obtained, the sonograms can be examined.

Model accuracies were estimated by evaluating predictions made of labelled recordings containing known species (Table 1). These recordings were made from bats emerging from roosts, on release from the hand following capture, or for species with characteristic calls, from recordings of bats in free flight.

Further reference calls from *Myotis alcathoe* and *M. bechsteinii* are needed to build and validate models with a higher degree of confidence. We did not catch either species during 2013 surveys, so the validity of an acoustic recognition approach for these species remains to be ground-truthed in the field. Further work is also needed to separate *Myotis brandtii* and *Myotis mystacinus*, which must currently be grouped. (Noctule, Leisler's and serotine bats are also grouped. These were not target species and were not sought out for recording.)

Precision is the proportion of the bats that the program identifies to a species that are identified correctly. Recall is the proportion of available recordings of that species the program retrieves from the recording. If the program were perfect, all values of precision and recall would be 1.00. As shown in Table 1, both *precision* and *recall* are high for most species, meaning that most bats will be classified by the software (83-100%) and identification will be correct in most (86-100%) cases. *Recall* for *Myotis bechsteinii* is relatively low, so that not all will be classified. However, since *precision* is still high, most or all *Myotis bechsteinii* that are classified will be identified correctly. With more training data it will be possible to improve *recall* for this species.

Species	N	F1	Precision	Recall
Barbastella barbastellus	243	0.95	0.96	0.91
Myotis alcathoe	23	0.85	0.83	0.87
Myotis bechsteinii	16	0.77	1.00	0.63
Myotis daubentonii	212	0.92	0.99	0.87
Myotis mystacinus / brandtii	237	0.90	0.86	0.95
Myotis nattereri	131	0.97	0.98	0.96
Noctule, serotine, Leisler's	391	0.99	0.99	0.99
Pipistrellus pipistrellus	510	0.99	0.99	0.98
Pipistrellus pygmaeus	308	0.97	0.96	0.97
Plecotus auritus	198	0.93	0.98	0.88
Rhinolophus ferrumequinum	79	1.00	1.00	1.00
Rhinolophus hipposideros	353	1.00	1.00	1.00

Table 1. Sample sizes (N sequences/bat passes) and out-of-sample measures of classification model accuracy (F1, precision and recall). Precision is the probability that a case classified as positive is in fact positive. Recall is the probability that a positive case is correctly classified. F1 is the harmonic mean of precision and recall. Trees in the classifier ensemble were built using 50% stratified samples of training data, leaving 50% out-of-sample for accuracy estimates.

3.2 Strengths and limitations of the software

- The package is small and easily transferred from user to user and needs no installation.
- It is a stand-alone package and does not need commercial software to prepare calls for analysis.
- It is freely available.
- The source code is available for further development, e.g. to include new species.
- It is easy to use and processes large data files rapidly.
- If the results are interpreted with common sense and a basic knowledge of bat echolocation call structure then errors should be few.
- The source code is cross-platform but for the moment has only been compiled and verified to work on computers with a Microsoft Windows operating system. We hope to release an Apple/Linux version in the future.

3.3 Source code and instructions

The source code and instructions are available at https://bitbucket.org/chrisscott/batclassify In the future these can be hosted by the University of Leeds and the BCT. Because the source code is provided those with the ability and interest to develop new identification models can do so.

3.4 Classification based on call sequences (bat passes)

We have had some success in using the contextual information in longer directly-sampled recordings to increase identification rates. This is still in development but initial results are reported below. We recommend using the call-averaging and call-by-call versions of the software in the interim.

A linear support vector machine (SVM) (Fan *et al*. 2008) is used to classify recordings based on histograms of features. We build binary models for each species, so that for each recording a species is predicted to be present or absent with some degree of confidence (SVM decision value; negative value=absent, positive value=present). Model accuracies were estimated by evaluating predictions made of labelled recordings containing known species (Table 2). These recordings were made from bats emerging from roosts, on release from the hand following capture, or for species with characteristic calls, from recordings of bats in free flight.

Using a histogram of features and moving the classification from the individual echolocation call level to the recording level has important advantages - recordings used for model training can contain multiple species, and models can leverage information from multiple calls. Training data for classification at the call level involves arduously removing noise and other species from the training recordings, so that the data are representative of a single species. Using this approach no editing is required, which makes updating species models much more efficient as further training data are collected. For species that use multiple call types (e.g. *Barbastella barbastellus*), models can assign greater confidence in presence where both call types occur in a recording. However, this approach results in a relatively large number of features compared to our previous call level approach, which increases the sample sizes required to achieve robust performance. We are still in the process of labelling calls from *Pipistrellus sp.* to build species-specific models for this genus. In addition, we will need to record further reference calls from *Myotis alcathoe* and *M. bechsteinii* to build and validate models with a higher degree of confidence. We used our previous call level system to search for these species in the 2013 field data but failed to find any matches. Additionally, we didn't catch either species during 2013 surveys, so the validity of an acoustic recognition approach for these species remains to be ground-truthed in the field.

Species	N	AUC	Precision	Recall
Barbastella barbastellus	383	0.99	0.97	0.98
Myotis daubentonii	212	0.99	0.91	0.92
Myotis mystacinus / brandtii	237	0.98	0.93	0.88
Myotis nattereri	131	0.99	0.98	0.94
Noctule, serotine, Leisler's	159	0.99	0.99	0.93
Pipistrellus	788	0.99	0.99	0.99
Plecotus auritus	210	0.97	0.97	0.93
Rhinolophus ferrumequinum	84	1.00	1.00	0.97
Rhinolophus hipposideros	338	1.00	1.00	0.99

Table 2. Sample sizes (N) and measures of classification model accuracy (AUC, precision and recall). AUC is the probability that a random positive example has a higher decision value than a random negative example. Precision is the probability that a case classified as positive is in fact positive. Recall is the probability that a positive case is correctly classified. Accuracy metrics were generated using Monte Carlo cross-validation (e.g. Kuhn & Johnson 2013), with 400 replicate train-test splits, subsetting 90% of data for modelling and 10% for prediction.

4. Survey methods, results and interpretation

4.1 Methods

<u>4.1.1 Survey designs: protocols, survey effort, detectability and power analysis</u>

Protocols and survey effort

Three basic survey protocols are available:

- **Spot checks** – recording species presence at a given number of specified locations, spending a specified time at each location. Locations would be chosen to sample specific habitats or all habitats without bias.
- **Transects** – continuous recording of species presence whilst moving at a uniform speed along a pre-determined track. The track would be chosen to sample specific habitats or all habitats without bias. The route may also be determined in part by where it is practical and safe to walk.
- **Area searches** – a survey of a specified area in a given time without the use of a predefined route, giving the surveyor flexibility to contend with difficult terrain or spend more time in locations likely to harbour species of interest.

All three offer advantages and disadvantages. Only spot checks can be used if bats are to be caught, all three are available for acoustic monitoring and spot checks and transects can be combined.

Spot checks remove the burden of simultaneous navigation and surveying, and provide a convenient opportunity for surveyors to check maps, equipment, and survey duration. Walked transects make more efficient use of surveyor time, as sampling is continuous, but introduce difficulties where terrain is rough or vegetation dense. A pragmatic approach would be to include both walked and spot elements in surveys, utilising any available woodland paths and rides for walked elements, with additional spot checks assigned to cover remaining areas. Given the variation in size, shape, and accessibility of different woodland sites, some flexibility in survey design is required for a large-scale monitoring programme. One solution is for survey effort to be standardised by duration (e.g. 90 minutes), but free to be made up from any combination of fixed length spot checks and transect segments, selected to suit the particular site. To illustrate, a woodland nature reserve with well-developed paths for visitors may be easily surveyed entirely by walked transect. In contrast, a steep-sided valley woodland with few access paths may require a series of spot checks to cover the site safely. (However, this may be more difficult to achieve with inexperienced surveyors). Once a survey design is selected for a particular site, replicate surveys (within and between years) should be carried out using the same survey design to ensure consistency within a site. However, it is not essential that all sites are surveyed using the same approach if other essential conditions are met, as described below.

An approach that has been applied in avian surveys is the area search, in which surveyors cover a fixed survey area in a set time, but without a prescribed route. Fixed route transects provide an effective method for investigating bat-habitat relationships at the landscape scale, but fixed area searches may offer distinct advantages in woodland surveys. Surveyors have the flexibility of pausing to ensure a species has been adequately recorded before continuing, and to attempt to approach faintly detected species more closely. Whilst we did not set out to directly assess the effectiveness of fixed area surveys during the 2012 season, all initial site surveys were of this nature, and resulted in high quality recordings. Additionally, the simplicity of the area search makes it highly suitable for volunteer based survey. We directly compared the fixed area search with conventional walked transects and spot checks in the 2013 field season, carrying out both methods simultaneously to account for nightly variation.

Detectability

Bats are mobile and cryptic, making them difficult to detect during surveys. Regardless of the field methods used during sampling, some individuals will go undetected. Chen and colleagues (2013) found that even in highly standardised surveys for plants, carried out by experienced field biologists, imperfect detection was the rule rather than the exception. The probability of detection ***p***, is the probability of detecting a species given that it is present at the site at the time of sampling. To illustrate, imagine Natterer's bat (*Myotis nattereri*) is only detected in half of all surveys of sites where it is actually present, resulting in a ***p*** of 0.5. Surveys designed to identify sites occupied by Natterer's would suffer a systematic bias, underestimating the number of occupied sites by half. In practice the picture is even more complex, since ***p*** may vary with season, habitat, survey method, observer, and other factors (e.g. Bailey *et al*. 2004; MacKenzie 2005). As a simple example, capture of bats in the field is only effective where there is sufficient habitat cover to help conceal traps, or natural flyways e.g. woodland rides, where bats are channelled towards traps. In more open habitats, relative capture success is considerably lower. In this example, ***p*** clearly varies with habitat type, and if ***p*** is not accounted for survey results may be misinterpreted. Where bats are *caught/detected* may easily be confounded with where bats actually *are*, when in fact they may be in many other places. Inferences made from naive counts of bats caught or detected, whilst intuitively appealing, may be error-prone. This potentially leads to biased habitat suitability models, the misallocation of resources for conservation management, and misguided selection of sites for protection. For data to be meaningful, a monitoring programme must be able to separate variation induced by sampling from actual variation in the population of interest.

We estimated detectability for a range of woodland bat species under the specified conditions of our surveys. Once estimated, ***p*** was used to correct for imperfect detection, reducing bias in the estimators of site occupancy. By visiting ***n*** sites ***k*** times within a season, recording detection (1) or non-detection (0) of the target species for each survey, the detection history (a matrix of zeros and ones) was used to estimate ***p*** (MacKenzie 2005). However, this implicitly assumes 'closure' between surveys, i.e. that occupancy does not change between surveys. For bats this assumption is likely to be violated, for at least some species, even if surveys are within days of each other, since in some cases home ranges will be larger than the area surveyors can cover in a single night. Where this is the case, non-detection may result from temporary emigration, where a bat is within its home range, but outside the bounds of the survey site, and therefore not actually available for detection. In this situation ***p*** actually represents the product of the probability of detection and 1 - temporary emigration probability. Tyre et al. (2003) interpreted

p as representing 'use' in this case. Two species that are equally 'easy' to detect when present at a site may not have the same ***p*** if their home ranges and site fidelity differ.

In order to try and separate detection from temporary emigration probability, a robust design protocol can be employed (e.g. Pollock *et al*. 2002). So called 'secondary' sampling periods are nested within 'primary' sampling periods, allowing the combination of open and closed population models in one analysis. As an example, primary sampling periods may consist of nightly woodland bat surveys, where the woodland community is not considered closed between nights due to possible temporary emigration. During each nightly primary survey, additional secondary sampling is carried out by walking transects twice (e.g. Kéry *et al*. 2009). Surveys within a night minimise the likelihood of violating the closure assumption, and can be used to separate the probability of detection from the longer-term temporary emigration probability. An alternative method is to employ 'double observer' surveys. Here, two independent observers survey the same site on the same night, comparing observations to estimate detectability.

A larger number of replicate surveys increases the precision of the estimate of ***p***, but if survey effort is allocated to more replicate surveys, fewer independent survey sites can be sampled. We favoured replicate surveys, as the primary interest at this stage is reliable estimates of ***p*** to compare methods and estimate the survey effort required to provide a set level of confidence in species presence. In the implementation of a monitoring programme, where ***p*** has been estimated, replicate surveys can be reduced as the primary interest becomes occupancy rate, which is most precisely estimated using a larger number of sites.

We therefore surveyed woodland sites with two independent observers conducting acoustic transects, using the robust design. Each surveyor used a slightly different transect protocol, allowing us to compare survey methods and ensure surveys were independent. Observer A carried out a conventional walked transect on a fixed route with additional static spot checks, planned *a priori*. Observer B was free to survey the site in a more flexible manner, allowing pauses and deviations from any fixed route to aid in locating and obtaining high quality recordings of bats: the area search approach. We compared the numbers of calls available for automated classification to species for each method. Replicate primary surveys allowed us to estimate temporary emigration, with secondary surveys used to estimate detection. Allocation of observers to survey methods was randomised. The software PRESENCE (http://www.mbr-pwrc.usgs.gov/software/presence.html) was used to estimate and compare ***p*** for the two acoustic transect protocols, and identify significant covariates. We used estimates of ***p*** to plot detectability curves (e.g. Wintle *et al*. 2005; Kéry & Schaub 2011). Detectability curves display confidence in estimates of occupancy against the number of survey visits, and allow the number of replicate visits to obtain a set level of confidence to be determined, e.g. four repeat surveys for 95% confidence in presence under average survey conditions. Detectability curves were created in R using the R2WinBUGS package (Sturtz *et al*. 2005). Power analysis was carried out using simulations in R to estimate the number of survey sites and replicate surveys required to adequately detect population changes of different magnitude (Guillera-Arroita & Lahoz-Monfort 2012).

Power analysis

We conducted prospective power analysis to calculate the power of a specific occupancy study design, and additionally to determine the required number of sampling sites to reach a target power level (Guillera-Arroita & Lahoz-Monfort 2012). The parameters for the power analysis are the number of survey sites, number of replicate visits to each site each season, proportional change in occupancy, initial occupancy probability, detection probability, and target power level. We assume a significance level of 0.05 for all analyses. R scripts to recreate these analyses are available online at http://onlinelibrary.wiley.com/doi/10.1111/j.2041-210X.2012.00225.x/suppinfo (Guillera-Arroita & Lahoz-Monfort 2012).

4.1.2 Acoustic lure and capture as complementary methods to acoustic survey

We also caught at woodland sites using harp traps and an acoustic lure. Harp traps were chosen over mist nets since the latter require intensive training for safe and effective use and are not therefore suitable for large-scale, volunteer-based surveys. Capture allowed us to compare the efficiency of acoustic vs. capture. It also enabled us to further verify species records obtained using acoustic methods. By making continuous recordings at the trap, we obtained field reference calls for captured bats, providing an unbiased test for automated species identification software. Murphy (2012) found evidence that response to an acoustic lure was species-specific, so we used several call types (but a different lure) during lure playback, as described for specific aspects in the results. We have high quality direct-sampling recordings suitable for playback. Effectiveness of the lure was tested by comparing captures made during silent 'control' periods, with those during true playback periods. If the lure could be shown to be effective in attracting *Myotis bechsteinii* and *Plecotus auritus*, it could be applied on acoustic transects to increase detection rates for these quieter species. However, for species readily detectable by passive acoustic methods, we believe records obtained using a lure should be used with caution until further research on the behavioural impacts of the lure on bats are carried out. Bats responding to a lure may well be a non-random sample of the target population (all woodland bats), limiting inferences that can be made regarding occupancy rates and habitat use.

