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British Islands Bats



**Volume Three
2022**



Welcome to the third volume of British Islands Bats.

The COVID-19 pandemic saw many aspects of bat field work grind to a halt in 2020 and severely curtailed through part of 2021, but it has been wonderful to hear about various projects getting under way again this year. With restrictions on people lifted and following guidance for working with bats, new projects are starting and longer term projects are up and running again. We hope some of them will make it into the pages of Volume Four next year!

Over the pages that follow we have a variety of articles from bat workers across the British Islands, from informal monographs to detailed scientific papers, there is hopefully something for every batty person in this volume. As editors, we find it incredibly inspiring to read about the activities of bat folks, the continued enthusiasm for research and the conservation of these incredible animals. But do let us know what you think via email to britishislandsbats@gmail.com or on social media #BIBats.

If you are inspired to write-up your own work please do get in touch. From sharing data and findings (whether formal research or more informal studies) to interesting observations, all articles can provide an inspiration to others. As always, we welcome articles about bat work from anywhere within the British Islands (England, Scotland, Wales, Northern Ireland, Channel Islands and Isle of Man). British Islands Bats is an annual publication that aims to record information about bats and bat work across this geographic area, providing a forum for information that might not otherwise be published, from full-length papers to brief notes.

British Islands Bats is a collaborative enterprise and we are grateful to everyone who has contributed content for Volume Three. Thank you to the Bat Conservation Trust for continuing to host British Island Bats (but please note we are an independent publication). Best regards,



Tina Wiffen and Lisa Worledge
British Islands Bats Editorial Team

Email: britishislandsbats@gmail.com

Webpage: <https://www.bats.org.uk/resources/accessing-journal-papers/british-islands-bats>

Cover image: Natterer's bats *Myotis nattereri* in flight, Westerham Mines, Sussex. © Daniel Whitby.

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The roosting ecology of grey long-eared bat *Plecotus austriacus* (Fischer 1829) on Jersey, Channel Islands

Piers Sangan; Sangan Island Conservation Ltd

piers@sanganconservation.co.uk

Introduction

Our study over three years from 2019 to 2021 has looked at the roosting ecology of the grey long-eared bat *Plecotus austriacus* in Jersey. The study has focused on an exceptional roost's phenology, colony size and emergence behaviour. The wider element of the study explored characteristics of buildings with confirmed grey long-eared bats looking for common themes in terms of size of roosts, height of roosts, structure of the building, access point type and colony size present.

The grey long-eared bat is a bat species restricted to Europe (Figure 1). This species can be characterised as a medium-sized bat with long ears and can be distinguished from the brown long-eared bat *P. auritus* (Linnaeus, 1758), by its longer and more slender muzzle which is normally darker. The grey long-eared bat can further be separated due to its black eye mask and the sharp delineation between the long grey dorsal fur and the pale whitish ventral fur (Dietz and Kiefer, 2016). The grey long-eared bat is currently listed as near threatened by the International Union for Conservation of Nature (IUCN) due to a decreasing population trend estimated at a 25-29% decline over the last three generations (Gazaryan and Godlevska, 2021).

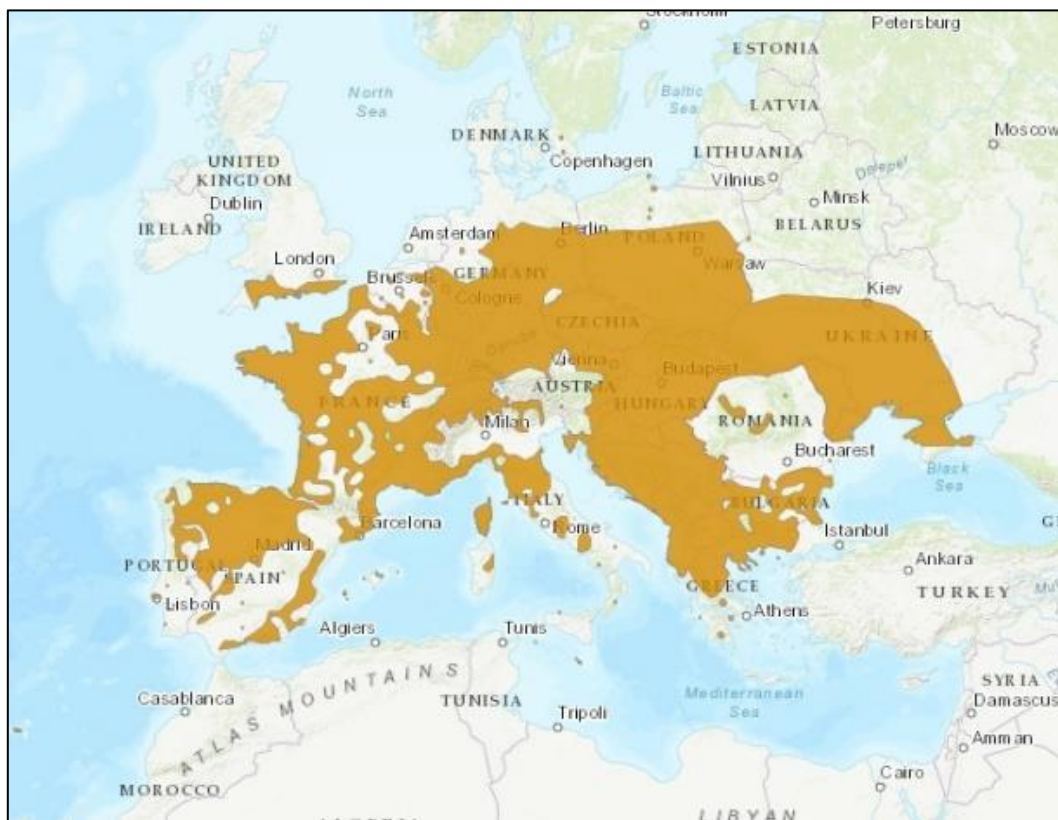


Figure 1: Extant (resident) range of the grey long-eared bat (Gazaryan and Godlevska, 2021).

In Jersey, *Plecotus* bats were historically recorded as being more abundant than *Pipistrellus* species (Sinel, 1908; Baal, 1950). The first confirmation of grey long-eared bat being present in Jersey was in 1963, with a specimen that had been sent to and examined by the British Museum's collection in 1939 (Le Sueur, 1971). It is now recognised as a commonly encountered bat throughout the island, with many small roosts identified from the bats encountered during ecological surveys for development applications (Hall, 2021). Despite this 80 year history of the species being present on the island, very little is known about the local ecology and phenology of the island's bat population, with only a few larger roosts identified (c.20 individuals) and a single exceptional roost which is explored in this study. Due to this lack of information, the species is threatened particularly as their roosts are closely associated with human settlements and due to the risks posed by modern developments. Threats to the species include roost loss and light pollution from the aforementioned factors (Boldogh *et al.*, 2007; Razgour *et al.*, 2013).

Aims

The first part of the study was to look at the ecology of the identified maternity roost, specifically, the number of bats present during the active season (the part of the year when bats are actively flying and not hibernating) and the change in the population size during the active breeding season. The second part of the study was to review existing records of known grey long-eared bat roosts to identify common themes in building structures, as well as using the details of the large new roost to identify other buildings which may also contain significant roosts.

Results

Ecology and phenology of maternity roost

A total of 31 emergence counts were undertaken during the three year period of 2019 to 2021, with 2019 $n = 6$, 2020 $n = 19$, and 2021 $n = 5$. Over the three years, a total of 2119 bats were counted emerging from the roost site. The highest peak count was 93 (09/08/2020) and the lowest count was 22 (27/09/2020) (Table 1).

Table 1: Summary of colony size surveys.

The total number of bats counted over the survey period	2119
Mean no. of bats	68
Standard Deviation	17
Peak roost count 2019	89
Peak roost count 2020	93
Peak roost count 2021	91

In all three years, there was a peak around weeks 24-25, before the population steadied for around three to four weeks, before increasing again. This is the point where the assumption is that the young bats have started to fledge and leave the roosts. The variation between the point of peak counts over the three years indicates a likely annual variation when pups are born (Figure 2).