One reason for using an acoustic lure is to record the presence of species that use low intensity echolocation calls, such as *M. bechsteinii* and *P. auritus*, since these may not be detected easily by acoustic means or the species may be so rare that attraction to a lure increases the probability of detection. However, if these species can be reliably identified from their calls, it is not necessary to capture them, but simply to bring them in range of the bat detector. For this reason we compared the number of bats captured using a lure/harp trap combination with those simultaneously recorded by a detector close to the lure.

Detector height

The position of the recording microphone could influence quality of the calls recorded, so we made use of a pair of D500X detectors to simultaneously record at chest height and at c. 3-4 m, to see if raising the detector increased the number of bats recorded or improved the quality of recordings.

4.2 Results and recommendations

4.2.1 Survey designs: protocol, survey effort, detectability and power analysis

The study sites in the Wye Valley area are listed in Table 3. Surveys resulted in capture records for *Barbastella barbastellus*, *Myotis bechsteinii*, *M. brandtii, M. mystacinus*, *M. daubentonii*, *M. nattereri*, *Nyctalus noctula*, *Pipistrellus pipistrellus*, *P. pygmaeus*, *Plecotus auritus*, and *Rhinolophus hipposideros*. Acoustic records were made for all of the above species with an additional record for *R. ferrumequinum*. However, capture rates in 2012 were low, with an average of 1.8 bats per night. *M. alcathoe* was not encountered using either survey method suggesting it is either absent or locally rare in the region. 2012 was an exceptionally wet summer and conditions were far from ideal for bat activity or bat study.

Bigsweir Wood	SO 546 060
Brilley Green Dingle	SO 271 488
Common Wood	SO 267 482
Fishpool Valley	SO 455 655
Lea & Paget's Wood	SO 598 343
Nagshead	SO 606 085
Nupend Wood	SO 580 354
Priory Grove	SO 526 139
Pwll-y-Wrach	S0 165 326
Romer's Wood	SO 604 632
Woodside	SO 555 157

Table 3. Woodland sites surveyed and OS grid references.

Detector height

Raising the D500X microphone above handheld height had no significant effect on numbers of bat passes recorded (Fig. 1; GLM with Poisson response; deviance: 147, df: 22, p: 0.23). Previous experience raising the recording system outside roosts resulted in bats circling the detector resulting in very high quality recordings, but this behaviour was not observed during woodland trials. This difference may be situational or behavioural, with bats more inclined to investigate novel objects in their airspace close to the roost. The ability to raise the detector microphone closer to the bats can increase the signal-to-noise ratio of recordings and reduce incidental surveyor-generated noise in the recordings, although this is surveyor dependent.

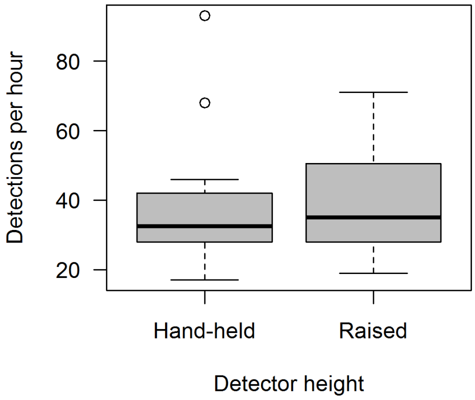

Fig. 1. Comparison of bat detections using a hand-held detector, and one raised c. 3-4 m above ground level.

Recommendation. The ability to use a raised external microphone with the D500X (and probably other detectors with this facility) is an advantage in obtaining the highest quality and potentially the most useful recordings, but this is not always practical, or a requisite for an effective woodland survey. However, surveyors should be made aware that orientation of the detector directly influences recording quality to ensure survey data is consistently high quality. Surveyors should make the minimum noise and orientate the detector ahead of them, angled up, at approximately 45° to the horizontal.

Protocols and survey effort

Spot checks and walked transects

Study sites were chosen on the basis that the rarer woodland species (except Alcathoe) were known to be present at some of them (or the habitat was considered suitable for them) and because bat diversity was expected to be high. Transects started 30 min after sunset and lasted 90 min. Six 5 min spot checks were distributed at approximately equal intervals throughout the transect, so that 60 min were occupied by slow, continuous walking. Transects were only walked in 'good' weather: temperature at the start of the transect >10°C, wind <20 km/h, no rain. Replicate transects (two at each site) were carried out at six woodland sites (Brilley Green Dingle, Lea & Paget's Wood, Nagshead, Nupend Wood, Romer's Wood, and Woodside).

Spot checks were no better or worse at detecting bats (Fig. 2; GLM with Poisson response; deviance: 178, df: 22, p: 0.97). However, spot checks and walked transects carried out at the same sites differed in their species records (Jaccard similarity 0.26). No species was consistently recorded by a single method, indicating that differences between survey records are likely the result of the stochastic nature of bat encounters rather than due to methodological issues.

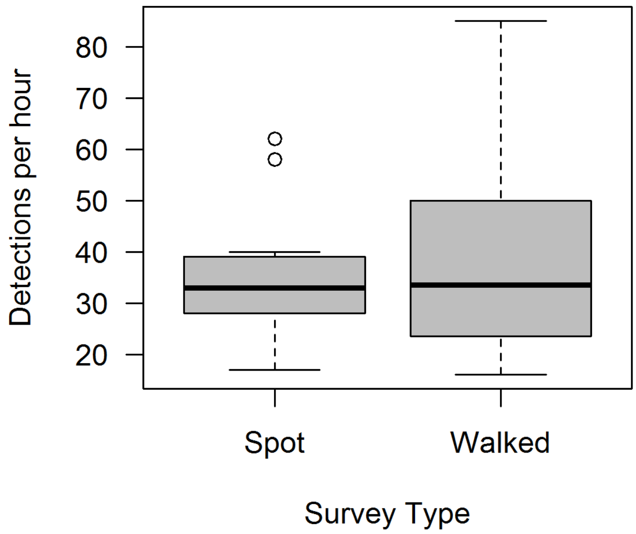

Fig. 2. Comparison of bat detections during spot checks and walked transects.

> ***Recommendation***. Either spot checks or walked transects are suitable survey protocols, or a combination of the two. However, the same approach must always be used at a given survey site. We suggest a combination and the protocol described in detail in the guidelines is essentially the same as that used to compare the two approaches.

Detectability

Walked transects versus area searches

Spread over five study sites, 23 walked transects (with spot checks) and 27 area searches were conducted. On all but four nights surveys were conducted simultaneously by different surveyors, who alternated protocols. Four walked transects were lost due to technical problems. We found no significant differences between estimates of detection probability between survey methods (Bayesian estimation of difference of means; Kruschke 2013). The results are summarised in Table 4.

Species	Conventional Mean [95% HDI]	Area-Search Mean [95% HDI]	Difference Mean [95% HDI]
Barbastella barbastellus	0.78 [0.61, 0.93]	0.89 [0.75, 0.99]	-0.11 [-0.35, 0.10]
Myotis mystacinus / brandtii	0.88 [0.76, 0.98]	0.89 [0.76, 0.99]	0.00 [-0.18, 0.17]
Myotis nattereri	0.44 [0.23, 0.66]	0.36 [0.18, 0.54]	0.08 [-0.19, 0.38]
Noctule, serotine, Leisler's	0.86 [0.73, 0.97]	0.86 [0.73, 0.97]	0.00 [-0.18, 0.18]
Pipistrellus pipistrellus	0.92 [0.83, 0.99]	0.83 [0.68, 0.96]	0.09 [-0.09, 0.27]
Pipistrellus pygmaeus	0.97 [0.91, 0.99]	0.97 [0.90, 0.99]	0.00 [-0.09, 0.09]
Plecotus auritus	0.29 [0.12, 0.46]	0.33 [0.16, 0.53]	-0.04 [-0.31, 0.21]
Rhinolophus hipposideros	0.50 [0.27, 0.71]	0.61 [0.36, 0.85]	-0.11 [-0.45, 0.22]

Table 4. Differences in detection probability between conventional transects and area searches by species, where sufficient data were available for comparison. Results are the mean and 95% Highest Density Interval (HDI) from the probability distribution over the estimated detection probabilities and their differences. Identification based on call-by-call software analysis.

Recommendation. Walked transects or area searches can be used, since detection probabilities for all species do not differ between the two survey protocols. However, the same approach should always be used at a given survey site.

Additional, replicated surveys were conducted at eight woodland sites (Bigsweir Wood, Brilley Green Dingle, Common Wood, Fishpool Valley, Lea & Paget's Wood, Nagshead, Priory Grove, and Pwll-y-Wrach) to estimate species-specific detection and occupancy probabilities (e.g. Bailey *et al.* 2004). For comparison sites were surveyed using the two acoustic survey protocols, the area search and conventional walked transect with spot checks, both two hours in duration starting at sunset.

Replicated site surveys (8 sites, 34 surveys, median replicate surveys = 5) were used to estimate detection probability (***p***) and occupancy probability (***psi***). Modelling was carried out in R using the package rjags (Plummer 2013) and following examples given in Kéry & Schaub (2011).

Since we found no significant differences between estimates of detection probability between survey methods, for clarity we present results for conventional walked transects only. Species-specific detection probabilities (***p***) for woodland bats ranged from 0.29 to 0.89, and occupancy estimates (***psi***) ranged from 0.68 to 0.80 (Table 5). Calls from *Pipistrellus sp.* were recorded in all surveys at all sites so no modelling was carried out. From estimates of ***p*** we simulated the probability of detecting each species at least once over multiple surveys (Fig. 3). The probability of detecting each species increases non-linearly with each additional survey night. The total number of surveys required to attain 95% certainty of detection is dependent on the species-specific single survey detection estimate, indicated by the position of the first box plot for each species in Fig. 3. The vertical height of each box plot indicates the uncertainty in each estimate. These estimates are valuable where surveys are required to determine presence/absence with a known confidence level, e.g. in SSSI site assessment. In occupancy analysis ***p*** is used to correct occupancy estimates, and the level of survey effort is not expected to provide a complete inventory for each site sampled.

Sites that were known or predicted to be species rich were selected for survey to maximise the chances of a species being present at multiple sites, increasing precision in detection estimates. Note that as site selection was biased, and not the result of simple random sampling, occupancy estimates are not representative of all available woodlands.

Species	*p* [1 SE]	*psi* [1 SE]
Barbastella barbastellus	0.78 [0.08]	0.68 [0.15]
Myotis mystacinus / brandtii	0.89 [0.06]	0.78 [0.13]
Myotis nattereri	0.44 [0.11]	0.71 [0.16]
Plecotus auritus	0.29 [0.09]	0.80 [0.15]
Rhinolophus hipposideros	0.49 [0.11]	0.70 [0.16]

Table 5. Species-specific detection probability (p) and occupancy (psi) estimates for conventional walked acoustic transects. Results are the mean and standard error of the posterior distribution.

Recommendation. Ideally surveys should aim to achieve 95% certainty of detection. This requires 1 survey for *Pipistrellus*, 2 for *M. brandtii/mystacinus* and *Barbastellus*, 4 for *Rhinolophus*, 5 for *M. nattereri*, and as many as 9 for *Plecotus*, but survey can be stopped as soon as all are detected. Based on the relative intensity of their calls we estimate 2-3 surveys for *M. alcathoe* and 4-6 for *M. bechsteinii*, but these remain to be tested.

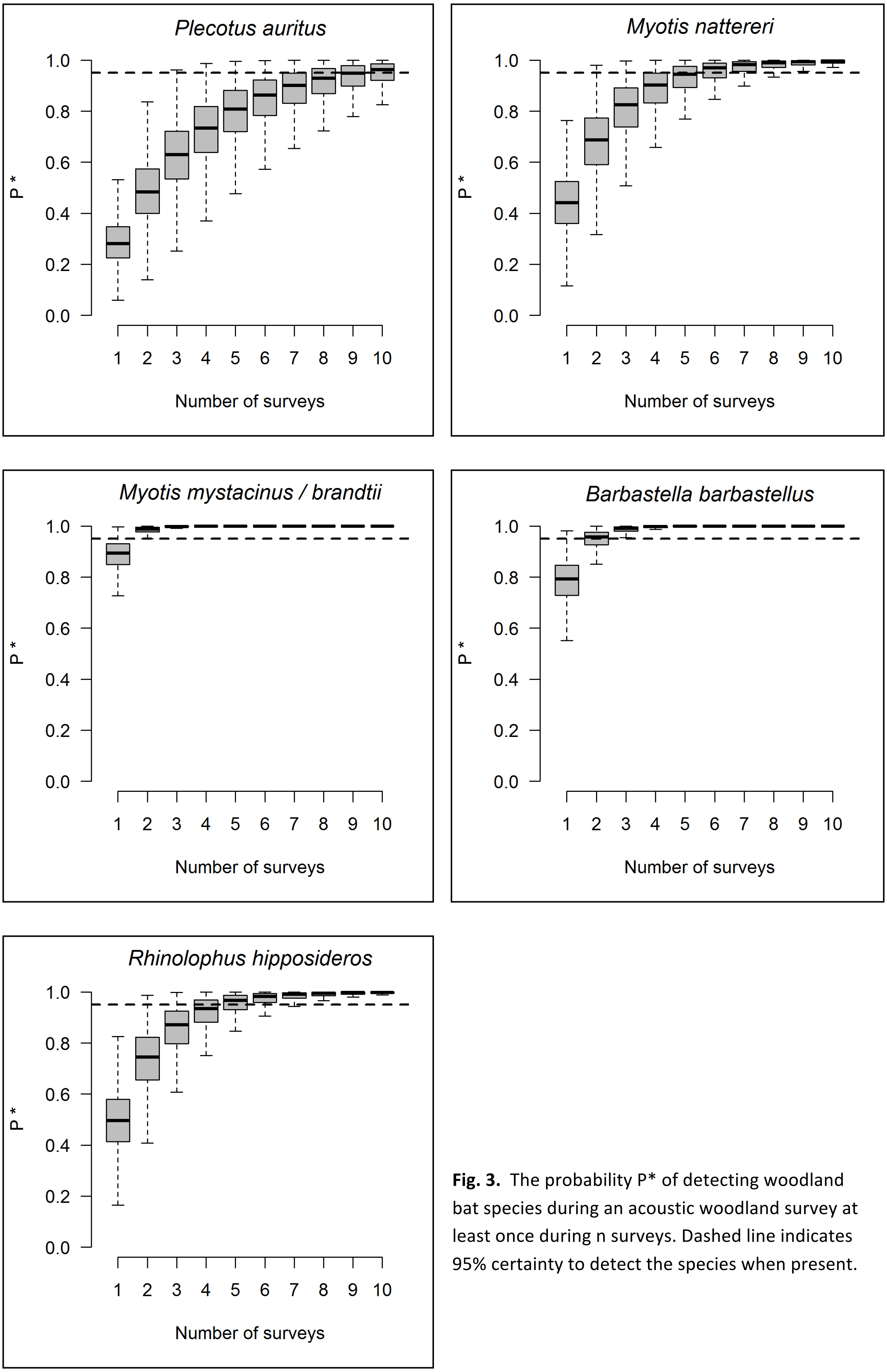

Fig. 3. The probability P* of detecting woodland bat species during an acoustic woodland survey at least once during n surveys. Dashed line indicates 95% certainty to detect the species when present.

Power analysis

The parameters for the power analysis were the number of survey sites, number of replicate visits to each site each season, proportional change in occupancy, initial occupancy probability, detection probability, and target power level. We assumed a significance level of 0.05 for all analyses. R scripts for these analyses were obtained from http://onlinelibrary.wiley.com/doi/10.1111/j.2041-210X.2012.00225.x/suppinfo (Guillera-Arroita & Lahoz-Monfort 2012).

Statistical power increases with survey effort (number of sites and replicates), and is proportionally higher for species occupying more sites and with greater detection probability, reducing the survey effort required to achieve a fixed level of power (Table 6 and Figure 4).

Species	***p***	***psi***	Required Sites
Barbastella barbastellus	0.78	0.68	31
Myotis mystacinus / brandtii	0.89	0.78	22
Myotis nattereri	0.44	0.71	56
Plecotus auritus	0.29	0.80	124
Rhinolophus hipposideros	0.49	0.70	47

Table 6. Number of sampling sites required to detect a 50% decline in occupancy between two time periods with 95% confidence, given species-specific detection probability (p) and occupancy probability (psi). Estimates assume 3 replicate surveys per site.

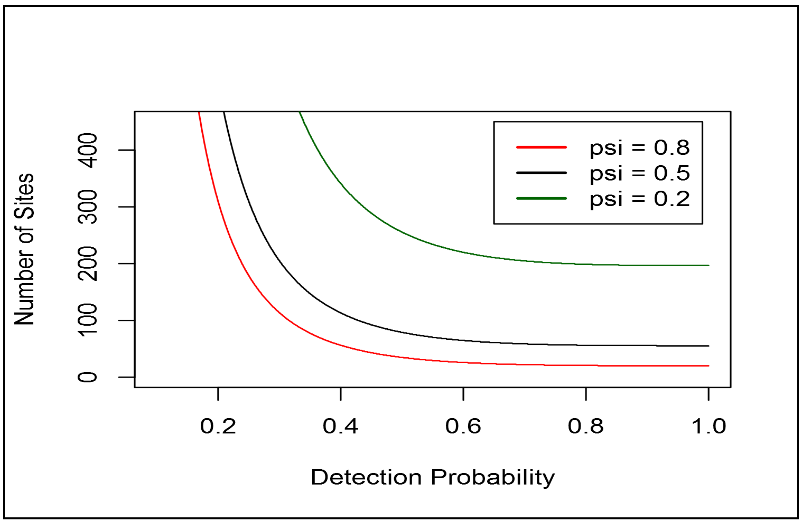

Fig. 4. Influence of species detection probability and site occupancy probability (psi) on number of sampling sites required to achieve 80% power to detect a 50% reduction in occupancy.

Recommendation. Effective monitoring may require the survey of 150 sites to capture useful data on all woodland species, but far fewer sites will yield valuable data for some species.

4.2.2 Acoustic lure and capture as complementary methods to acoustic survey

We addressed the following primary questions:

- Does a low cost lure attract bats as effectively as one capable of broadcasting in the 'full' frequency range of echolocation calls?
- Does the use of an acoustic lure increase capture rate - both real capture (bats in harp traps) and acoustic capture (bat calls on sound files)?
- Does use of the acoustic lure and/or capture add to the species inventory collected from passive acoustic recording?

Lure playback

Four recordings were prepared for acoustic lure playback experiments (see Appendix A for spectrograms):

- *Myotis alcathoe* distress call sequence
- *Barbastella barbastellus* social call sequence
- *Myotis bechsteinii* social call sequence
- Empty wav file (control)

The *Myotis alcathoe* call was recorded from a bat caught in Sussex, which emitted a distress type call prior to hand release. The barbastelle and Bechstein's bat calls were recorded directly from the speaker output of the Sussex Autobat. All recordings were made at 500 kHz using a Pettersson D500X. An empty wav file was also selected for broadcast through the playback equipment as a control during experiments.

Call sequences were repeated within recordings to produce fixed duration files of 5 minutes. A playback sequence containing all available call types was repeated for the duration of sampling, ensuring each call type was played for the same duration over the study. The order of call types was randomised within each sequence (e.g. set 1: A, B, C, D; set 2: C, B, A, D; set 3: A, B, D, C; etc.) to avoid any systematic bias of sequence order on observed bat activity. Playback sessions lasted up to 4 h given favourable weather conditions. Surveys were only undertaken during dry periods with temperatures above 9 °C, but bat activity was generally observed to be low across all sites. Unusually wet weather in 2012 may have reduced bat activity generally, as well as bat responses to acoustic stimuli.

Effect of lure type

We tested two playback systems over 18 survey nights. The first was a 'high-fidelity' Pettersson L400 speaker (10-110 kHz, >100 dB at 1 m, http://batsound.com/?p=12) used in combination with a netbook computer. This had an extended high frequency response in comparison with the cheaper L60 speaker (2-60 kHz, requires amplification, http://batsound.com/?p=13) used with an Edirol R-09 digital recorder. The L400/netbook and L60/Edirol were alternated for all experiments except transects where the L60/Edirol was used exclusively due to portability.

We had successful captures using both playback systems, although capture rates were low, so the results should be viewed with some caution. There was no significant effect of playback equipment on catch rates (Bayesian test of equality of proportions; 95% HPD interval 0.26-0.63) (Pettersson L60 captures = 14, L400 captures = 11). Bats caught are listed in Table 7.

Since high frequencies attenuate rapidly, and since most of the energy of bat social calls is at frequencies well below 60 kHz, bats may not perceive differences between the two lures until they have already been attracted by the lower frequency content of the playback signals.

Species	N
Barbastella barbastellus	1
Myotis mystacinus / brandtii	4
Nyctalus noctula	5
Pipistrellus pygmaeus	7
Plecotus auritus	7
Rhinolophus hipposideros	1

Table 7. Numbers of bats caught by species using harp trap and acoustic playback using Pettersson L60 or L400 speakers at sampling rates of 96kHz and 192kHz respectively.

Recommendation. Low cost lures capable of broadcasting at up to 60 kHz, such as the Pettersson L60, may be effective lures, but those capable of emitting higher frequencies, if available, should be used pending further testing. A consideration that may be more important than the ability to broadcast frequencies above this range is the output amplitude – the L60 requires an external amplifier to reach the levels of the Pettersson L400 speaker.

Does the use of a lure increase recorded bat activity?

Results from 12 nights of playback within five woodlands in Herefordshire and the Wye Valley were analysed. Woodland species, as a group, (*Barbastella*, *Myotis*, *Plecotus* & *Rhinolophus spp*.) showed no preference for call type, but activity levels increased during playback of bat calls relative to the silent control (Bayesian estimate of difference in proportions; mean: 0. 52, 95% HDI [0.34, 0.68]; Fig. 5). Assigning detected calls to species, *Myotis mystacinus / brandtii* bats showed a preference for the Bechstein's calls relative to the Barbastelle (Bayesian estimate of difference in proportions; mean: 0.35, 95% HDI [0.15, 0.54]). There were no other significant preferences for playback type among other species (Table 8).

Genus/Species	*Barbastella barbastellus playback*	*Myotis alcathoe playback*	*Myotis bechsteinii playback*
Barbastella barbastellus	4	1	2
Myotis mystacinus / brandtii	10	19	24
Myotis nattereri	5	4	3
Plecotus auritus	3	0	9
Rhinolophus hipposideros	2	5	2

Table 8. Numbers of bats attracted during lure playback.

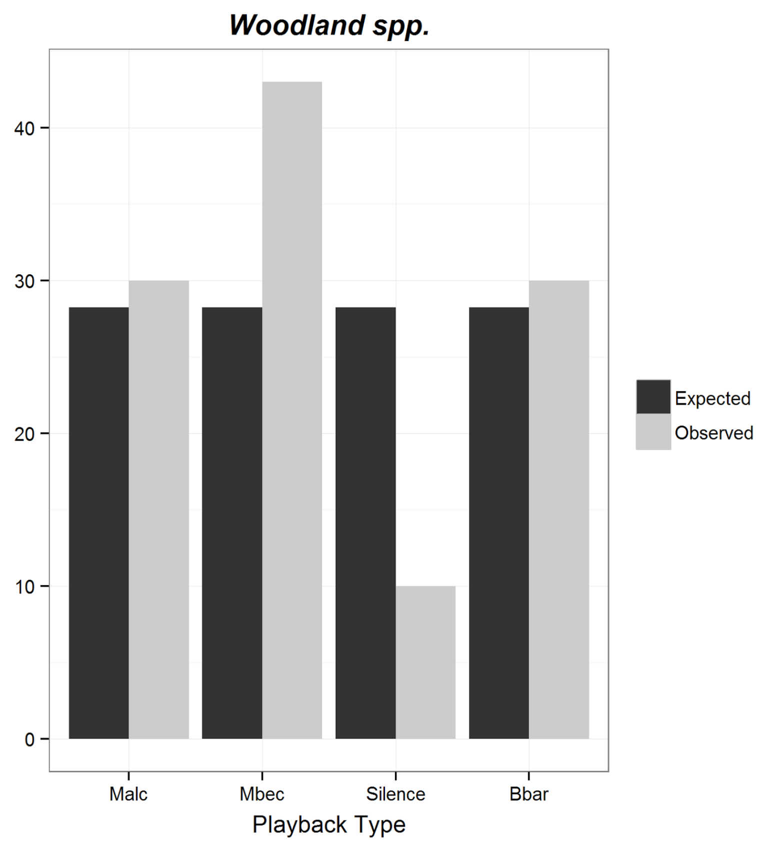

Fig. 5. Observed versus expected levels of bat activity (bat passes, excluding *Pipistrellus* spp.) for each playback type. Activity was significantly lower than expected during the silent control (Fisher's exact test p = 0.007), indicating that playback of bat calls acted as a lure. Statistical tests revealed no species preferences by bats for the Alcathoe, Bechstein's or barbastelle call types (multiple Fisher's exact tests with Bonferroni correction).

Recommendation. Use of the lure does increase recorded bat activity. A mix of broadcast call types is probably the best approach until more extensive studies show whether or not bats respond differently to different calls. By switching calls bats are also less likely to habituate to one call type. However, we do not recommend lure use given our present poor understanding of how they work (see Discussion).

Real versus acoustic capture

If bats can be attracted to lures so that they can be captured acoustically, then if the identification software is reliable, capture of bats in the harp trap is unnecessary. If acoustic capture is more effective than real capture and lacks species bias, then this argument is strengthened.

Encounter rates at harp traps (indicated by acoustic activity) were consistently higher than catch rates (Table 9; Fig. 6). The logical assumption is that some bats avoid capture. Lure-assisted acoustic survey is therefore more effective at detecting bats than capture for confirming species presence. The results are broken down by species in Fig. 6, which shows considerable variation between species in the percentage of those recorded that are captured. The number recorded for most species are low, so it would be unwise to read too much into inter-specific differences without further study. However, those most likely to escape capture have wing morphology and behaviour that suggest greater manoeuvrability.

Number of bats recorded during lure playback	Number of bats recorded during 'silent' control playback	Total number of bats captured
86 (30, 28 and 28 by the three lure calls used)	10	17

Table 9. The number of bats recorded and captured during 12 nights of playback trials in 2012, same sites as in previous section.

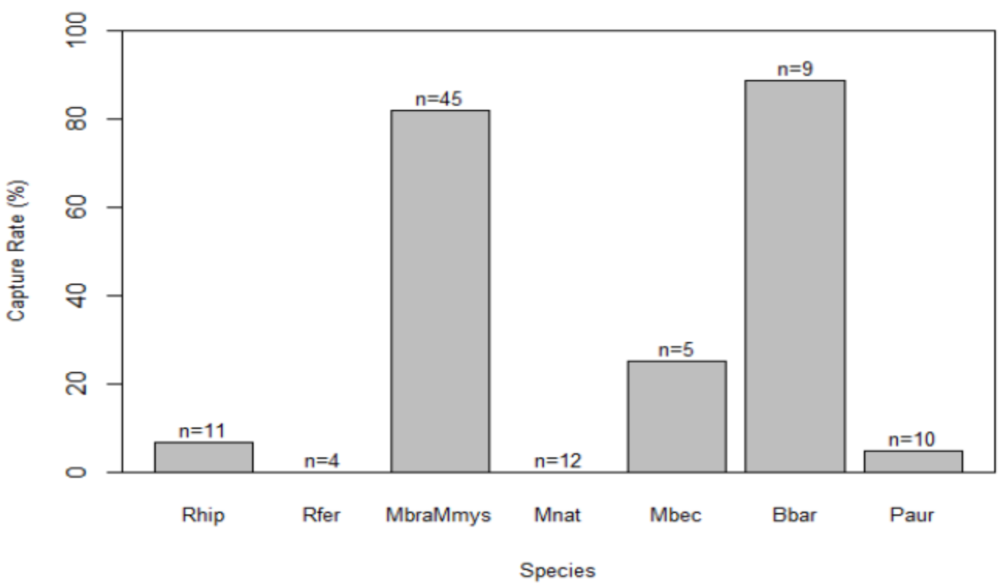

Fig. 6. Capture rates (number caught/number recorded x 100) for each species over the 2012 season. Numbers above bars represent the number of bats recorded at the trap. Rhip = *Rhinolophus hipposideros,* Rfer = *R. ferrumequinum,* MbraMmys = *Myotis brandtii* and *M. mystacinus,* Mnat = *M. nattereri,* Mbec = *M. bechsteinii,* Bbar =*Barbastella barbastellus,* Paur = *Plecotus auritus*.