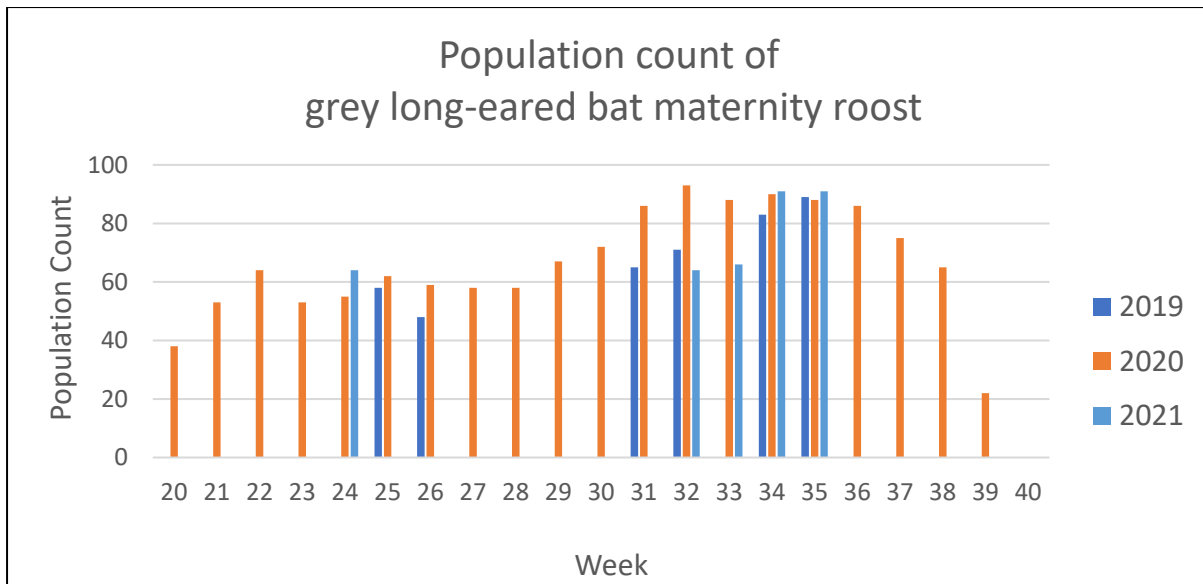


Figure 2: Variation in colony population size from surveys in 2019 to 2021.

The emergence time of the first bat was recorded on all surveys ($n = 31$). This showed a degree of variation with the latest that the first bat emerged 41 minutes after sunset and the earliest was three minutes before sunset. Apart from the single outlier, all emergences began during dusk, not in the darkness. The mean emergence time was 20 minutes after sunset with a standard deviation of eight minutes. The average time of emergence reduced from post-hibernation (27 minutes after sunset) to a low average time during lactation and fledging (17 minutes after sunset).

Building characteristics of grey long-eared bat roosting sites

A total of 27 buildings which contained suitable features such as the identified maternity roost or were available from historic records, were included within the data set. These buildings represented structures from across the island, including rural and urban structures and provided a good representation of the buildings which could be used by grey long-eared bats.

Roost size was broken down into categories based on the number of individual bats recorded on site: 1-3 small roost likely individuals, 4-6 small roost, 7-9 moderate roost possible early maternity roost, 10-30 average maternity roost size (Scheunert *et al.*, 2010; Uhrin *et al.*, 2017) and 30+ roosts of exceptional size (Scheunert *et al.*, 2010). Where a live bat was not seen, but evidence of grey long-eared bat was identified (droppings), the roost was given the roost category of 1-3.

Of the 27 roosts for further analysis, 81.5% of the roosts were recorded in the roost category of 1-3. 3.7% were in the category of 7-9. 11.1% in categories 10-30. 3.7% in the 30+ category. No roost was recorded with a roost size category of 4-6. Roost sizes of 10-30 and 30+ were only recorded in buildings that had a crevice entry point. The smaller roosts were more commonly associated with those structures with an open access point.

There was considerable variation in the size of the roost space used by grey long-eared bats. Only one roost void was found with an internal height to the void of less than 3m. The

majority (66%) of roosts included in the survey had a height between 3m and 4m. The largest void height was recorded at 15m, which was inside a church. All four of the roosts identified with a roost category of 10-30 or 30+ were in voids of 3m to 4m.

The average width of the roost spaces included in this survey was 7.9m (with a range of between 4m and 16m). The average length of a roost occupied by grey long-eared bats identified in this survey was 17.7m (with a range of between 8m and 26.8m). From the width and the length of the void space, the floor area was calculated in square meters. The average floor space of a void area where the species was present, was considered very large at 150.7m². It was noted that of the four roosts that were categorised as 10-30 or 30+, all four of these roosts had a floor space greater than 200m². The largest roost void was 26.8m long with a width of 16m giving a void floor space of 428m².



Figure 3: Grey long-eared bat emerging from roost over the top of the wall plate.

Conclusions

This study has provided the first definitive reference point for the ecology and phenology of grey long-eared bat roosts in Jersey, Channel Islands. The data has shown that as a rule, the bats in Jersey behave similarly to those which have been studied in continental Europe, with slight variations which may be attributed to annual differences rather than geographic variations in population. The 19 week survey effort of a roost of exceptional size has provided an insight into the fluctuations and behaviour of a maternity roost on the island, as well as multi-year survey data showing annual variations in the roost phenology.

This survey has drawn together initial work for the specifications of grey long-eared bat roosting voids, as well as identified variations in the requirements of different roost sizes. Noting particularly the large floor area required for this species and the specific type of entry point.

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BatCam: a novel trail camera for detecting tree roosting bats

Gareth Lang; BSG Ecology

g.lang@bsg-ecology.com

Introduction

Project background

Determining whether bats use potential roost features (PRF) is extremely challenging. Aerial inspections have demonstrable advantages over emergence/re-entry surveys conducted from the ground, but also significant limitations owing to irregular use of tree roosts by bats, and the rapidity with which evidence of use disappears, and current evidence-based guidance on tree survey for bats (Andrews, 2018; Diez and Pir, 2011) highlights the regularity of roost switching behaviours of bats. For instance, Bechstein's bats *Myotis bechsteinii* move roost locations on average every 1.5 days during May and June (during pregnancy) and every 3.3 days in July and August (during maternity).

For this reason, standard 'snapshot surveys' such as those recommended by the Bat Conservation Trust's (BCT) guidelines (Collins, 2016) have a low likelihood of encountering bats, and this is suggested by Andrews (2018) to be as low as 5%. In addition, Andrews indicates that, because of the nomadic nature of tree-roosting bats, the probability of encountering them is not cumulative for any number of randomly spaced surveys. However, surveillance over consecutive dates does increase the likelihood of encountering bats, such that surveillance over a period of 14 consecutive nights (based on an encounter probability model using roost switching data (Diez and Pir, 2011) does allow a 'more likely than not' (>50 %) conclusion to be drawn.

This level of survey effort is suggested to be applied to PRF that are suitable to support Bechstein's bat, barbastelle *Barbastella barbastellus* and Alcaethoe bat *M. alcathoe* as these species are relatively rare, their conservation status uncertain and there is an absence of evidence that they will adopt artificial roost boxes. For other tree-roosting species (those that are more common and readily adopt standard compensation measures), the surveillance effort suggested by Andrews is reduced. However, if the level of survey effort required to reach a >50 % confidence in the data could be achieved at a reduced cost then survey resources can be targeted more equally, whether the species of interest are rare bats or bats of lower conservation status.

Existing trail cameras

Andrews (2018) recognised the potential of trail cameras in recording bat emergence/re-entry but noted a lack of consistent reliability in detecting emergence of groups or individuals, principally because of the delay between detection and activation of the camera. If a bat is captured by a camera in mid-flight (after being triggered by motion), it is speculative to conclude that it emerged from the target PRF.

This had also been noted by the author, initially when assisting with trials led by Jim Mullholland in 2018, and later with cameras that he had tested in the field. Whilst the cameras were able to capture some blurred images of bats passing through the frame, most photographs taken at around sunset and sunrise (the periods during which bat activity at

the roost entrance is likely to be greatest) were blank. This indicated that the cameras were missing most of the activity that they were set out to record.

At the present time, the fastest trigger speed available on a commercial trail-camera is advertised as 0.07 seconds. However, this is the time taken for the Passive Infrared Circuit to record motion and signal to the camera module to take a photo or record a video. The camera module requires additional time to wake from a sleep state, fire the flash, adjust focus and exposure, and capture the image. The additional time (over the 0.07 second trigger time) varies according to ambient light levels and distance to the target.

A new camera

The author considered the detection delay problem found with traditional trail cameras in relation to the way in which common bat detectors work. Bat detectors with built in recording functions do not 'miss' bat passes because they record constantly whilst the record function is set. When the bat detector is 'triggered' by a bat pass, the associated audio file is saved in full, even though the bat call started before the trigger could react. The author set to applying this concept to cameras and purchased a Raspberry Pi and camera module in late 2018. A working prototype had been developed by February 2019. The resultant camera provides detection trigger from a narrow beam, high-sensitivity passive infrared sensor and saves discrete video clips from five seconds prior to five seconds following the trigger event, to ensure that bat activity within the field of view is captured in full. This is achieved through continuous loop recording onto internal RAM memory and extraction of the recording to a separate video file in response to a trigger event.