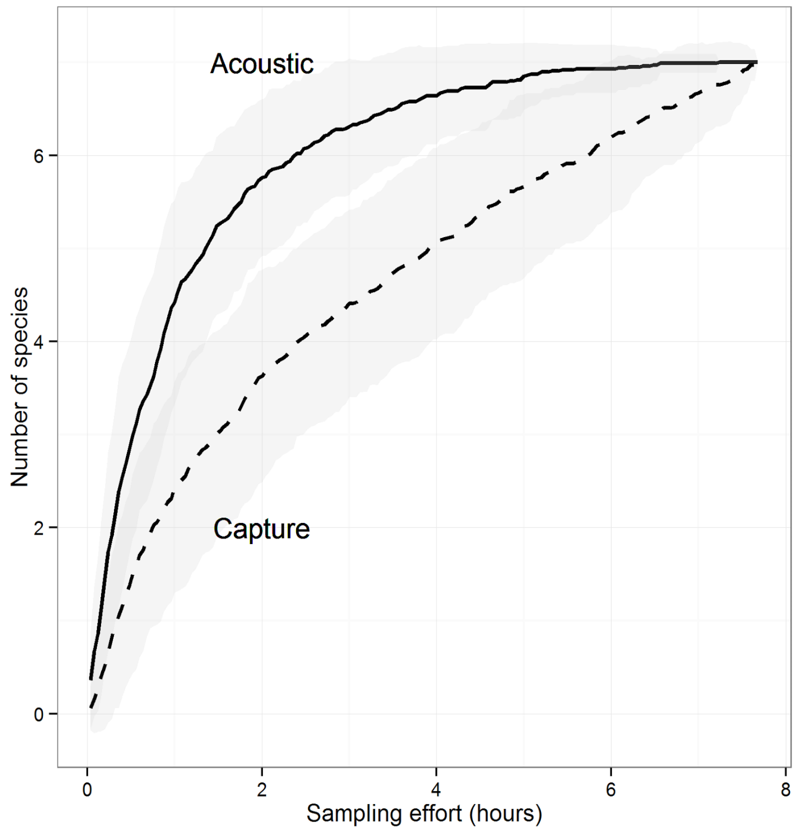

Fig. 7. Species accumulation curves for static acoustic sampling (continuous line) and harp trapping (dashed line). Shaded areas represent ± one standard deviation. Data averaged over five sampling sites.

Species accumulation curves for capture and acoustic sampling are given in Fig. 7 for all data. Inventory completeness is reached much more rapidly with acoustic sampling.

Recommendation. Static surveys may be carried out without traps, as high quality recordings of all species were possible as bats approached the playback speakers. This would be additional the primary method of transect/area search. However, lures may not be sufficiently widely available for them to be part of a standardised survey and the work would need to be approved and licenced. There are other concerns with lures, see Discussion.

Use of lure during spot counts on transects

Playback of lure calls during transects was trialled during the 2012 season. Bats were observed to respond to the onset of the lure on only three occasions out of a total of 72 spot checks (responses by *M. nattereri*, *P. pygmaeus*, and *R. hipposideros*). The response of bats appears to be highly situation and time dependent. The static lure playback over the course of several hours, as used in other trials (and similar to that used in the Bechstein's Bat Project), is a more effective method of surveying using an acoustic lure.

The effects of time and environmental conditions on lure effectiveness

Responses to lure playback were often encountered only after several hours of surveying, after many conventional surveys would already have ended (Fig. 8). One possible explanation is that bats were responding post-foraging, as appear to be the case in the BCT Bechstein's bat survey. This has practical implications, since it suggests that the best use of lures will be made only late in the night.

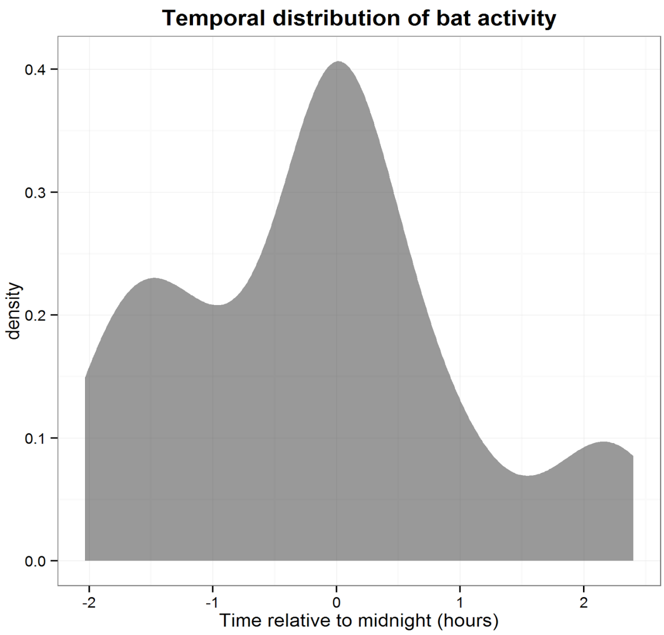

Fig. 8. Density plot showing levels of nightly acoustic bat activity relative to midnight in June/July (sunset varied by ca. 10 mins over the period). The plot shows the smoothed distribution of activity as a probability density function with unit area under the curve. The y-axis indicates relative proportion of total activity.

Evidence from the Bechstein's Bat Project also indicates that weather influences the effectiveness of acoustic lure playback (BCT 2012), and the generally low response rate of bats encountered during this 2012 season may be attributed to the unusually wet summer. The results of the 2012 field trials must therefore be considered in light of this.

Practical considerations

It was not possible to acoustically isolate the bat detector completely from the lure speaker, which would have eliminated recording of the lure calls. However, it was possible to position the equipment to minimise the crosstalk between lure and detector, and the call extraction software was modified to prevent accidental triggering and extraction of lure calls. Detailed guidelines would be required for this setup to be replicated by other surveyors and it would not be suitable for inexperienced surveyors.

5. Discussion

This section covers some issues not discussed in the main text, which we wanted to keep short and focused.

Long term monitoring and changing technology

Since all equipment ultimately fails or becomes obsolete care should be taken when embarking upon long term monitoring that protocols and analysis can handle the introduction of new methods and the obsolescence of older technology. This applies to bat detectors, analysis software and lures. Technological advances can greatly benefit species monitoring by making more effective and affordable equipment available, but like-for-like replacement is rarely possible. This is especially relevant for niche equipment that is made by a single manufacturer. Preparing for equipment change at the design stage means surveys can initially be carried out with equipment that is currently readily available, but migration to alternatives can occur as they become available. The overlapping use of both old and new technology in monitoring allows direct comparison to help the transition.

Robustness to changes in methods can be achieved by conducting replicate surveys and using generalised linear mixed models (GLMM), as in the occupancy analysis framework, to account for the effect of equipment on detection probability by including it as a covariate. In this scenario the overall efficiency of surveys may change over time as equipment is replaced, but if the data are modelled using equipment as a covariate, results should not be biased. The consistency of using the same equipment is warranted and recommended in a short-term study, but is not a realistic aim in long-term monitoring.

Capture and lure considerations

Capture rates were low, with and without the lure in both years of this study. This could be put down to the very wet summer weather of 2012. Low rates are to be expected in many situations, which is why acoustic lures are used. However, the effectiveness of acoustic lures is variable and as yet there is little published data illustrating their effectiveness or evaluating when, where and under what circumstances they work best. Brown long-eared and Natterer's bats were caught on a high proportion of nights during the BCT Bechstein's bat Project. We caught small numbers of both in this study. We have no explanation of this, but we are finding differences in the regional abundances of some species (e.g. Bellamy et al. 2012a, 2012b, 2013).

It is possible that the unique 'twiddler' attachment for the Sussex Autobat may be a factor in luring bats not only into the vicinity of traps but directly into contact with them, but again there is no published evidence to indicate that they are better than alternative lures. Both the Sussex Autobat and its twiddler are now difficult to obtain, but perhaps the principle of the twiddler, a device to constantly reflect the ultrasound from the speaker in different directions, is worth exploring further.

We failed to find a simple and repeatable method of reliably isolating a bat detector from a lure during playback. This means the presence of lure calls is unavoidable in recordings made using this method. We had some success in automating the extraction of non-lure calls only, based on a high frequency content method. Whilst this approach showed some promise, it required fine-tuning for each night of data collection. As such it would be difficult to standardise across multiple surveyors and is not suitable for a long-term monitoring study. There is scope for specifically training classification models to discriminate between known lure recordings and novel bat calls, but this proved to beyond the scope of this project. We are unaware of any studies testing for bias in bats sampled using lure and non-lure methods (and note that such a test would be non-trivial to conduct), which means inference from lure based methods in a long-term monitoring study would rely heavily on untested assumptions. We do not recommend lure use given our present poor understanding of how they work.

Capture rate could have been increased by using mist nets, perhaps in combination with harp traps. However, mist nets are not suitable for most volunteer surveyors due to the high level of skill required to safely and effectively extract captured bats.

Transect protocol flexibility

We found that survey protocol was not critical in detecting presence, probably because the major source of variation is spatial and temporal heterogeneity in bat activity, not surveyor activity. Transect protocols can therefore have some flexibility to adjust to site conditions, without rigid requirements such as a fixed distance or walking speed, as long as survey areas within sites are broadly similar in size. However, it would be advisable to use the same protocol consistently at any one site. However, such flexibility may be confusing for volunteers and make the development of training resources harder.

Random versus structured sampling

Survey effort (sites*replicates) is limited by available resources – primarily funding, surveyors, and equipment, but in bad summers weather may also be a factor. Whilst the number of sites that a species occupies in the *landscape* cannot be controlled by the study design, the number of sites occupied in the *sample* can to some degree. To illustrate, if a species is present in approximately half of all woodlands, in a study where survey sites are selected by simple random sampling the species will be absent from approximately half of all sites. This leads to an inefficient monitoring study as unless rapid colonisation is anticipated, useful data are only collected from a small proportion of study sites. This is especially problematic for rare species, as the likelihood of the species being absent from *all* survey sites increases. Stratified and cluster sampling designs alleviate this problem by incorporating *a priori* information on, for example, habitat characteristics or species distribution, during the site selection process. However, the optimum survey design for e.g. *M. nattereri* (widespread) and *B. barbastellus* (restricted range) will be different, which presents significant difficulties for a multi-species monitoring study.

There are, however, inherent dangers in selecting sites based on knowledge of species' preferences. The first is that this knowledge may be imperfect and important sites may be missed. Another danger is that selection may be appropriate and only the best sites may be surveyed. If a species is under pressure and declining, signs of such a decline may reveal themselves last in these optimal sites, long after significant declines have occurred in sub-optimal locations. Early detection of declining populations may be best detected in sub-optimal sites. There is no one solution to these problems, but some form of stratified sampling is likely to be the most effective for multi-species, long-term monitoring.

Large-scale studies and automation

Acoustic monitoring offers a means to generate species presence data from sites in a non-invasive manner. Since detectors can be carried by surveyors who have only minimal training, or left to gather data remotely, acoustic survey methods scale up much better than manual capture surveys. The automated analysis software we have developed reliably detects calls under real-world conditions typical of transect field recordings, capturing > 90% of useful bat calls. This process can be done manually by the well-trained expert, but is so time-consuming that its manual application is limited to small scale studies. In contrast, automated analysis can be left to run unattended. Detected calls can be assigned to a range of species with high classification accuracy. Classifier decision thresholds can also be post-processed, and adjusted to control the ratio of false positives (incorrect species assignment) to false negatives (missed species). A threshold higher than zero increases precision (reduces the chances of misclassification), at the expense of reduced recall (increasing numbers of recordings left unclassified), although the rate of false positives is low using the default threshold of zero. It is important to decide on appropriate thresholds early in project design and analysis, but if data are stored appropriately, it is never too late to go back and change them.

Resource issues

Unlike the heterodyne bat detectors used in some volunteer survey studies, the higher-end time expansion and direct sampling detectors suitable for automated analysis are not commonly owned by amateur enthusiasts. However, traps and lures are also rarely held by amateurs, and suitable detectors are no more expensive than harp traps and lures. The problem of equipment is therefore shared by both acoustic and survey methods. The running costs of a long-term monitoring study may be lowered by using volunteer surveyors, but finding funding for equipment may be a prerequisite for successful launching of a large scale programme. Given that the timescale to generate useful long-term monitoring data is typically 5-10 years minimum then thought must be given to maintenance and replacement. The development of the pc-tablet/Pettersson M500 microphone combination, and similar equipment from other manufacturers, does appear to have brought costs down very significantly, but these have not been tested in this study. As discussed above, technological advance is a double-edged sword: it can make survey more effective and cost-effective, but raises problems in standardisation.

Survey objectives and interpreting trends

There are many reasons to monitor, but to be successful a long-term monitoring study should have explicit and well-defined objectives (Yoccoz *et al.* 2001). Monitoring to detect declines does nothing to provide insight into the causes of the decline (Nichols & Williams 2006), but appropriate meta-data, e.g. weather and habitat, may help to gain this insight. Moreover, if monitoring results are intended to be useful to natural resource managers, they should be involved in defining the study objectives (Gitzen & Millspaugh 2012). Occupancy analysis can be used to estimate colonisation and extinction rates, and by jointly modelling habitat change, potentially inform conservation actions (e.g. Falke *et al.* 2012). However, as bats are mobile and have relatively large home ranges for their size, woodland surveys are typically sampling a super-population. Apparent colonisation or extinction at the site level could reflect habitat changes extrinsic to the site, e.g. commuting routes. As such, habitat modelling must consider the wider landscape.

Initial surveys and site inventory/assessment

A further consideration is survey effort. Our surveys were of a fixed length and duration regardless of woodland site, to facilitate the direct comparison of methods. However, this approach does not generate data at the site/patch scale, e.g. for SSSI assessment. For example, in a small woodland a fixed length transect route will sample a larger percentage of the available area than the same length transect in a larger, more complex site. In this situation the small woodland will effectively be 'oversampled' relative to the larger site, and therefore more likely to produce an accurate estimate of species richness. This is an important consideration when making inferences regarding bat-habitat relationships, compiling site inventories or undertaking, for example, SSSI assessment. Watson (2003) devised the 'standardized search' as a means of ensuring sample completeness is consistent across sites of differing sizes. The standardized search employs a stopping criterion, whereby sites are repeatedly sampled using the fixed area search (or alternatively transects) until species richness has reached a plateau. This approach means that site survey effort can be variable, but species richness estimates will be equivalently accurate. Our methods can be utilised in this way, by generating species accumulation curves as shown in Fig. 7.

Abundance or Occupancy?

Using the protocols developed, reliable estimates of occupancy at large numbers of individual sites is feasible with a committed volunteer base. With sufficient sites, regional and national trends can be determined with some accuracy.

Collecting long-term monitoring data on the real abundance of woodland bats is simply not feasible, as the mark-recapture techniques necessary to achieve this are extremely labour intensive, and therefore prohibitively costly to implement at large scales. Even obtaining stable estimates of abundance indices (e.g. counts of bats caught or recorded) is complicated by spatial and temporal variation in bat activity within and among nights (e.g. Adams 2013). Broders (2003) found that >14 nights of acoustic sampling were required to get stable estimates of bat activity. More importantly, abundance indices have been criticised, as the relationship between the index and actual population size is frequently unknown, and therefore conclusions based on their estimates may be unfounded and not scientifically defensible (Stanley & Royle 2005). Given this situation, it is difficult to recommend the use of counts, either numbers of bats caught or recordings made, as a suitable state variable in monitoring woodland bats.

In contrast, proportion of area occupied (occupancy), is more directly interpretable. In addition, at the appropriate scale, abundance and occupancy should be positively correlated (MacKenzie & Nichols 2004), and the sum of occurrences represents a "population size" of occupied spatial units (Kery & Schaub 2011). Occupancy is used as a state variable in the Swiss biodiversity monitoring programme BDM (Weber *et al.* 2004; www.biodiversitymonitoring.ch), and is one of the most important and widely used criteria by which IUCN Red list status is assessed (www.iucnredlist.org/about/red-list-overview#redlist_criteria). Although it is true that a decline in abundance may not be detected by a monitoring study applying an occupancy approach, some changes in range and occupancy may not be reflected by changes in abundance (MacKenzie & Nichols 2004). Given the difficulties of measuring abundance we believe an occupancy approach is the best for long term monitoring.