Proof of concept

The author built the prototype model into a stripped-out security camera with protruding cables to connect it to an external computer and power supply. Following initial testing and refinement of this prototype, the author, with the support of BSG Ecology revised the form of the camera (named BatCam) to be as compact as possible with no external lighting (to reduce possible disturbance effects as far as practically possible). Refinements of the passive infrared circuit made it more sensitive in the centre of view than standard trail cameras (which are designed to detect slower moving animals at distance) and a ¼ inch camera thread allowed connection to standard camera equipment, such as articulating arm attachments (Figure 1).



Figure 1: The first run of test units built within compact enclosures and fitted with articulating arms.

Deployment on trees

The BatCam has been deployed in several settings between 2019 and 2021 both on known roosts to trial the function of the camera and at PRFs with unknown use to supplement standard survey methods. The photographs in Figure 2 show the BatCam camera in position.

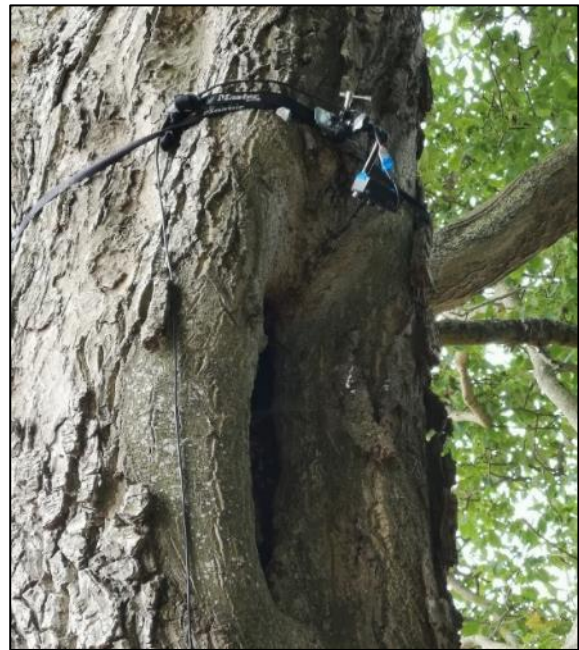


Figure 2: The articulating camera arm allows direct attachment to small limbs (if present, as shown in the left-hand picture) or to the buckle of a ratchet strap (as in the right-hand picture).

The camera's first tree deployment was in a commercial forestry in Conwy during August 2019. A roost of Daubenton's bat *M daubentonii* was discovered in a canker (enlarged by a woodpecker) on a mature beech tree during a climbed inspection in July 2019. The feature

was inspected again on four further occasions between July and September 2019 inclusive. The camera was set up during a climbed inspection in July and recorded for four nights and again in August and recorded for four nights.

Seven bats were recorded in the roost during the first inspection in July, but the feature was vacant on all other visits. The camera recorded bats roosting in the feature on one night and activity near the roost entrance (but no bats entering the feature) on two other nights. Bats therefore used the feature for roosting on two out of thirteen days of surveillance (five inspections and eight nights of observation using the camera).



Figure 3: The video stills captured by the BatCam show Daubenton's bat landing at the roost entrance (not visible in the frame).

Further trials of the camera's performance against commercial survey work based on current guidelines (Collins, 2016) have been undertaken. In some of these cases, the camera did not record evidence of use by bats (but did record use by nesting birds or small mammals). However, the camera has repeatedly identified occupied roosts where internal inspection alone has not.

As an example of this, the BatCam was deployed on a known Bechstein's bat maternity roost at Tortworth during September 2020. Whilst this is a known roost (identified by Jim Mullholland during a radio tracking study in 2017), monthly climbed inspections of the feature between January and December 2018 inclusive only recorded droppings on one occasion, but no presence of bats. No bats were present on installation or on collection of the camera in September 2020. On the first few nights of recording no bats used the tree for roosting, but they were recorded landing on the tree close to the entrance hole (Figure 4, left-hand image). Subsequently they used the tree in high numbers, with 37 bats roosting in it four nights after deployment and a peak of 39 bats present five nights after deployment. This illustrates the transient nature of tree roosts. If sufficient cameras were deployed on known roosts within a woodland this technology has the potential to improve roost size estimates for woodland bats colonies that may be split between multiple roosts on any one night.

In another example, a tear-out was identified on a tree in a woodland in Newport, South Wales. The feature was inspected on two occasions during May 2021, but no evidence of bats was found on either survey. The BatCam was installed during the first inspection survey and recorded for 14 nights. Two brown long-eared bats *Plecotus auritus* were recorded using the tree as a night roost seven nights into the recording period (Figure 4, right-hand image).

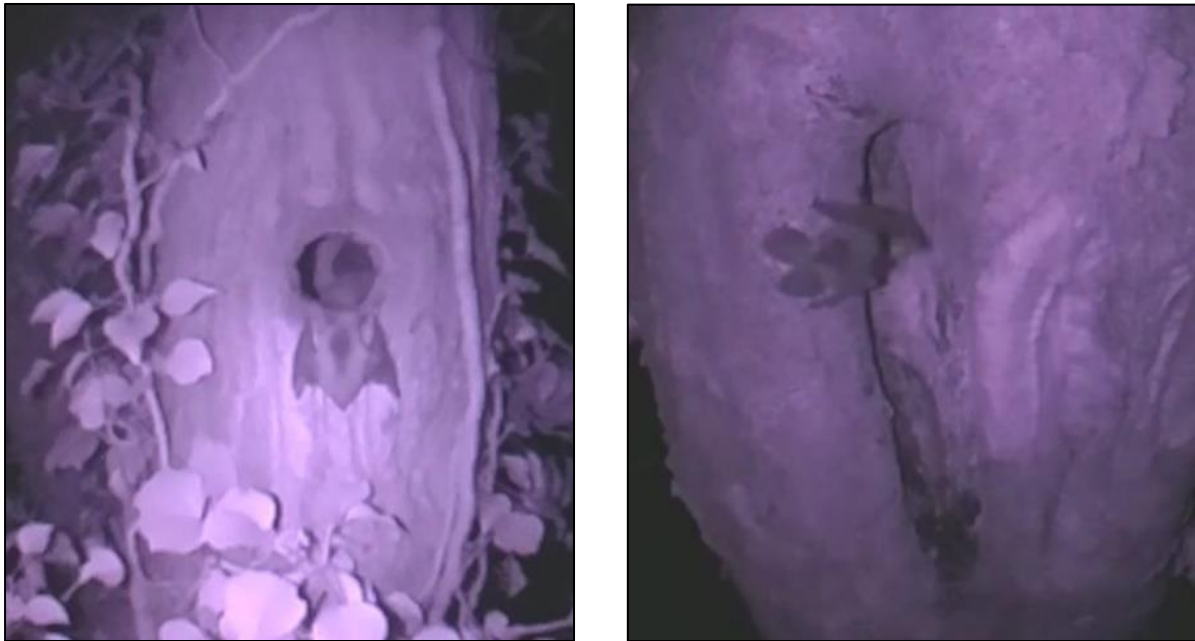


Figure 4: The left-hand image is a video still of a Bechstein's bat entering a woodpecker hole at Tortworth. The right-hand still is of a brown long-eared bat emerging from a tear-out at Newport.

Most recently, a canker leading to a cavernous hollow stem within a veteran beech was inspected on three occasions (once in each of July, August and September 2021) to support an assessment of impacts on bats for a nearby windfarm proposal. No evidence of use of the feature by bats was found during any of the inspections. The internal dimensions of the feature and relatively narrow access made a full internal inspection difficult and not all parts of the internal void could be fully viewed. Therefore, the BatCam was installed on the second inspection visit to supplement the standard climbed survey work. It recorded for 12 consecutive nights and captured regular use of the feature by wood mouse *Apodemus sylvaticus*. However, a brown long-eared bat was recorded using the feature as a night roost 10 nights into the recording period.

Comparative tests with trail cameras

The author has commenced comparative trials against off-the-shelf trail cameras. Early results have demonstrated consistently clearer evidence of the use of the target PRF. The comparative tests have used dual camera brackets to enable placement of the BatCam alongside a trail camera. The trail camera had been set up to take a photograph (because this results in a faster trigger) and then a video. The point at which the trail camera captures a photograph and then a video, can be seen on the video footage captured by the BatCam because the trail camera's flash is much brighter than the illumination of the BatCam.



Figure 5: The photograph above left shows a camera setup including a BatCam camera alongside a trail camera, mounted on a camera wall bracket. This system was set up to view two previously identified Bechstein's bat roosts in Tortworth, Gloucestershire in August 2020. The right-hand image is a video still of a noctule *Nyctalus noctula* inspecting the feature.

In the video from which the still in Figure 5 was taken, the trail camera manages to take a photograph of the bat at the feature, but the bat leaves before the trail camera's video recording starts. The bat in this example flies off and does not enter the roost, but this behaviour was not recorded on the trail camera, and use of the feature by bats would remain unknown.

In other comparative tests involving Bechstein's bat, the BatCam captured individuals flying through the frame without triggering the trail camera and landing and taking off out of frame before the trail camera's flash fired. The resultant blank photographs and videos on the trail camera did not provide information on the use of the feature by bats.

A similar setup was used to test the comparative trigger times at a lesser horseshoe bat *Rhinolophus hipposideros* in the basement of a church in Monmouth (Figure 6). The roost location is in a disused boiler room accessed through a flue hole in the brick wall. Emerging lesser horseshoe bats were recorded by the BatCam, but in most cases, the bats were out of shot before the trail camera took a photograph. Where the trail camera recorded photographs of bats, they were in flight near to the roost entrance, but no conclusive evidence of emergence or re-entry could be gained. The full recordings by the BatCam also allowed accurate counts of individuals as they emerged and re-entered the roost. It had also allowed a better understanding of how the roost is used through the year. Previously thought to be a hibernation roost only, the BatCam recorded evidence of regular use through May and June.



Figure 6: The photograph above left shows a camera setup including a BatCam camera alongside a trail camera. The right-hand video still shows a lesser horseshoe bat emerging from the roost entrance.

Developing function and usability

In addition to iterative refinements of the motion detection and video capture capabilities of the camera, the author has designed an intuitive, remote 'user interface' for camera setup and data download. The interface is broadcast over Wi-Fi (which can be received on any Wi-Fi compatible smartphone, tablet or computer). A radiofrequency 'fob' allows users to turn the camera on and transmit the user interface remotely. The interface allows for intuitive set-up by a wide range of users. The appearance of the BatCam has also been refined through use of a 3D printed case, designed in CAD software.



Figure 7: The screen grab on the left shows the case design in CAD software. The photograph on the right is the current BatCam with remote control fob.

Next steps

KDP Electronic Systems Ltd produced a trial run of five units based on a wiring schematic and CAD drawing at the end of 2021. A second run of 50 units is in production and will be provided as a research tool for academic institutions, specialist consultancies and

conservation organisations as *Beta* units. Performance feedback will inform product refinement. Further production runs will follow demand to make the BatCam widely accessible providing a cost-effective way of undertaking surveillance over consecutive dates that will increase confidence in the use of PRFs. In the long term, the camera has potential to be widely adopted to inform impact assessments and conservation projects. This will help ensure that loss of bat roosts does not occur without appropriate consideration of impacts and adequate mitigation and help ensure that the favourable conservation status of bats is maintained.

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Bat Roost Tree Tag Scheme

Sonia Reveley; Bat Conservation Trust

brtts@bats.org.uk

Introduction

Woodland owners, managers and contractors on the ground often have difficulty locating and distinguishing trees that have been identified as a bat roost, because trees are subject to change over time and tree roost features can be transient and also be fragile. It is also acknowledged that re-locating the tree in question can be difficult for bat workers, ecologists and others working with trees in woodlands. In addition, changes of ownership and site managers over the years can lead to information being misplaced and result in the accidental loss and damage of important bat roosts.



Figure 1: Tree tag in situ. © Ellie Hack.

To ensure trees containing confirmed tree roosts are easily identified, the Bat Conservation Trust (BCT) started the Bat Roost Tree Tag Scheme (BRTTS), which provides tree tags that can be purchased. The presence of a tag on a tree is well recognised by woodland workers and site managers, so providing a bat roost tree tag will bring clarity to those on the ground about those trees already identified as bat roosts that are difficult to find again, especially as GPS units will have reduced accuracy in a wooded environment (Figure 1). When a woodland operative sees a tag and their actions may impact the tree, they will know they

need to seek appropriate advice before proceeding with any work, therefore giving a significantly increased level of protection for bat roosts in trees.

The Bat Roost Tree Tag

The bat roost tree tag (Figure 2) is made of anodised aluminium and is 80mm x 60mm in size and 1.2mm thick. The text is silver against a dark blue background. Each tag has the wording 'Bat Roost', a bat logo and a unique number that relates specifically to the roost. It also has a webpage address for a landing page on the BCT website, containing the reason why the tree is tagged and access to general information including bats and the law. Following feedback from surveyors, we are considering making smaller tree tags (that will be appropriate for small diameter trees) available through the scheme at a later date.



Figure 2: Bat Roost Tree Tag.

Purchasing bat roost tree tags

A charge for the tags and nails is necessary to ensure the scheme is self-sustaining so BCT can purchase more tags when sufficient funds have built up. Tags can be ordered through the BCT [website](#) and multiple tags can be purchased. To ensure tags are purchased by surveyors with bat survey experience i.e. a professional or voluntary bat worker we are requesting that a licence is provided where possible¹ when placing an order. We have a limited stock of bat roost tree tags and would like to make sure that they are available to many rather than a few. We have therefore limited purchases to six tags per surveyor, to

¹ If the surveyor doesn't have a licence but would like to purchase some tree tags or a landowner/site manager has confirmed tree roosts they would like to tag, further information on what to do can be found on the order form.

avoid stockpiling and would encourage that tags are ordered when there are confirmed tree roosts that need tagging.²

Guidance

[Guidelines aimed at surveyors](#) with bat experience can be downloaded from the BCT website. This guidance contains important information about seeking landowner permission, when to use the tag, recommendations about the placement of the tag and how to attach it to a tree, further details about the records we want surveyors to collect and how we will store and share the data. In addition, we have provided [an associated briefing note for woodland owners and managers](#). This document covers the role landowners/managers will have in the bat roost tree tag scheme and provides extra advice to consider before habitat work is carried out, with links to relevant good practice guidance. It is recommended that this briefing note is shared with landowners/site managers when seeking permission to survey and tag a tree roost.

Records and Database

Though the primary purpose of the BRTTS is to ensure trees containing confirmed bat roosts are easily identifiable, we would like tree roost and species records to be collected by the surveyor, because data collected through the scheme will support current and future work studying the use of different tree species by bats and the roosting opportunities provided. Information collected from the confirmed and tagged tree roosts will feed into two databases - at BCT and with the Bat Tree Habitat Key (BTHK). All records submitted will be kept on a BCT Access database which will be managed by BCT and when sufficient records are collected, they will be shared with the BTHK project.



Figure 3: Endoscope survey - Natterer's bat *Myotis nattereri*. © Ellie Hack.

We do urge surveyors to collect as much information as possible so we have species records as well as roost feature and habitat records, but we understand how much is collected will

² If however, the surveyor has more than six confirmed tree roosts that they would like to tag, or there's a project that requires more tree tags because of a planned tree survey of a woodland, or a radiotracking survey, we would encourage the surveyor to email us at brrts@bats.org.uk with the number of tags they would like to order and the reasons why extra tags are needed.

depend on the surveyor's experience, their capacity and the suitability of the feature. Therefore surveyors can submit [basic records](#) only (as this is still of vital importance as a record), but if experienced or able to do so, we would encourage surveyors to also submit [additional records](#), i.e. information about the roost feature collected from an endoscope survey (Figure 3), which means the information has a greater chance of being included in the BTHK database subject to their approval. We would also like to share the records with the National Biodiversity Network Atlas (public access and enhanced access) if permission from the landowner is provided.

One year on

Since the BRTTS started, 183 tags have been sent out to surveyors and 106 more tags have been ordered. Twenty-three basic records and one additional record have been submitted to BCT to date.

Acknowledgements

Thank you to our funders: The Ernest Kleinwort Charitable Trust, the Edith Murphy Trust and the Pilkington General Charity. We would also like to say thank you to the surveyors who have contributed to the scheme and supported it.

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Where do Daubenton's bats roost? A project

Annette Faulkner; Lincolnshire bat Group

annettefaulkner@btinternet.com

Introduction

I live in Spalding, in the heart of the Lincolnshire Fens, an area intersected by two major river systems - the Witham and the Welland, and the very end of a third, the Nene, which is mostly in Cambridgeshire and Northamptonshire. The natural history of the Lincolnshire Fens is little known, despite forming nearly half of the 1,500 square miles of the fenland basin, with nearly all the historical records and general information coming from the entirely different Cambridgeshire Fens, such that outsiders could be forgiven for not knowing ours even exist.

Much of the reason for this is that most of our natural history is hidden. Thanks to 17th, 18th and 19th century drainage the whole area is criss-crossed with dykes (ditches) and canal-like drains that feed into the main rivers, plus another smaller river, the Glen, that feeds into the Welland. What these rivers and drains have in common is a rich aquatic flora, and consequently fauna, that is only now being studied. They are the lungs that keep our bats breathing in a world of otherwise intensively farmed agriculture. Daubenton's bats *Myotis daubentonii* are found foraging over nearly all of the bigger water courses, while common pipistrelles *Pipistrellus pipistrellus* and, to a lesser extent soprano pipistrelles *P. pygmaeus* are to be found foraging over all of them. But where do Daubenton's bats roost? This is what my little project set out to try to find out.