Difficult species: quiet and rare

In this study we found that Bechstein's bat was often difficult to detect because of its rarity and quiet echolocation calls. Only by implementing acoustic surveys on a large scale will we know how effective they will be for monitoring this species. Although the brown long-eared bat is also quiet, it is sufficiently abundant that it is detected frequently. The methods used in BCT Bechstein's Bat Project (capture techniques using an acoustic lure and harp trap) may possibly be the best way to generate sufficient data on *M. bechsteinii* for long-term monitoring, particularly if the protocol includes three or more surveys per site so that heterogeneous detection can be accounted for when analysing the resulting data, e.g. when creating habitat suitability models. If possible, simultaneous acoustic surveys would be carried out to cover all species.

Remote monitoring

One possible solution to the difficulties of recruiting a volunteer force is to investigate the potential for remote monitoring of managed woodlands, such as those owned and/or managed by the National Trust, Wildlife Trusts, Forestry Commission, Woodland Trust and the RSPB. Monitoring applied within a resource management framework can provide information directly relevant to managers, to increase knowledge and inform future management actions (e.g. Nichols & Williams 2006). Although this reduces the number of volunteer hours and the commitment of individual volunteers, funds must be found for the bat loggers (e.g. Pettersson D500X or Elekon Batlogger), but these could perhaps be raised through partnerships. Loggers can be left securely (e.g. tree mounted) to gather data of fine temporal resolution. Devices can now run unattended continuously for >2 weeks before data are retrieved, and batteries can be recharged if further monitoring is required. A species detected on average in only 20% of nightly surveys has a more than 95% probability of being detected after a fortnight of monitoring. Remote monitoring makes efficient use of equipment and volunteer time, and quantity of data is not a concern from an analysis viewpoint as it can largely be automated. However, as the quantity of data increases so too does the burden of data storage and management.

Future development

We will continue to develop the software and test it with Pettersson and other detectors beyond the end of this project.

6. Potential development of woodland monitoring based on the Woodland Bat Survey and Monitoring Protocol

A key output of this project is to complete an assessment of how the proposed protocols could be incorporated into the NBMP including likely resource implications. This assessment is provided by Bat Conservation Trust based on the information provided in the previous sections of this report and Appendix C (Woodland Bat Survey and Monitoring Protocol).

The acoustic transect methods proposed in Woodland Bat Survey and Monitoring Protocol (Appendix C) could provide a replacement for the existing NBMP bat detector transect survey in woodlands, the Woodland Survey (http://www.bats.org.uk/pages/woodland_survey.html). The current NBMP Woodland Survey, targeted towards identifying the presence of barbastelles, requires volunteers to establish and walk a transect in a woodland on three occasions between July and early September and record bat activity using frequency division bat detectors. Analysis of recordings is mainly completed by BCT staff using sound analysis software (Pettersson BatSound) using manual species identification. It is relatively time-consuming, as the entire duration of each transect recording needs to be viewed to determine the presence of bat calls, followed by measurement and analysis to identify calls to species. Barbastelle calls can be quite readily recognised from recordings made using frequency division bat detectors, however other species such as the *Myotis* group are difficult to identify to species level with any certainty. The range of woodland bat species that can be monitored using the current approach is therefore limited. At the present time, this survey is funded by Natural England and is used successfully to monitor annual presence of barbastelles at Special Areas for Conservation (SACs) that have been designated for this species in England.

The potential advantages of the new protocol described in this project include:

- Improved species identification due to the use of direct sampling and/or time expansion bat detectors to ensure high quality recordings and use of automated sound analysis methods
- Increased efficiency of processing recordings due to the development of free software enabling rapid analysis and automated species identification
- Additional records for species of woodland bats for which it is presently difficult to confirm presence through existing NBMP surveys

However, there are also potential barriers to the wide-scale application of the new Woodland Bat Survey and Monitoring Protocol due to the models of detector chosen for use in the survey and the likely costs associated with providing volunteers with the equipment needed to take part in the surveys.

The following areas would need to be addressed in detail for the proposed new Woodland Bat Survey and Monitoring Protocol to be integrated into the NBMP to replace the existing Woodland Survey:

- Assessment of the outputs of the Woodland Bat Survey and Monitoring Protocol and how integration of this new survey into the NBMP would enhance the programme.

- A costed plan to provide volunteers with the equipment needed to carry out surveys; and funding to purchase sufficient equipment to meet the survey coverage requirements set out in this report.
- Identification of the time and resources required (and therefore cost) for NBMP staff to set up and administer the new survey; for example this would include staff time to develop and deliver training resources, staff time to manage the survey, volunteers and data.
- Identification of database and data storage requirements to ensure that survey results can be easily submitted by volunteers and managed by NBMP staff.
- Identification of the staffing resources required to allow interpretation and analysis of the data collected by the survey.

Species coverage of the Woodland Bat Survey and Monitoring Protocol

Gaps in coverage of woodland bat species by the current National Bat Monitoring Programme are as follows:

- *M. mystacinus*: no data are collected on this species during summer, surveillance of activity, particularly in woodland habitats, is needed. It is monitored in winter through the Hibernation Survey but is not distinguished from Brandt's bat for population trend analysis.
- *M. brandtii*: no data are collected on this species during summer, surveillance of activity, particularly in woodland habitats, is needed. It is monitored in winter through the Hibernation Survey but is not distinguished from whiskered bat for population trend analysis.
- *M. alcathoe*: no current monitoring through NBMP, however it has only been confirmed in a small number of locations in the UK to date (Jan et al. 2010) and its distribution may be very localised.
- *M. bechsteinii*: BCT's Bechstein's Bat Survey and follow-on habitat suitability modelling has recently determined the distribution of this species in England, however no ongoing population monitoring is in place and is needed.
- *B. barbastellus*: presence of barbastelle is monitored using current Woodland Survey (see above for details), however no current population monitoring is in place and is needed.

Changes in populations of other woodland bat species such as *P. auritus, M. nattereri* and species that use woodland but are not woodland specialists, for example *Pipistrellus* and *M. daubentonii*, are monitored through NBMP surveys including Hibernation Survey, Roost Counts and bat detector surveys. The current surveillance approaches allow population trends to be produced for each of these species from two survey types. However, additional data on changes in occupancy assessed from summer surveys in woodland habitats would complement the existing NBMP, by providing comparison datasets for these species.

The results described in previous sections suggest that the new Woodland Bat Survey and Monitoring Protocol is suitable for monitoring *B. barbastellus*, *M. mystacinus/brandtii*, *M. nattereri*, *P. auritus* and *R. hipposideros*, with details on the detection probabilities, occupancy and estimated number of woodland sites required to detect change for these species. Although all extra information on changes in populations of all species in woodland habitats would be useful, of these species, only *B. barbastellus* would be a new addition to the list of species currently monitored by the NBMP to give population trends.

To maximise the benefit to the existing monitoring programme of the addition of the new Woodland Bat Survey, the survey should:

- Provide full identification to species for woodland bats including separate data for *M. mystacinus* and *M. brandtii*; and
- Estimate the probability of detection and number of surveillance sites required for targeting *M. bechsteinii* (within its known range) in the survey.

Equipment

The main and most costly piece of equipment required for the woodland bat survey proposed here is the bat detector. The survey protocol recommends the Pettersson D500x. This currently retails at £1600-1800 per unit (including VAT). The costs of the additional equipment required alongside each detector unit would also need to be allowed for: GPS unit, thermometer and anemometer, data cards (plus replacements) and batteries. This equipment is not currently held by the NBMP and is not widely owned by NBMP volunteers or bat groups. Purchase of sufficient sets of equipment to ensure that the required number of woodlands could be surveyed by volunteers in each year would therefore be necessary for the survey to be implemented. We recommend that the survey follows the model of BCT's Bechstein's Bat Project, in which bat groups were engaged in the project, agreements were drawn up between BCT and the bat groups to set out the surveys to be completed and equipment was loaned to the group for an agreed period of time. Surveys were then organised within the bat group at a local level via a bat group co-ordinator and data returned to BCT for analysis.

The number of sets of equipment required to reach the recommended woodland coverage will depend on how the survey is organised and on how many woodlands can reasonably be surveyed in a single summer season by a group of volunteers sharing one set of equipment. The new Woodland Bat Survey protocol proposes that at least 3 repeat surveys would be needed at each woodland site in a three month period between June and August to determine species presence. From the current study it is not possible to accurately estimate the number of woodlands that could be surveyed by volunteers during the survey period (June to August) using one set of equipment as that has not yet been assessed. We recommend a pilot survey in the first instance to trial the approach of co-ordinating the survey through working with bat groups and to provide an initial assessment of equipment logistics.

Administration

We recommend that the survey would be best implemented as follows:

- BCT would engage bat groups who are interested in taking part in the new Woodland Bat Survey
- The bat groups involved nominate one or more co-ordinators to organise surveys in their area
- BCT would provide training resources and one or more sets of equipment
- The group co-ordinators organise woodland selection, land ownership arrangements, setting up of transects and sharing of equipment by volunteers

- Volunteers complete surveys throughout the survey period and return results to co-ordinators
- Bat group co-ordinators organise survey data from their group and remain point of contact with BCT
- BCT collate survey data and sound analysis outputs and complete analysis of results across all groups

Surveys co-ordinated at a group level could, depending on local equipment availability, be supplemented with surveys carried out by individual volunteers who already own the required equipment (for example a Pettersson D-240x bat detector and recorder).

Centralised resources that would be required to administrate the survey would include:

- BCT staff-time to develop training materials for bat groups and individuals and to deliver training workshops to groups of bat group co-ordinators
- Resources to allow easy transfer of data files between volunteer surveyors and a central data storage location at BCT. This could include a web portal to allow transfer of sound files between bat group co-ordinators or individual volunteers and BCT; and a database to store and manage survey data returned to BCT.
- BCT staff-time to administer the survey and provide support to bat groups and individual surveyors, for example to answer queries on survey methods or provide advice on site selection,
- BCT staff-time to compile the outputs from analysis of recordings, to map sites and report on survey findings

In addition to the Woodland Bat Survey and Monitoring Protocol presented in this report (Appendix C) further training resources would be required to support volunteers in selection of woodland sites, design of transects, completing transects, downloading and analysing data and transferring data to BCT. Similar formats of training resources as are in place for existing NBMP surveys are recommended: these include combinations of online training materials, training videos and face-to- face training workshops (for bat group co-ordinators for example) to ensure that the survey methods are implemented and equipment used correctly.

Data management

The survey methods proposed have the potential to generate large amounts of data. Maps, sound files and outputs from the sound analysis software would be generated from each survey in each woodland. For a pilot survey in a testing stage, this could be managed with minimal database development. If a larger scale survey were to be implemented in the future and incorporated into the NBMP, additional development of a database and online portal for uploading data files and recording sites would be required to allow efficient administration of the survey.

Pilot survey

The scale of resources (staff time, equipment, data storage and management) required to set up and continue to implement a survey in later years would depend on the scale of survey effort and coverage planned. It would be prudent to follow this project with a testing stage in the first instance to develop and implement a pilot survey, as suggested in the original project proposal, based and building on the Woodland Bat Survey and Monitoring Protocol. Detailed information is needed on the ease of following the Woodland Bat Survey and Monitoring Protocol for volunteers and the number of woodlands that in practice can be surveyed by volunteers in a season per set of equipment. A pilot survey would allow this information to be gathered and to inform future development of the survey on a larger scale. Feedback on the ease of use of the sound analysis software and further analysis on detection rates of species would also be gathered during a pilot survey to help inform ongoing development and improvement of the survey methods.

We recommend a pilot survey of one year initially, engaging and working with 3-6 bat groups in one region in England for example. We propose the following would be carried out as part of the pilot:

- BCT to engage 3-6 bat groups and ask each group to identify and nominate a survey co-ordinator
- BCT to provide one or more sets of equipment to each co-ordinator
- BCT to develop and deliver an initial training workshop for bat group co-ordinators to outline the aims and approaches of the survey based on the Woodland Bat Survey and Monitoring Protocol and to provide guidance on woodland selection
- Bat groups to identify and select woodlands for survey (organised by the co-ordinator)
- BCT to develop and deliver a further training workshop for bat group co-ordinators on the survey methods and use of equipment
- Bat group volunteers to complete woodland surveys (organised by the co-ordinator) and return data to BCT
- BCT to organise and store survey data, to report on results and to collate feedback on survey methods and software from volunteers

A fully costed proposal and timetable would need to be developed for a pilot survey, based on previous knowledge of pilot and administration of existing surveys through the NBMP. A pilot could be implemented in 2015.

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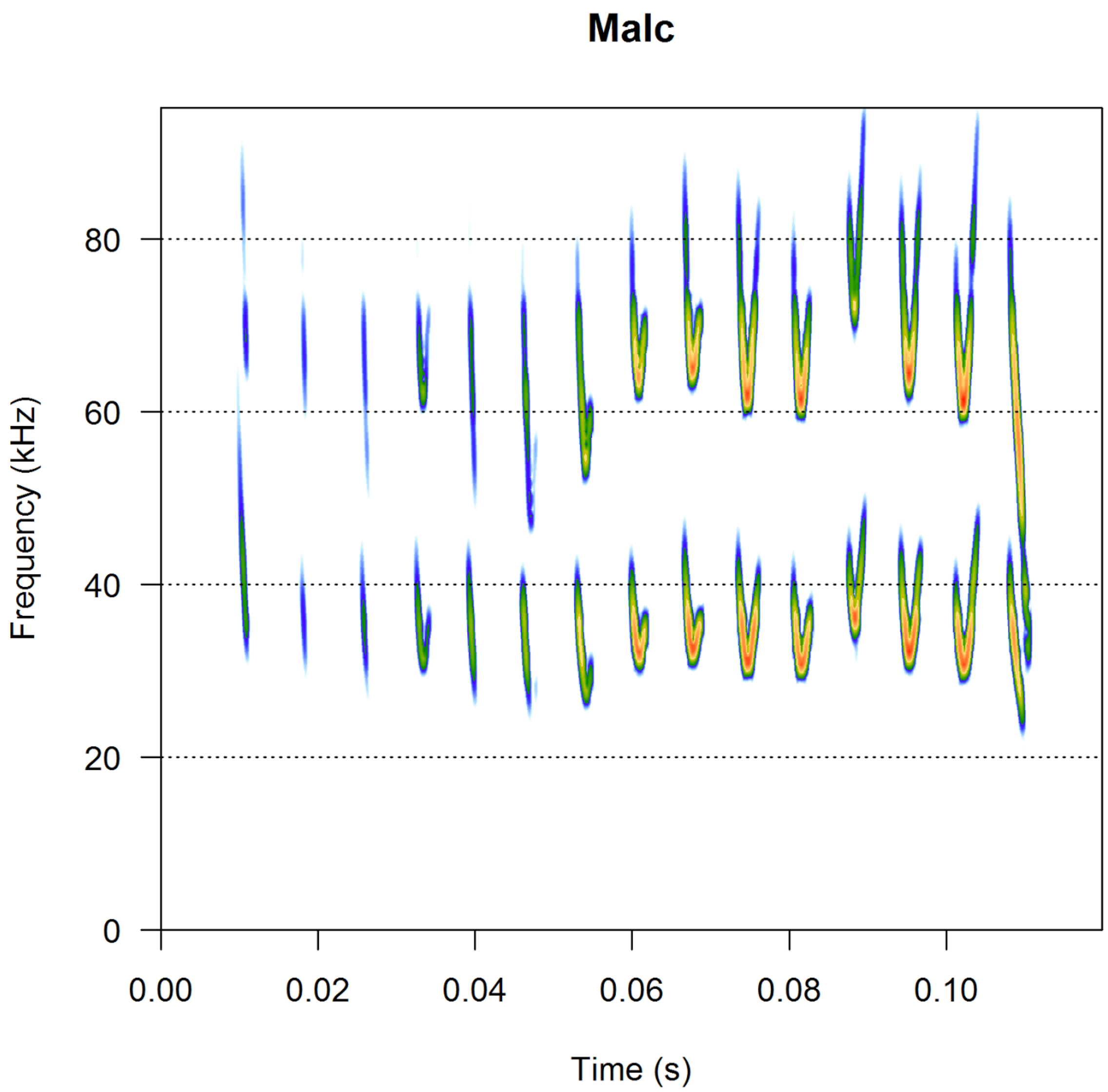
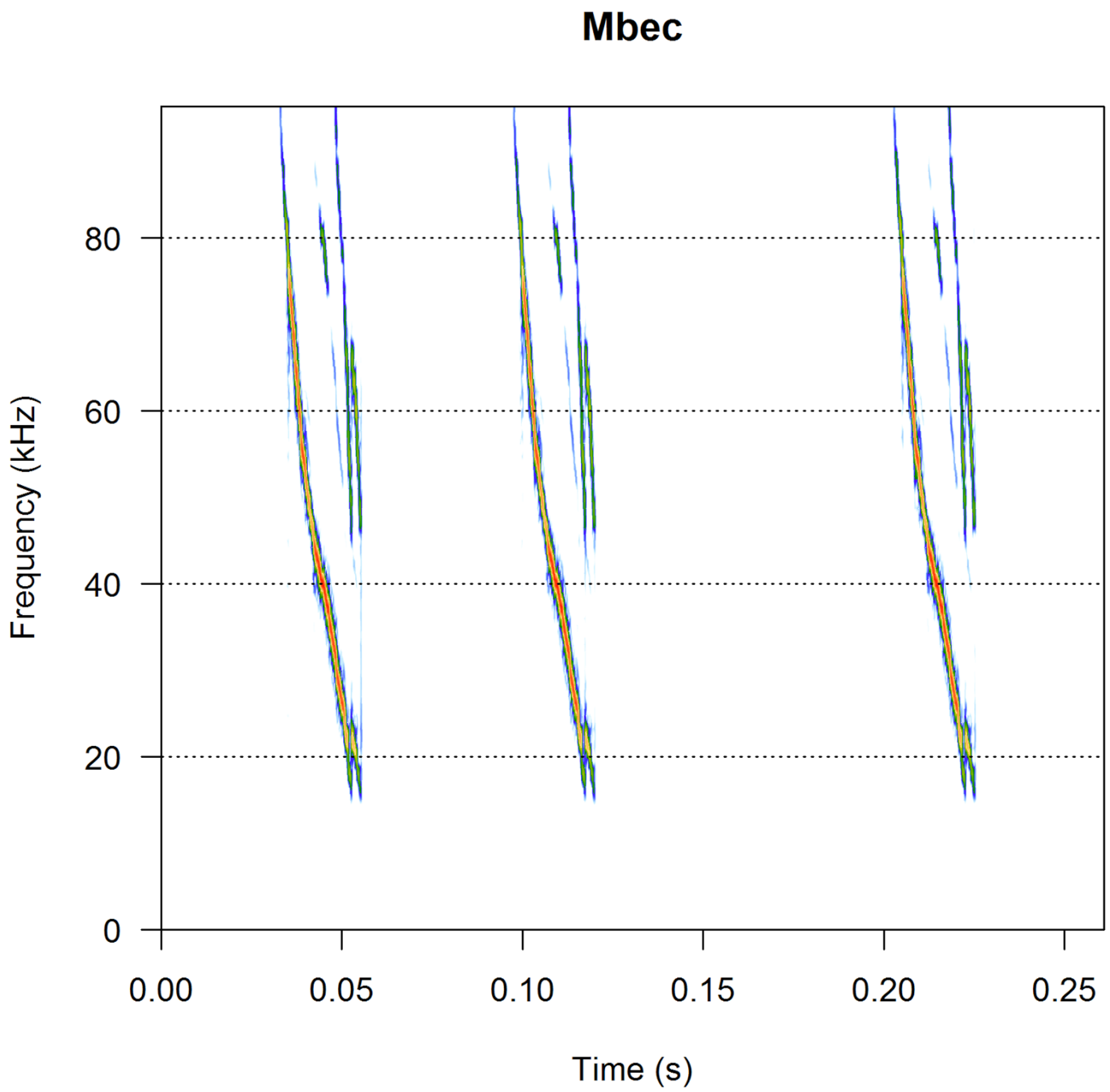
9. APPENDICES

Appendix A - Lure calls

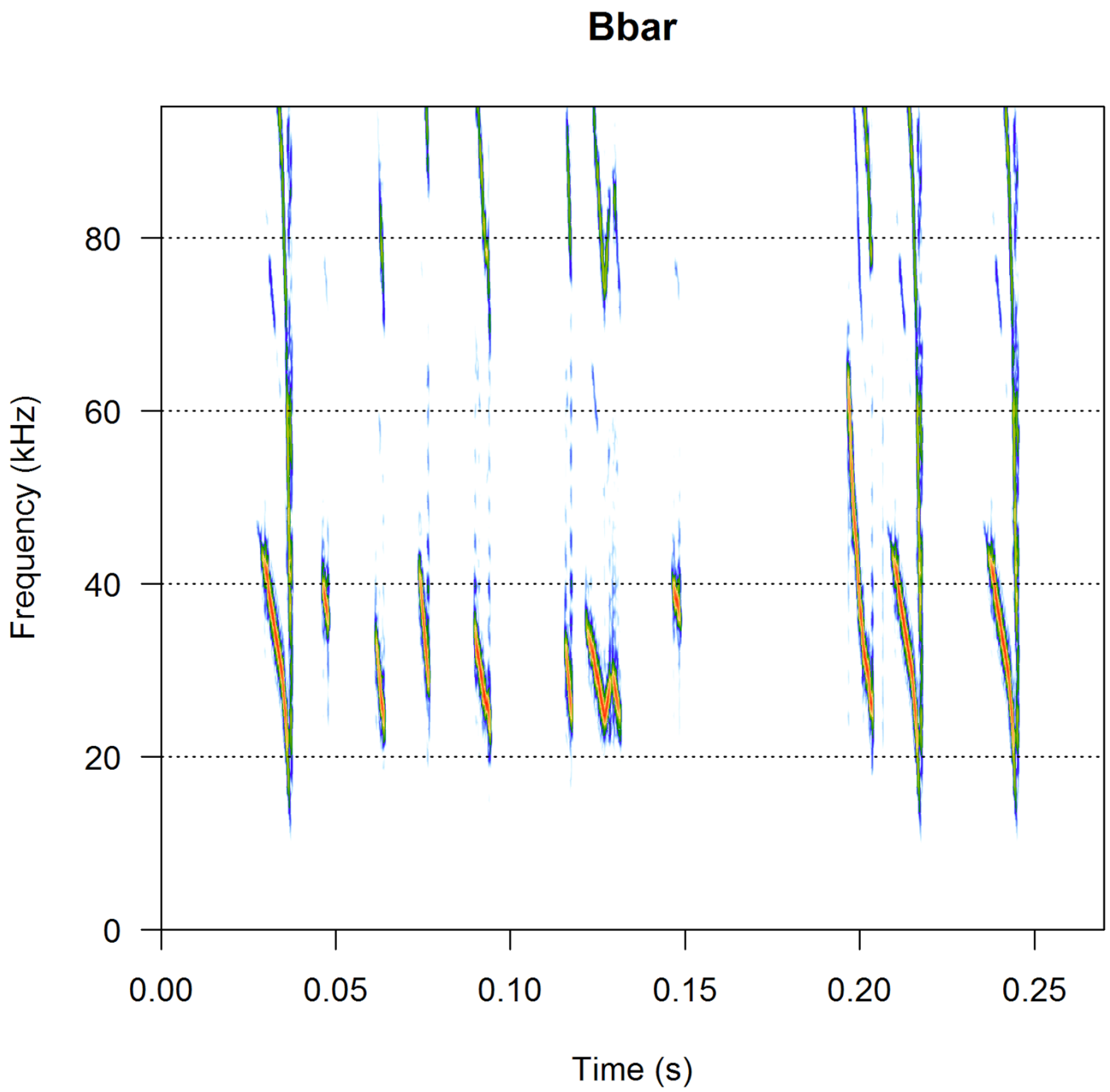
Spectrogram (frequency versus time plot) of a distress call emitted by an individual *Myotis alcathoe* caught in Sussex and recorded prior to hand release. Warmer colours in the spectrogram indicate regions of higher amplitude.



Spectrogram (frequency versus time plot) of a synthesised social call emitted by an individual *Myotis bechsteinii* as used in the Sussex auto bat. Warmer colours in the spectrogram indicate regions of higher amplitude.



Spectrogram (frequency versus time plot) of a segment of a synthesised social call emitted by an individual *Barbastella barbastellus* as used in the Sussex auto bat. Warmer colours in the spectrogram indicate regions of higher amplitude.



Appendix B

Development and evaluation of early stage software

The original software developed at the Univesity of Leeds converts audio recordings into spectrograms (time-frequency representations), which are segmented into regions of interest using simple thresholding rules. Calls are then characterised by their frequency-time course, extracted by finding the maximum pixel intensity in each row of the spectrogram. Classification is carried out by support vector machine (SVM), with results presented on a call by call basis with associated spectrogram segment.

The software we developed prior to the start of the project was distributed for evaluation. As we expected, the software performed well with recordings made from Pettersson detectors since it was developed using them (Table 1a-f).

Table 1a: Summary of echolocation call library. **1b:** Summary of *Myotis* echolocation call library.

	Seqs	Calls
Barbastella	62	186
Eptesicus	13	330
Myotis	300	3207
Nyctalus	27	502
Pipistrellus	67	782
Plecotus	80	270
Rhinolophus	16	93

Abb.	Species	Seqs	Calls
M. alc	*Myotis alcathoe*	23	309
M. bec	*Myotis bechsteinii*	16	191
M. bra./mys.	*Myotis brandtii/mystacinus*	88	1221
M. dau	*Myotis daubentonii*	96	775
M. nat	*Myotis nattereri*	73	712

Table 1c: Genus sequence classification. Confusion matrix showing the classification of sequences to genus level using power spectra features and a random forest classifier. Positive predictive power (PPP) indicates the percentage of calls predicted to be from a group that were actually from that group. Overall accuracy was 98.4%, with an average PPP over all classes of 99.2%.

		Predicted class							
		Barbastella	*Eptesicus*	*Myotis*	*Nyctalus*	*Pipistrellus*	*Plecotus*	*Rhinolophus*	unclassed
Actual class	*Barbastella*	**35**	0	0	0	0	3	0	2
	Eptesicus	0	**12**	0	0	0	0	0	1
	Myotis	0	0	**296**	0	0	0	0	0
	Nyctalus	0	0	0	**26**	0	0	0	0
	Pipistrellus	0	0	1	0	**66**	0	0	0
	Plecotus	0	0	0	0	0	**54**	0	1
	Rhinolophus	0	0	0	0	0	0	**16**	0
	PPP	100.0	100.0	99.7	100.0	100.0	94.7	100.0	

Table 1d: Genus call classification. Confusion matrix showing the classification of individual calls to genus level using power spectra features and a random forest classifier. Positive predictive power (PPP) indicates the percentage of calls predicted to be from a group that were actually of that group. Overall accuracy was 97.6%, with an average PPP over all classes of 95.6%.

		Predicted class						
		Barbastella	*Eptesicus*	*Myotis*	*Nyctalus*	*Pipistrellus*	*Plecotus*	*Rhinolophus*
Actual class	*Barbastella*	**174**	3	4	0	2	3	0
	Eptesicus	1	**293**	0	36	0	0	0
	Myotis	2	0	**3196**	0	9	0	0
	Nyctalus	0	38	0	**455**	0	9	0
	Pipistrellus	2	0	10	0	**770**	0	0
	Plecotus	2	3	0	3	0	**262**	0
	Rhinolophus	0	0	0	0	0	0	**93**
	PPP	96.1	86.9	99.6	92.1	98.6	95.6	100.0

Table 1e: *Myotis* sequence classification. Confusion matrix showing the classification of *Myotis* sequences using power spectra features and a random forest classifier. Positive predictive power (PPP) indicates the percentage of calls predicted to be from a group that were actually from that group. Overall accuracy was 95.9%, with an average PPP over all classes of 97.1%.

		Predicted class					
		M.alc	*M. bra./mys.*	*M.bec*	*M.dau*	*M.nat*	unclassed
Actual class	*M. alc*	**23**	0	0	0	0	0
	M. bra./mys.	1	**86**	0	0	0	1
	M.bec	1	6	**8**	0	0	1
	M.dau	0	0	0	**94**	0	2
	M.nat	0	0	0	0	**73**	0
	PPP	92.0	93.5	100.0	100.0	100.0	

Table 1f: *Myotis* call classification. Confusion matrix showing the classification of individual *Myotis* calls using power spectra features and a random forest classifier. Positive predictive power (PPP) indicates the percentage of calls predicted to be from a group that were actually from that group. Overall accuracy was 93.1%, with an average PPP over all classes of 92.5%.

		Predicted class				
		M.alc	*M.bra./mys.*	*M.bec*	*M.dau*	*M.nat*
Actual class	*M.alc*	**285**	19	4	1	0
	M.bra./mys.	16	**1169**	9	23	4
	M.bec	14	84	**90**	3	0
	M.dau	0	39	0	**735**	0
	M.nat	0	5	0	0	**707**
	PPP	90.5	88.8	87.4	96.5	99.4

As expected, work was needed to improve software performance on calls recorded using some other systems. Time-expansion detectors include settings for variable sampling times and trigger thresholds, with different settings influencing the resulting recordings. To investigate these effects we wrote a script for converting continuous D500X recordings into time-expansion recordings, with settings to emulate the behaviour of typical hardware detectors. This facilitated processing continuous recordings to simulate a time-expansion recording, enabling the effect of detector settings to be directly analysed in terms of numbers and quality of calls. This analysis is described in the previous section.

Two people have been particularly helpful in assessing software performance on calls recorded using detectors other than Pettersson models and continue to work with us:

Stuart Newson, Senior Research Ecologist with the BTO

Found the software to be user-friendly, and that it discriminated *Myotis* from EcoObs Batcorder (www.ecoobs.de) and Batbox Griffin (www.batbox.com) files with high accuracy. Table 2 summarises the results for the Batcorder. An analysis based on the consistency of classification within passes/files was capable of assigning species with a very high degree of confidence.