By 2000 we had very few records of Daubenton's bat roosts. In 1997 a roost was found in a Victorian pumping station that straddled the North Engine Drain in the Isle of Axholme, northwest Lincolnshire, when what was thought to be a seasonal outbreak of mice round the heating element turned out to be a colony of Daubenton's bats that were presumed to be entering the pumping station via cabling below, and roosting on the guard around the heater. When the cover was removed the true occupants were discovered, but this was all due for replacement, and in those pre-licensing days a heated box was created around the cabling below the floor of the pumping station and the bats were evicted. Would it work? Work was completed by the end of May 1999 and early monitoring showed it to have been explored but not used. No further monitoring took place after that. At a visit we made in 2014 not a single Daubenton's bat was recorded over the drain, and the conclusion was that it had been unsuccessful.

There was a large colony of Daubenton's bats in a fen edge church, the only one in a building that we knew of, first recorded in 1985, which is still present and counted every year as part of the National Bat Monitoring Programme (NBMP) and which is adjacent to a large gravel pit complex. In 1987 a colony was discovered by accident in a brick culvert that opened on to a large fenland drain, after a survey of the adjacent bridge that was due for replacement revealed no evidence of bat use. This was at Leeds Gate Bridge (Figure 1) on the South Holland Main Drain (Figure 2). The culvert was redundant and had collapsed some way in; years later I learned that rather than being repairable it had been scheduled for destruction, as it crosses under nearby roads. The presence of the bats was found in the nick of time, the culvert was saved, and the bats are using it to this day. Then in 2000 a small

colony of Daubenton's bats were seen to emerge from a culvert over the river Lud in Louth during a survey, though this observation was later disputed. Other than that, in 2000 we had found a small number to be roosting in a hole in a lime tree on the roadside bank of the River Welland very near where we live and we thought we had located a roost in a bridge upstream of this, but no evidence had been found at a later consultancy survey.



Figure 1: Leeds Gate Bridge and culvert.

Since then a Daubenton's bat roost had been found in 2003 through another consultancy survey under a busy road bridge over the Vernatt's Drain in Spalding (Figure 3) and in July 2010 a roost was destroyed when a large rotting horse chestnut tree was being felled and bats starting flying out from a hidden hole about 25 feet up. Fortunately, the branch was roped down rather than dropped, one bat was rescued, allowing for identification, and the branch was wedged horizontally in another tree to allow the colony to continue using it or disperse. Interestingly, the roost was three miles from the Little Holland Drain, which eventually enters the South Holland Main Drain, but where we'd had very low levels of Daubenton's bat activity throughout. And that was it.

But Daubenton's bats are a common species! They don't often turn up in people's gardens, or houses, so there are only a few grounded bat records, and rarely in outbuildings (one record in some derelict barns close to the River Glen, found during a routine survey in 2017 and currently the subject of further surveys as part of a planning application is an exception). So where are they?

In 2014 I had an idea. There was growing evidence that they may be roosting in bridges. Supposing we were to survey a series of adjacent bridges, working in pairs, using the standard NBMP technique of tuning detectors down to 35kHz, and just record what time the bats appeared? At the very least it could tell us which way they were moving. Thus was the Daubenton's Bat Project born.

The books tell us that Daubenton's bats emerge from their roosts at 40 minutes after sunset. Was this true? By recording our exact local sunset time (there is a difference of six minutes between north and south in our large county) and using 40 minutes after that as 'anticipated emergence time', or 'ant em' for short, it should be possible to tell us many things, such as how far from or how close to a roost they were, and also, with several bridges being surveyed simultaneously, which way they were going. So if they were recorded before anticipated emergence time they were 'minus ant em' (- ant em), or if after it they were 'plus ant em' (+ ant em). We started the surveys in 2014 and continued until 2018, with some surveys carrying on beyond that.

Results

These were instructive. Although we concentrated largely on the main watercourses in the Fens themselves, there are a number of drains along the coastal areas north of Skegness; the Isle of Axholme, to the west of the River Trent is a 'mini' fenland area; and I was also interested in the River Lud through Louth and to the north east. As the Lincolnshire Bat Group had members across the county it was possible to recruit further afield and get greater coverage. But for the purpose of this short report I will concentrate on three main areas:

1. South Holland Main Drain, which runs for a slightly meandering 15 miles from east to west, to empty into the River Nene at Sutton Bridge via a sluice.
2. River Welland (and part of the associated Vernatt's Drain) which enters the county at Stamford, flows north east, through Spalding, and out to sea beyond the A17 main road, a distance of approximately 30 miles, being tidal from the northeast end of Spalding.
3. South Forty Foot Drain, which runs from its start midway between Spalding and Bourne and flows 12 miles due north, before bending round to the east and discharging, via a large sluice, into the River Witham at Boston, a distance of around 18 miles.

South Holland Main Drain

At the South Holland Main Drain (Figure 2) over the 2015 season all eleven bridges were surveyed in groups of three or four, with the Leedsgate culvert acting as control, where nine extra visits were carried out by a local member between the beginning of June and the beginning of August. Here emergence times varied from 40 minutes post sunset (i.e. at ant em) in early June, getting steadily earlier, at around 6-7 minutes minus ant em to mid July, but then 20 minutes minus ant em in late July and early August.

Meanwhile, timings at a bridge to the west of Leedsgate of 5 minutes minus ant em suggested a small roost there. This bridge is less than half a mile from the east end of the 1km Waterways Survey we have carried out for many years for the NBMP and the bats have always been recorded coming upstream from the direction of this bridge. Then three miles to the north east of Leedsgate a roost was confirmed in a concrete bridge, with five surveys, where the bats were seen to emerge on 16th June, 7th and 9th July 2015, with emergence times varying between 5 minutes plus ant em and 7 minutes minus ant em. By September the bats had moved on.

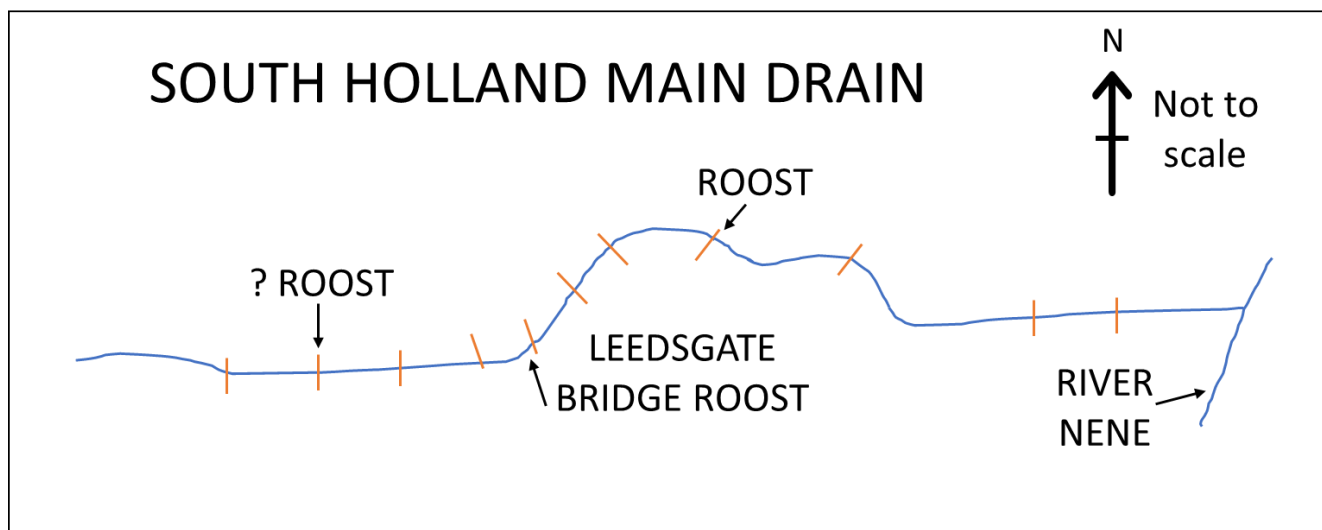


Figure 2: Annotated map of South Holland Main Drain (not to scale).

River Welland

On the River Welland (Figure 3) the focus in 2016, 2017, and 2018 was on the tidal stretches of the river, as Daubenton's bats were recorded there, and it was more a question of whether they were crossing from the Vernatt's Drain, which runs parallel and very close to the Welland for some two to three miles before discharging into the Welland via a sluice, and where the known roost in a bridge at the Spalding end - see below - was found to be still in use. With no more bridges for miles in either direction we simply spaced ourselves out at intervals along the banks and continued timing appearance of the Daubenton's bats, collating afterwards. Timings around the confluence of the Vernatt's Drain (and River Glen) with the Welland strongly suggested a roost in this area, but there was nothing to indicate presence in either of the sluices, so possibly a tree? Further work on this continued, as they were still being recorded two miles from the river's entry into the Wash, at which point we had run out of available bank and could go no further, so the question then became, 'Are they going out to sea?', and it was hoped to be able to book an evening boat visit. In 2019 this started to be investigated, but then COVID-19 hit.

However, in 2018 we also did a little more work closer to home in Spalding and surveyed from the bridges through town. There was no evidence to suggest bats were roosting in the upstream (south) road bridge mentioned above, but a small roost was discovered in the brickwork of the walls of a disused railway bridge further downstream, and there appeared to be clear evidence of roosting in a busy road bridge at the north (downstream) end of town, from timings both upstream and downstream of it. What is interesting is that the Victorian stone road bridge in the centre of town is not only unused (there are no potential roosting features), but timings from all the adjacent footbridges seem to indicate that it is the cut-off point for both the upstream colony (which mostly turn into the flood relief channel that loops round the town) and the downstream colony, which may head off into tidal reaches or even cross over to the nearby Vernatt's Drain. Only radio tracking could solve this one!

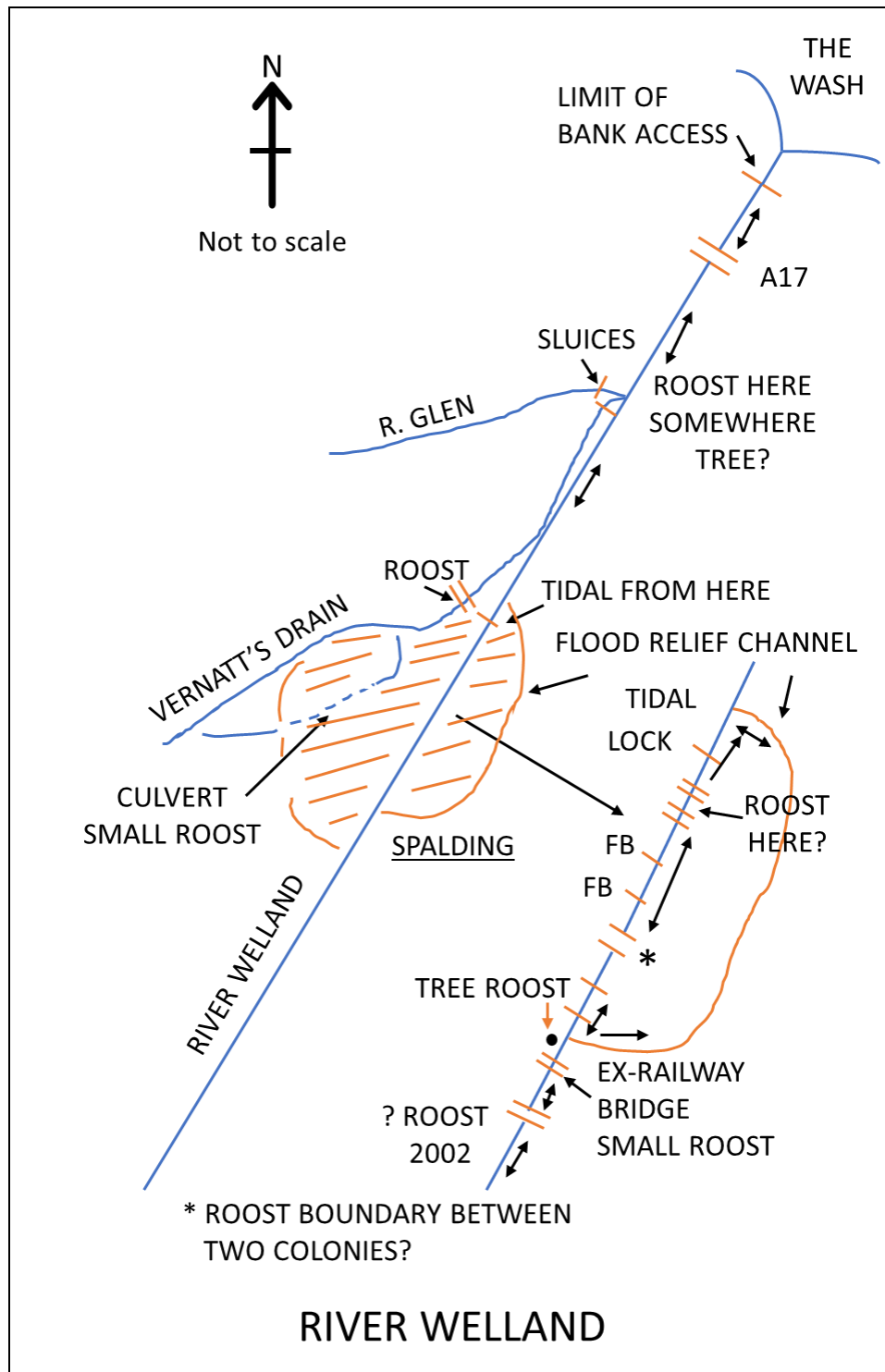


Figure 3: Annotated map of River Welland (not to scale).

South Forty Foot Drain

Finally, the South Forty Foot Drain (Figure 4). In a survey some years ago this drain was shown to be one of the most botanically rich drains in the area. Common pipistrelles are recorded everywhere along it, but where are the Daubenton's bats? There are few bridges, well spread out, and few trees, so at surveys of the southern end in June 2015 one survey had to be from the bank side, but it was only at the very end of the drain that Daubenton's bats were recorded at all, and then only one or two individuals and very late. However,

coincidentally in 2015 a team of consultant ecologists had been engaged by the local drainage board to survey all the various pumping stations along the drain. The surveys were carried out between July and September and the report provided sufficient timing data to be able to calculate potential emergence times, but, with one exception, timings were either late or there were no Daubenton's bats recorded at all.

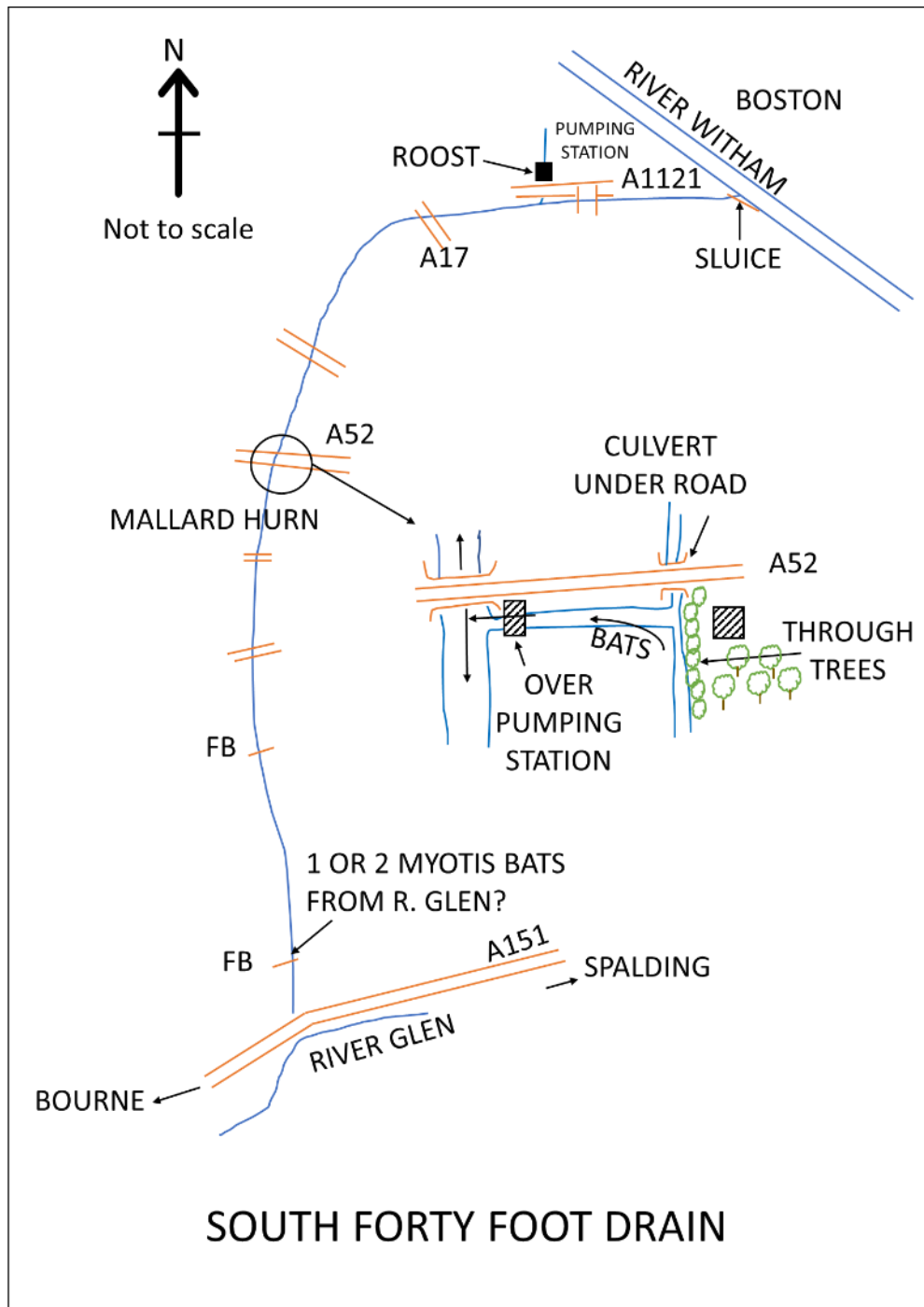


Figure 4: Annotated map of South Forty Foot Drain (not to scale).