Both detectors use microphones similar to those in Pettersson detectors. The software processed 1,100 files in 25 min (using Sonobat/iBat, the same files took 16 hours) and performed better than the EcoObs software at *Myotis* discrimination. The software was poor at discriminating species in files recorded on the Wildlife Acoustics SM2. At the time the microphone in the detector had a poor response curve. This has been replaced in the new SM3Bat+ model, but we have been unable to test this model. In addition, the sampling rate of Wildlife Acoustics detectors is low in some settings (192 instead of 384 kHz) and this would remain a problem if used inappropriately.

Table 2. Consistency of identifying calls within bat passes recorded on a Batcorder

Natterer's bat
In 30 files (bat passes) >99% of all calls (336/338) were assigned to Natterer's bat
In 3 additional files 70% of all calls (26/37) were assigned to Natterer's bat
Whiskered/Brandt's bat
In 26 files > 99% of all calls (433/435) were assigned to Whiskered/Brandt's bat
In 12 additional files 78% (146/187)
Daubenton's bats
In 11 files 97% of all calls (111/115) were assigned to Daubenton's bats
In 9 additional files 81% of all calls (120/149) were assigned to Daubenton's bats
In an additional 39 files Whiskered/Brandt's and Daubenton's bats could not be assigned at acceptable confidence levels.
Pipistrelles and noctule/Leiser's/serotine (NSL) were identified with near 100% accuracy.

Jon Whitehurst, BAE Chief Engineer, radar specialist (and 'amateur' bat researcher)

Jon uses an Elekon Batlogger and BatExplorer software (www.elekon.ch). He found the software processed files approximately ten times faster than BatExplorer, and that it unpicked mixed calls very well, which have to be split out manually in BatExplorer. The sampling rate of the Batlogger is an unusual 312.5 kHz, much slower than the Pettersson (500 kHz), and the microphone does not have the same characteristics. Identification of most species was good (Tables 3 and 4), but for reasons we have yet to determine Natterer's bat was not resolved well. Jon is keen to see an effective and truly open source program released, so we are exploring ways to improve its performance with this detector. It is possible that retraining the software with calls recorded on the Elekon Batlogger will give a significant improvement for many species.

Table 3. Identification of known bats from recordings made on and Elekon Batlogger

Species	Correctly identified %	Number of bats tested
Barbastelle	100	40
NSL (noctule, serotine, Leisler's)	87	129
Common pipistrelle	100	111
Soprano pipistrelle	100	34
Whiskered/Brandt's	90	52
Natterer's	9	22

Table 4. Direct identification comparison between our software and Elekon's Bat Explorer of recordings made on a randomly selected transect

Species	Bat Explorer	Our software	comments
Common pipistrelle	56	59	Not classified to species, see main text
Soprano pipistrelle	3		
Whiskered/Brandt's	11	11	
Alcathoe	2	2	
Daubenton's	1	6	No obvious explanation
Natterer's	1	1	
Bechstein's	1	1	
Barbastelle	11	13	2 type 2 calls not found by Bat Explorer detected by our software
NSL	1	2	

The BCT also evaluated the software and reported a number of difficulties with processing Pettersson D240X files, as did some of our own project students. Long continuous recordings (>20 mins) failed to load, and we experienced similar problems with shorter duration but larger file size D500X recordings (hundreds of megabytes in size). Whilst it is possible to use other programs to split recordings into smaller files, we modified the software to resolve this problem. Files of arbitrary size can now be analysed directly, but we recommend recording data in sequences of less than 20 min, to facilitate easy storage and handling.

None of the bat workers who downloaded the updated software reported difficulties in using it. We fixed minor operational bugs and identified some areas for improvement. It is clear however, that instructions for use must give very clear guidelines for rigorous identification acceptance criteria. Given the huge numbers of files that will be processed in any one study, some errors are inevitable and without rigour and common sense error levels could become unacceptable.

In summary, the early version of the software worked well with the Batcorder and the Batbox Griffin, in addition to the Pettersson models it was developed for. Problems with the Elekon Batlogger were thought to be surmountable, but we did not see an easy solution for Wildlife Acoustics detectors before changes were made to the microphones on future models.

Appendix C

Woodland Bat Survey and Monitoring Protocol: options

We see this as a template for the final protocol based on the work completed to date. It presents a range of options, all of which could be made to work, each of which needs further consideration, testing and refinement to determine which would be most suitable for wider scale surveys. The protocol can then be refined and expanded into a set of survey instructions suitable for volunteer surveyors.

AIMS

The aim of the project is to sample woodlands for bats using standardised and therefore repeatable acoustic surveys so that data from across the UK, collected by a large number of volunteers, can be compared and combined over many years. The data will initially be used to determine presence or absence of species to improve knowledge of species distributions. As data accumulate from year to year, they will be used to monitor national population trends and, depending upon the intensity and frequency of monitoring effort, regional and local trends.

Overview of survey protocol and analysis

The basic survey can take one of two forms. Geography or personal preference can dictate which you use to survey a given wood, but the same protocol must be used for all subsequent repeat surveys of that wood.

- the continuous recording of bats using direct-sampling or time-expansion bat detectors during a 90 min, slow walk (2.5-3.5 km/h) on a pre-determined path. The walk will be interrupted by six 5 min stationary spot checks, during which bats will again be recorded continuously. A GPS is used to track the walk, automatically recording position every 20 s. If laid down during day-time reconnaissance the GPS track will make night-time navigation and control of walking speed easier. It will also enable each bat pass to be located accurately on a map.
- An ‘area search’ in which you plan a similar transect, without the spot checks, but you are free to depart from the transect route to briefly ‘chase’ quiet bats that you hear, or to explore areas of woodland that are difficult to include in a transect. However, in all other respects the survey is the same – same equipment, timing, protocol.

The number of surveys required per site to reliably detect all species in a given year is species-dependent, from 1-9 (1-5 excluding the brown long-eared bat). We recommend that five surveys are carried out, with the option of fewer if all species are detected before reaching five.

DETAILED PROTOCOL

<u>Site selection, timing and route planning</u>

The aim is to survey all woodland types likely to be significant bat foraging sites: ancient woodland, other broadleaved woodland and mixed woodland with a high proportion (>30%) broadleaved cover. Coniferous woodland is used by bats, but may be given lower priority. Targeted woodlands should ideally have an area >4 ha (200 m x 200 m), but several blocks of woodland (connected or in close proximity) that in combination exceed this area and can be walked in a single survey, are acceptable. An alternative way to assess suitability: subtracting the 30 min taken to record the six 5 min spot checks, you have to be able to walk for one hour at 3 km/h around the edge and within the confines of the wood(s) without repeating any part of your route. Open and cluttered habitat must be given roughly equal attention. Again, smaller woodlands are used by bats, but may be given lower priority. Very large woodlands are best assessed by dividing them into sections, using natural features where possible, so that any one section can be covered in a single 90 min survey.

One approach would be for bat groups to identify possible woodlands for survey at county level, draw up a pool of sites that can be surveyed (i.e. they have landowner permission, suitable transects can be walked, they are safe) and select a random subset from this pool for survey.

The surveys will ideally follow paths and rides – aim to make equal use of narrow paths and broader rides and tracks. It is acceptable to walk off the path into the interior of woodland, but the route must be easy to follow safely. Do not walk any section more than once during a survey, try not to cross your path, and keep nearby sections of your route >100 m apart where possible. A circular or closed-loop survey is ideal - it makes practical sense to return to your start point - but not essential. Some surveys may have to be linear, e.g. those in narrow woods along streams. The survey should cover as many of the woodland habitats present as possible: woodland edge, wide rides, narrow paths, interior (where practical), ponds, clearings, etc.

Surveys are best done June-August inclusive. May and September may be acceptable but bat foraging activity may be lower than in other months and behaviour and use of habitat may not be typical of mid-summer. For example, swarming species travel more widely in September. Presence may therefore vary.

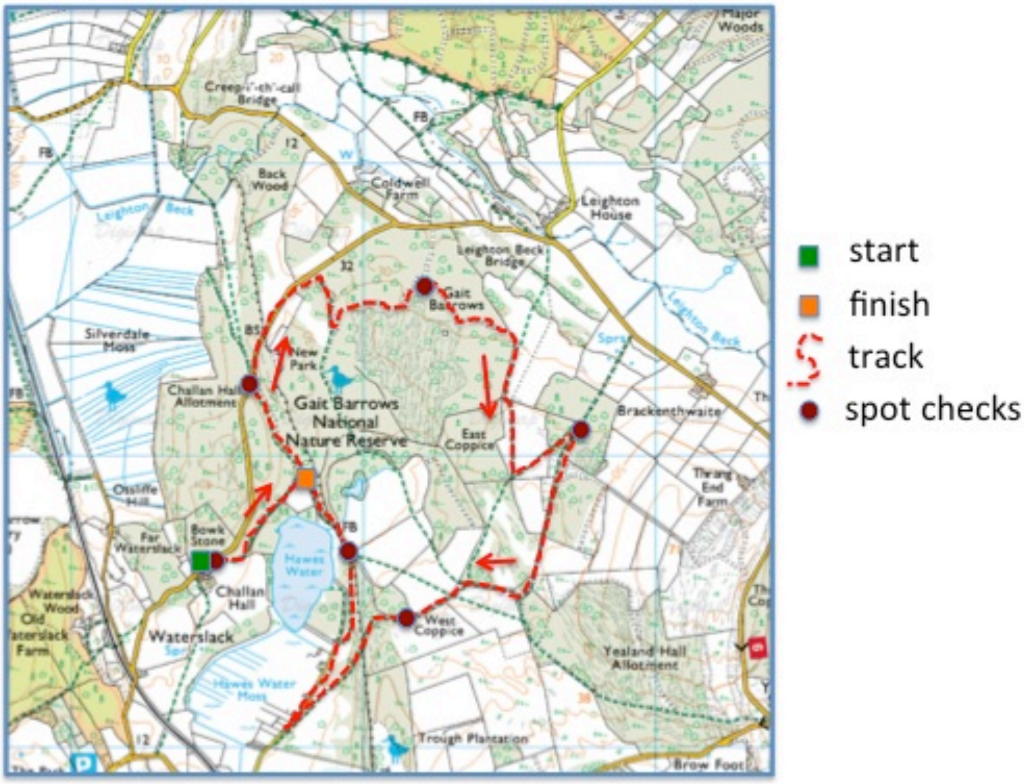


Fig. 1. Example of closed loop transect with spot checks. Crown copyright / database right 2014. Ordnance Survey / EDINA supplied service.

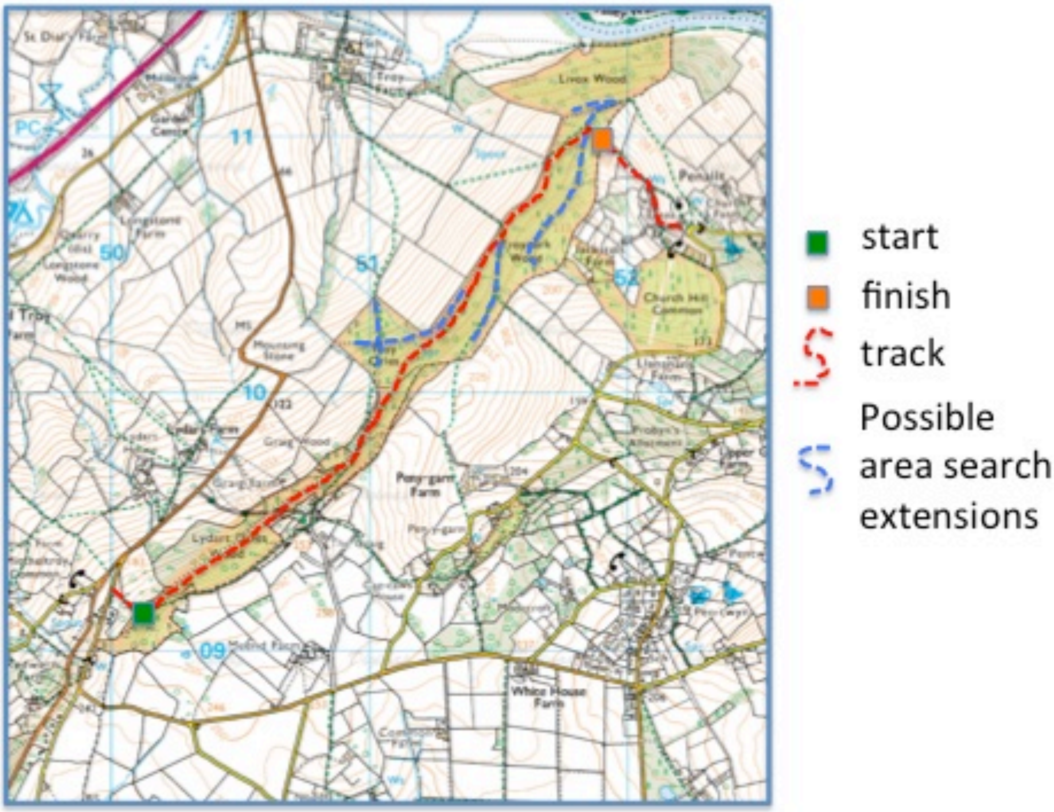


Fig. 2. Example of a linear transect demanded by the terrain and woodland shape. No spot checks, but where terrain and paths allow, there are possible area search extensions. Crown copyright / database right 2014. Ordnance Survey / EDINA supplied service.

<u>Surveyor and equipment details / Documenting woodland habitat</u>

A datasheet is provided in Microsoft Word and Excel format. An electronic copy should be returned with the sound and GPS data files.

Use of the datasheet ensures that no important information is forgotten and gives a common format for easy and accurate data compilation.

A simple assessment of the woodland habitat will be extremely useful in getting the most out of the data. Assessment should be done in daylight in the few days before or after the survey. The following information is requested on the datasheet:

- Grid Reference of approximate centre (for large scale mapping).
- Name of wood
- Name of nearest village or town, and county
- Type of wood: ancient, other broadleaved, mixed (with minimal detail)
- Dominant tree species (only those making up more than approx. 20% of the trees)
- Ground flora – poor (absent or low/thin), good (> 50% cover, dense, diverse), excellent (almost complete cover, dense, diverse, good height variation)
- Understorey – poor (<10% cover), good (10-50% cover and 2-3 dominant species), excellent (>50% cover, >3 dominant species)
- Presence of still or flowing water
- Include a Google Map/Google Earth map/photo or digital OS map showing your route.

Weather conditions

Surveys should only be done in 'good' weather: temperature at the start of the survey >10°C, wind <20 km/h, no rain. Weather conditions should be recorded at the start and end of the survey using a handheld thermometer/anemometer. If weather conditions deteriorate significantly (wind, heavy rain, temperature below 7°C) during the survey it should be abandoned.

Team size and safety

Make sure you have the landowner's permission to visit the sites.

Always plan your survey in daylight and consider a daylight or even a night-time dry run to check your ability to walk the route safely in the correct time, handle all the equipment and take appropriate notes. A risk assessment should be carried out and documented.