The one exception was at a site called Mallard Hurn. Here two small field drains join, via a culvert under the adjacent A52 road, to form a short stretch of wide drain that runs east-west, parallel to the road, through the pumping station works and into the Forty Foot Drain.

It was here that in September 2015 the ecologists had Daubenton's bats commuting along the short drain, over the pumping station and into the Forty Foot Drain, to disappear. The time of appearance was approximately two minutes post ant em, so clearly a roost nearby. I was told about this, and we did a day time investigation. Could they be roosting in the culvert under the road? So one evening in late May 2016 a group of us went back, spread ourselves out - and waited. And what we had was exactly the same, with ten Daubenton's bats commuting down the drain from the east, over the pumping station and into the Forty Foot Drain, this time clearly dispersing along the drain. But were they emerging from the culvert? No, they were coming through the trees of an adjacent property, conveniently owned by one of our members, from further east. We concluded they had to be using a tree roost somewhere in an area of big gardens and many mature trees - and that was as far as we could go.

Other than that the consultants drew almost as many blanks as we had - until they reached the middle of the shorter west-east arm, half way to Boston. Here the Drain runs alongside and south of a main road, with two drains entering from the north via the usual pumping stations. Here, on one of them they did two surveys, one on 22nd August 2015 and one on 13th September 2015. In August they had six Daubenton's bats seen in the basin between the pumping station and the adjacent road bridge, with a timing of 16 minutes minus ant em; in September they had 22 Daubenton's bats emerge from under the pumping station and from under the road bridge, but with a timing of 16 minutes plus ant em. No further work has been done on this to confirm whether the bats are using both structures or only one of them.

The importance of culverts

Although the focus of the project was timed surveys from bridges, as well as the two culverts referred to above, anecdotal as well as confirmed records show culverts are likely to be extensively used, certainly when beyond a certain length, and we have a number of records from retired council workers of service tunnels and underground drains where bats were found. Indeed, in 2013 an ecologist was called out by Anglian Water when a total of six Daubenton's bats were found roosting under two manholes in a storm drain running under a housing estate in Lincoln. As far as he could work out the nearest possible access was 325m (approx. a third of a mile) away, but unfortunately never had the opportunity to check this. In 2015, at Project surveys of the River Lud through Louth, the culvert mentioned above was confirmed to have Daubenton's bats roosting in it, despite extensive works having been carried out. And in 2016 at a survey of the culverted section of a small drain close to the Vernatt's Drain in Spalding, during routine surveys in June and July, two and one Daubenton's bats respectively emerged, both at 4 minutes minus ant em, and headed towards the nearby drain (Figure 3).

Conclusions

As a means of identifying possible roosts in bridges and culverts and plotting which way Daubenton's bats are moving, timing their appearance is a simple technique that requires minimal training - just an accurate local sunset time, a tuneable detector and a watch (or, these days, a mobile?) - so the method is suitable for less experienced surveyors. It can then act as a starting point not only for further investigations but to flag up potential roost sites to maintenance teams and the need for full surveys before any work is carried out. And one

thing that became abundantly clear was that the 40 minute rule doesn't stand up to scrutiny! The 20 minutes minus ant em (i.e. 20 minutes after sunset) emergence at the Leedsgate bridge culvert may have been an anomaly, but even at other confirmed roosts the bats were regularly emerging at least five minutes early (35 minutes after sunset).

That said, these surveys posed nearly as many questions as they answered, but two things became very clear. The first is bridge preference: pretty and architecturally valuable though they may be, Lincolnshire's brick hump-backed bridges appear to be of no interest as roosts to Daubenton's bats. Separate work on the Grantham canal, which runs west and then northwest from Grantham to the county boundary and beyond, which is full of these bridges, shows the watercourse to be used very sparingly by Daubenton's bats - they are mostly to be found on the feeder reservoir at Denton, but this has not been surveyed further. The one brick bridge on the South Holland Main Drain, even with bat bricks installed years earlier, showed no evidence of being used and the same appears to be true of the Hobhole Drain, running north-south and into the River Witham below and south east of Boston, where there is a mixture of brick and concrete bridges. All the bridges that showed potential for or confirmed roosts were modern concrete bridges which have, so I understand, various service tunnels through them, creating gaps and cavities.

Additional information also shows the importance of culverts and tree roosts, though the latter can be difficult to find, and pumping stations generally don't seem to be being used by Daubenton's bats, probably because most don't appear to have suitable features.

Implications

Daubenton's bats would appear to be using a number of discreet features which are not widely understood or even catered for. Because there are far fewer roosting opportunities than there are for, say *Pipistrellus* and brown long eared bats *Plecotus auritus*, this makes them extremely vulnerable to both disturbance and roost damage or destruction, as they appear to be very faithful to these roosts. Bridge works are at least above ground, underground tunnels are not, and awareness of the potential for them to be there needs to be highlighted with local authorities and water companies to ensure that surveys and the appropriate mitigation are carried out. There also needs to be far greater awareness of their use of tree holes.

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Using camouflage to help bats see. The use of ‘bat fencing’ to retain connectivity

Greg Slack; The Strategic Pipeline Alliance

GregSlack@hotmail.co.uk

Introduction

Anglian Water have set up and commissioned the Strategic Pipeline Alliance (SPA) to create a series of new, interconnecting potable water pipelines. It represents one of the largest infrastructure projects in the UK. The pipeline route is divided into a number of schemes with field surveys, consenting and construction running concurrently across multiple sections of the pipeline route. Construction began in the summer of 2021 and will take nearly five years to build.

Most of the pipeline will be laid using open cut techniques. The removal of sections of hedgerow is needed to facilitate these works. Various pipeline diameters will be used across the schemes.

Larger diameter pipes will be used for most of the continuous length of the route. This stretches between Elsham (Lincolnshire) in the north and Ipswich (Suffolk) and Colchester (Essex) in the south. Along this part of the route hedgerow gaps of more than 10m are required. The size of the hedgerow gap required depends on the angle that the pipeline intersects the hedgerow but most will be 40m or less. Where smaller diameter pipes are used (generally on spurs off the main route, but also on independent sections of the local network away from the main route), hedgerow removal can be restricted to gaps of less than 10m. Bat Conservation Trust (BCT) guidance on landscape and habitat design (Gunnell *et al.*, 2012) suggests that the creation of hedgerow gaps of more than 10m should be avoided where possible.

Hedgerow gaps may need to remain in place from the start of construction right up until the completed section of pipe has been tested. Construction is likely to take one or two years for each section. At this point hedgerows will be reinstated but will take time to mature and provide suitable connectivity. Therefore, although the hedgerow gaps are temporary, they have the potential to affect the local populations of bats until the reinstated plants develop sufficiently to function as connective habitat.

While it is acknowledged that bats can cross gaps in linear habitat, it is widely accepted that most UK species prefer not to (BTHK, 2018). Gaps of >2m in linear habitat can cause bats to turn back either before, or while they are attempting to cross (Bennett and Zurcher, 2013). The frequency at which bats turn back increases as the size of the gap increases (Bennett and Zurcher, 2013).

To mitigate potential severance impacts key connective locations along the route were identified. These were locations where the retention of connectivity was considered to be strategically important for bats. One proposed solution to retain this connectivity was the use of 2m high steel fencing covered with camouflage netting to span the gap.

Rather than hiding the fence panels, the camouflage netting was intended to provide additional texture making it easier for bats to pick up using echolocation. It was also hoped

that the netting would provide some passive noise through the movement of the fabric in the breeze, similar to that which would be created by the rustling of leaves. This could be important for bat species which may be moving across the landscape without echolocating. Finally, it was considered that the netting may also provide a small amount of shelter for bats flying across the gaps.