The survey should be done by at least two people for reasons of safety. Someone 'at home' should know of your whereabouts and itinerary and an emergency plan should be in place. If part of the survey involves walking along a riverbank or other site with fishing interests, it would be advisable to notify the local fishery management authority.

The Survey

Two protocols are possible. We have tested both and they are equally likely to determine the presence of all woodland species. Geography or personal preference can dictate which you use to survey a given wood, but the same protocol must be used for all subsequent repeat surveys of that wood.

1. Transect with spot checks

Surveys should be 90 min duration, starting 30 min after sunset, and bats will be recorded "continuously". Many brands and models of bat detector will have to be used differently (see **Analysis** and **Equipment**) but some instructions are common to all. The detectors should be held at waist to chest height, pointing directly ahead and up at an angle of approximately 45°. Maintain as near a constant walking speed as possible, 2.5-3 km/h – a very slow walking pace. This can be checked in a dry run if you calculate survey length and know the time taken (minus spot checks). More conveniently, most GPS units will give you a continuous output of speed. The detector should be at the front of the survey party to minimise the recording of extraneous noise from vegetation and clothing.

The transects will be interrupted, at approximately 10 min intervals, for 5 min stationary 'spot check' recordings at six varied locations, such as woodland edge, change in woodland type, clearings, streams or ponds, and major path junctions. For consistency in file management, always start with a walk.

A GPS track should be started on commencing the transect and should run continuously. If you are using a digital recorder such as an Edirol or Zoom, recording should start simultaneously with the GPS track at the beginning of the transect. Recording should stop and restart immediately at the beginning and end of each spot check, so that your recordings are a series of short, alternating files:

walking1, spot1, walking2, spot2, walking3, spot3 …….. walking6, spot6

These shorter files are easier to organise and analyse. If no gap is left between stopping and restarting the recorder then time through recording matches time on the GPS track and bats can be accurately located on the map. The data can then be used for modelling bat habitat preferences. If it helps, you can use the GPS to create waypoints at each spot check, but these are not essential. If using a direct sampling recorder set to auto-trigger and record for 1 s, each file will be automatically time-stamped.

In the absence of a GPS track the data will be used for investigating distribution, abundance and population trends, which are the primary goals, but not for the secondary goal of studying bat:habitat relationships.

2. Area search

Plan a transect route as for the first protocol, but omitting the spot checks. Walk the transect, but use your judgement to depart from the route to improve recordings of quiet bats and explore patches of woodland that do not fit comfortably on the transect. This may allow you to cover the woodland more uniformly, without being constrained by a fixed route, walking speed or spot checks. However, it is important to cover the wood as uniformly as possible. As for protocol one, the area search should start 30 min after sunset and last for 90 min and cover the chosen woodland as effectively as possible. Use the same detectors in the same way, recording continuously and laying down a gps track if possible. If you are using a digital recorder, break your recordings into approximately 10 min sections by stopping and immediately restarting the recorder as for protocol one. Label recordings in numerical order.

Post-transect data handling and analysis

As soon as possible after surveying the transect, download and back up sound files and GPS tracks. If possible, rename files to make them easy to interpret, e.g.

WildWoodwalk1.wav
WildWoodspot1.wav
Etc.
WildWood.gpx

This will be possible if you are recording a relatively small number of files, e.g. using a TE detector-recorder combination. If you are recording large numbers of short, auto-triggered files, e.g. using a Pettersson D500x, then they will be given sequential filenames and will be time and date stamped. Put all files from a single night into a dated folder: WildWood_04_07_2014, with the completed datasheet. In short, whatever detector-recording system is on use, ensure that you have a well-organised folder of relatively short sound files.

Sound files can be in WAV, FLAC or MP3 format. WAV and FLAC can be read by BatClassify. MP3, although small and therefore easier to store, must be converted to WAV or FLAC. FLAC files are about half the size of WAV files. See **Recorders** below.

Analysis

BatClassify

The output of BatClassify, the 'Results.csv' file, is a simple spreadsheet file that will open automatically in Excel if double-clicked. It gives the date of analysis on the top line beneath which is a line for each file analysed, gving the fiilename, date and time, followed by the probability of occurrence (between 0 and 1) for each species, within the file, as follows:

Date									
Filename	Date	time	Bbar	Malc	Mbec	Mbra Mmys	Mnat	Paur	etc.
WildWood_001	01.07.14	22:48:45	0.02	**0.92**	0.01	0.04	0.02	0.04	
WildWood_002	01.07.14	22:50:11	0.03	0.01	0.03	0.20	**0.95**	0.01	

An acceptable default threshold for correct identification would be >0.9.

BatClassify is capable of extracting a very high percentage of calls and identifying them to species. Weak calls may be missed, but identification of these will in any case be less certain. However, even with successful identification rates in the 90-100% range, errors will be common when processing many thousands of calls. However, through the analysis of a large dataset with an overall low error rate, the results will be robust. Nevertheless, results must be interpreted intelligently, knowledgeably and cautiously. Many recordings made during transects typically contain noise only, and species predictions should be close to zero. Where BatClassify outputs higher levels of confidence in species presence, but you have reason to question the results (e.g. a rare species not recorded in the area before, or outside its known range), recordings can be viewed as spectrograms and inspected for obvious misidentification, perhaps due to extraneous noise interfering with analysis. Ask yourself the question: do the sonograms match the expected form of the species or genus? The identification of rare species should not be based on recordings containing single calls if identification confidence is low. If a single *Myotis* species is identified with high confidence then the identification is reliable, within the stated limitations of the software. However, if more than one *Myotis* species is predicted within the same brief recording there may be a misidentification.

Several levels of analysis are possible. For submission to the national database, only the first step is essential, but you may wish to go further for your own interest.

1. Submit the folder with data files and datasheet without analysis. Via Dropbox or similar – to be arranged.

2. Run each night's folder through BatClassify as described above. It will generate a 'Results.csv' file giving a confidence of species presence for each recording analysed. If a Pettersson D500x was used to make the recordings the time and date of the recording will also be included with the species predictions. Rename 'Results.csv' according to the survey site and date, e.g. 'WildWood_04_07_2014.csv'. Submit both sound files and data files.

3. Assess the accuracy of species identification for each recording.

   - ***1 s files from direct sampling detectors (e.g. Pettersson D500x)***
     If the recording has identified species with >90% confidence then identification can be considered reliable.

   - ***100 ms files from Pettersson D240x time-expansion detectors***
     Only 1 or 2 calls are likely to be recorded in each downloaded sequence, but several sequences may be recorded from the same bat. Examine the spectrogram and reject any obvious misidentifications or those with low confidence: <80% for regularly recorded species, <90% for species previously unrecorded in the area or the first survey in a particular wood.

4. Match each bat pass/call, from the time during the transect it was recorded, to its position on the GPS track and assign an 8 figure OS Grid Reference to it. Add this information to the data file. This is easy with D500x recordings, since they are date and time stamped. D240x recordings require that positions are estimated from the time of occurrence within the sound file.

Equipment

<u>Bat detectors</u>

Pettersson D500x direct sampling detector.

User Profile Menu:
SAMP. FREQ = 500
PRETRIG = OFF
REC. LEN = 1
HP-FILTER = YES
AUTOREC = YES
T. SENSE = VERY HIGH

Recording Settings Menu:
INPUT GAIN = 25

TRIG LEVEL = 0
INTERVAL = 0

The 1 s file will give near-complete bat passes, facilitating accurate ID.

Pettersson D240x time-expansion detector.
Set to auto trigger at maximum sensitivity, i.e. so the detector is triggering and recording continuously (triggered by internal/external noise, not bats), and record on 'min' setting of 100 ms (therefore with a playback time of 1 s). This ensures that all detectors are set to the same sensitivity to make data as comparable as possible. The detector will inevitably record extraneous noise and many periods without bats. The extraction software will extract calls. Only 1-3 calls will be captured in each section, but since the detector will re-arm, any bat that is around for more than 1 s will be captured again. This is better than the 1.7 s/17 s option since this will miss a high proportion of bats during the 17 s download time.

Recorders

Edirol R-09HR, Zoom 2, or equivalent: i.e. any digital device that can record WAV, FLAC or MP3 files at 16 or 32 bit and 320 kbps (256 or 196 kbps are acceptable). WAV and FLAC files are better for archiving, but are much larger files. MP3 files can be batch converted to WAV or FLAC format (using free software Foobar, www.foobar2000.org) for analysis with BatClassify or other software.

GPS

Most GPS units are now accurate to 3-4 m in the UK, although accuracy may be a little lower under dense tree canopy or under cliffs. Most are also capable of recording your route as you walk.

Preparation checklist

- Have you the landowner's permission to visit the site?
- Site selection and route planning in daylight
- Habitat assessment in daylight
- Dry run in daylight

Survey summary/checklist

- Have you a safety plan in place?
- Have you checked the weather forecast?
- Equipment – do you have it all, does it work correctly? (detector, recorder, headtorch, map, datasheet, thermometer/anemometer, GPS, spare batteries)
- Start 30 min after sunset
- 90 min transect walked at 2.5-3 km/h, with six 5 min spot checks at approx. 10 min intervals.
- OR an area search
- Record bats throughout using TE (separate sound files for each walked and spot check section) or DS detectors
- Don't walk in front of the detector
- Make use of GPS if possible
- Download, organise and back up data
- Submit folder with sound files (analysis files), GPS track and datasheet

Equipment: what to buy, approximate costs
NB: prices and models change rapidly, those given (July 2014) are only for guidance.

Bat detectors

Ideal (continuous recording)
Direct sampling:
Pettersson D500x (~£1600) ideal, the software was developed for this detector

Acceptable (only records 100 ms every second)
Time expansion: Pettersson D240x (~£1100)

Bat identification software

Many detectors now come with identification software. Automated call extraction and identification is a field in its infancy and accuracy is still improving, sometimes from a poor and undocumented baseline. If the software you buy does not come with some clear statement of how well it extracts calls and how accurate it is at identifying species, then you need to test it. This is not a trivial task. We recommend that you use only BatClassify at present.

Digital recorders

Edirol R-09HR (~ £250), Zoom H2 (~ £125) are tried and tested. There are many others available

GPS

Most GPS units are now accurate to 3-4 m in the UK. Models capable of recording your route as you walk can be bought for less than £100.

Anemometers / thermometers

A wide range of devices is available from £15. We found the Technoline EA 3010 to be reliable

Data cards for detectors
These will vary with recorder settings, but as a guide:

For Pettersson D500X:
1 track * 500,000 samples/second * 16 bits/sample = 8,000,000 bits/second
~ 5GB per 90 min transect
8GB CF card ~ £10-20

For Pettersson D240X:
2 tracks * 44,100 samples/second * 16 bits/sample = 1,411,200 bits/second
~ 1GB per 90 min transect
2GB SD card ~ £5-8

BatClassify

Step 1. Download
Find 'BatClassify_win32.zip' at https://bitbucket.org/chrisscott/batclassify/downloads and right click and select 'Save link as...' to download the file. Unzip the file contents to a location of your choice.

Step 2. Run BatClassify
The BatClassify.exe is found in the 'bin' folder inside the 'BatClassify' folder previously extracted. Double-click the .exe file to bring up the BatClassify user interface.
If the recordings to be analysed were made with a time-expansion detector and are long continuous files, go to step 3. If the recordings are from a direct-sampling detector go straight to step 4.

Step 3. Split time-expansion recordings
Continuous time-expansion recordings must be broken up into smaller files prior to analysis. The 'split' process extracts non-silent regions of the recording, saving each as a separate file.
Click the 'Split' tab of the user interface. Select the folder containing the recording(s) to be split using the directory browser (click 'Browse...'). Next select the folder where the output files should be saved, as above. Click run. If a large number of files were selected for splitting, a progress bar will indicate the percentage of work complete.

Step 4. Analyse recordings
Select the Analyse tab of the user interface. Select the folder containing the recording(s) to be analysed using the directory browser (click 'Browse...'). Next select the folder where the output files should be saved, as above. Select whether spectrograms of extracted calls should be saved using the check box. Click run. If a large number of files were selected for splitting, a progress bar will indicate the percentage of work complete.

Step 5. View results
Once analysis has finished, the 'Results.csv' file will be found in the output folder selected in step 4. CSV files can be viewed in a number of programs e.g. Microsoft Excel, OpenOffice and Google Docs. Analysis results are organised with a row for each recording, and a column for each species. Classifier output for each species or species group is a number between 0 and 1, and represents an estimate of presence within that recording. For example, a recording containing calls from a lesser horseshoe only should have values near 0 for all species except *Rhip*, where values closer to 1 indicate increasing confidence in presence. Note that multiple species may be present in a single recording, in which case more than one value in that row may be non-zero.

ADDITIONAL ELEMENT: Use of static lure.

NB: at present we do not recommend the use of lures (see Discussion)

If available, a static acoustic lure and second recording system can be left running at an appropriate location (described later) to attract and record bats whilst you are walking the transect, to provide additional data, possibly of the quieter or rarer species.

To increase speed of analysis and remove the subjectivity of identification, bat calls will be extracted and identified to species using automated software, followed by brief visual inspection.

If a static lure and a second detector/recorder are available, select a location likely to be used by bats at a place convenient to your survey, but not within 100 m of your transect. Suitable locations include the edge of an internal clearing in the wood, a junction of several paths or tracks, where a track emerges from woodland, on a wooded stream or pond. To avoid disturbance the lure should not be placed within 200 m of a known or suspected roost. It should be within 2 m of a tree or trees and approximately 2 m above the ground. The supplied call sequence should be set to play once every minute. The lure and detector should be placed so as to minimise recording of the lure itself by the static detector. This may require some trial and error testing. It may be possible to run the system during the walked survey, but pilot studies suggest the lure will be most effective in the hour or two immediately after completion of the survey. Identify bats in captured sequences as above. Lure playback calls have a characteristic structure and a regular repeat and since they are not will not be .

Acoustic lures

NB: a licence is required to use an acoustic lure

We suggest one of three possible acoustic lures:
1. The Sussex Autobat.
2. An Edirol R-09HR (96 kHz playback) or similar digital recorder (e.g. Zoom 2) in combination with a Pettersson L60 ultrasound speaker (60 kHz) is a low cost and portable playback setup.
3. A Samsung N220 Netbook (or similar) in combination with an E-MU 0202 USB 192 kHz soundcard and a Pettersson L400 ultrasound speaker (or similar card that is compatible with the L400). This has a significantly higher cost (but still less than the Sussex Autobat) but gives full frequency range playback. However, in trials this performed no better than the low cost option.

Date	Surveyors (name and email address)		Temp. (°C)	Wind (m/s)	Rain (no/light)	Cloud cover (%)
	1.	Start				
		End				
	2.					
	3.					

Woodland Name:		Ground flora (delete as applicable)	poor good excellent
Nearest town or village / county		Understorey (delete as applicable)	poor good excellent
OS Grid Reference (XY 123 123)		Water (delete as applicable)	stream river pond lake
Type of woodland (delete as applicable)	Ancient deciduous mixed	Map attached (delete as applicable)	yes no

Additional comments: (e.g. open woodland, dense woodland, dominant species, approximate % conifer if mixed)

Detector and recorder used. Check your settings – are they as described in the guidelines?