At the time of the trial, vegetation had already been cleared at all locations. The vegetation clearance at the locations covered by this study was completed in the winter of 2020-2021. The hedgerow loss in these study locations was originally mitigated by a simple steel fencing and camouflage netting system. This comprised a single line of steel fencing with camouflage netting attached. However, the simple steel fencing and camouflage netting system had failed. Strong winds had blown over fences, ripped camouflage netting from the steel fencing and in some cases, broken the steel fencing itself.

Due to concerns that wind-blown fencing could cause serious damage or injury, the simple system had been removed at all locations. However, in some locations steel fencing without camouflage netting remained in place.

Prior to the reinstallation of the mitigation, it was redesigned to ensure it could cope with the anticipated wind shear. This involved the inclusion of additional fence panels to create a triangular layout, and heavier weights to anchor the panels in place. The specification for the redesigned fencing with camouflage netting is given in Appendix A.

In current literature there is a lack of examples of successful techniques for maintaining habitat connectivity for bat species when temporary severance has occurred. Considering this, a trial of the use of fencing and camouflage netting was proposed on the first section of the SPA pipeline to be constructed.

This trial looked to compare the effectiveness of a single line of steel fencing alone, comparing it to a triangular configuration of steel fencing with camouflage netting (shown in Appendix A) and locations which remained unmitigated (control locations). This paper summarises the results of that trial and suggests additional testing and potential applications.

Methodology

Overview

Preconstruction work classified hedgerows as either:

- a tall bushy hedge or row of scrub
- a hedge with standard tree
- a low hedge

This information, coupled with other bat survey and desk study, was used to identify key connective locations.

The trial aimed to sample each treatment on each hedgerow type requiring nine survey locations in total.

Field surveys

Surveys were conducted over a single week in August 2021 to identify the behaviour of bats at each treatment type. Each hedgerow location was surveyed on two occasions, once at dusk and once at dawn.

Each dusk survey commenced at sunset and lasted for 90 minutes. Each dawn survey commenced 90 minutes before sunrise and lasted up until sunrise. All surveys were conducted under suitable weather conditions (sunset temperature 10°C or greater, no rain or strong wind), as stated in the BCT good practice guidelines (Collins, 2016).

The length of each hedgerow gap was estimated (paced out) by surveyors on site at the time of survey.

For each survey a surveyor was located at each end of the hedgerow gap. Surveyors were positioned to allow clear observation of the hedgerow gap.

Surveyors were each equipped with an Echo Meter Touch Pro bat detector and an infra-red camera kit¹ to record the behaviour of bats during the survey. The behaviour of bats was categorised as follows:

- Crossed the gap
- Started to cross the gap and turned back
- Turned back before the gap

Post survey analysis

Bat call data collected during the surveys were analysed using Kaleidoscope or Kaleidoscope Pro to verify surveyors' field identification. Infra-red camera data were analysed to verify surveyor observations.

On completion of the bat call data and infra-red camera analysis, a one-way analysis of variance (ANOVA) was undertaken to determine whether there was a significant difference in the number of bats crossing, turning back before crossing, or starting to cross and then turn back during each survey. This was done for each treatment type.

Additional separate ANOVA tests were completed to determine whether there was a significant difference in the number of bats crossing at each treatment type; turning back at each treatment type; and starting to cross and then turning back at each treatment type.

Limitations

Access constraints meant it was not possible to complete surveys for every treatment at every hedgerow type. For this reason, only two 'low hedgerows' could be monitored. One of these locations had camouflage netting and steel fencing, the other had no mitigation installed. To ensure that an even number of locations with each treatment were monitored,

¹ The infra red camera kits comprised: 1 x Sony FDR-AX53 camera, 2 x FireFly 2.4W 850NM IR LED Bullet Lamps and batteries and tripods.

an additional hedge with standard trees was monitored where only steel fencing was present across the hedgerow gap.

Results

At least five species/species groups were recorded commuting along the hedgerows during the trial. These comprised common pipistrelle *Pipistrellus pipistrellus*, soprano pipistrelle *P. pygmaeus*, barbastelle *Barbastella barbastellus*, brown long-eared bat *Plecotus auritus* and unidentified *Myotis* species. Most observations were of common pipistrelle, the second highest number of observations were of *Myotis* species.

Commuting bats were recorded on 67 occasions, seven records were of bats starting to cross before turning back and seven records were of bats that turned back before crossing. The number and type of each observation recorded at each treatment is shown in Figure 1.

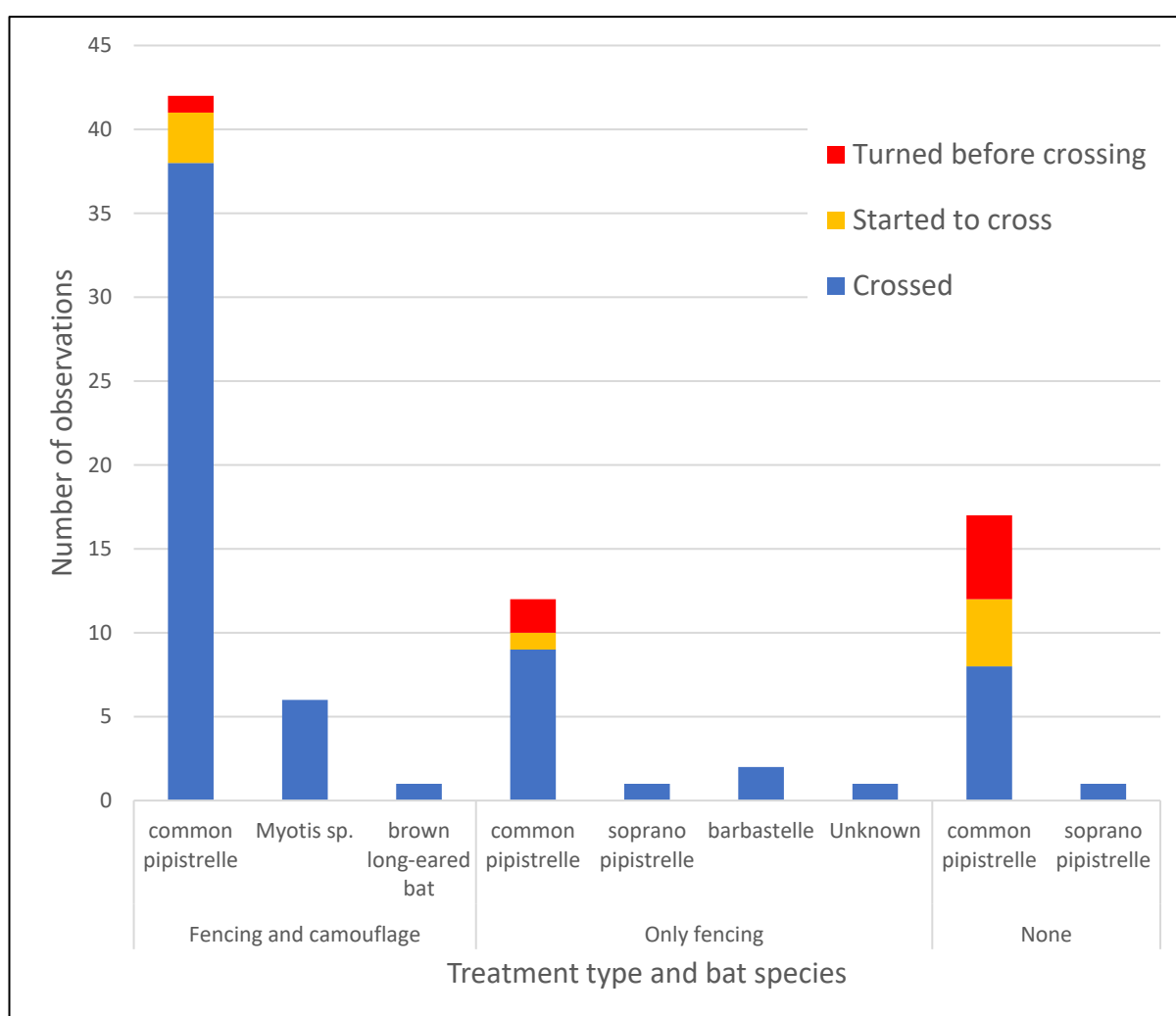


Figure 1: Results of bat fence monitoring.

Many of the bats recorded crossing (60%) were picked up at one hedgerow (HG7) where fencing and camouflage was installed as mitigation. Although the proportions of bats recorded crossing, and turning back at other hedgerows back up the trend recorded at HG7, when compared to hedgerows with other treatments, it is notable that this work represents a small sample size and the results must be considered in this context.

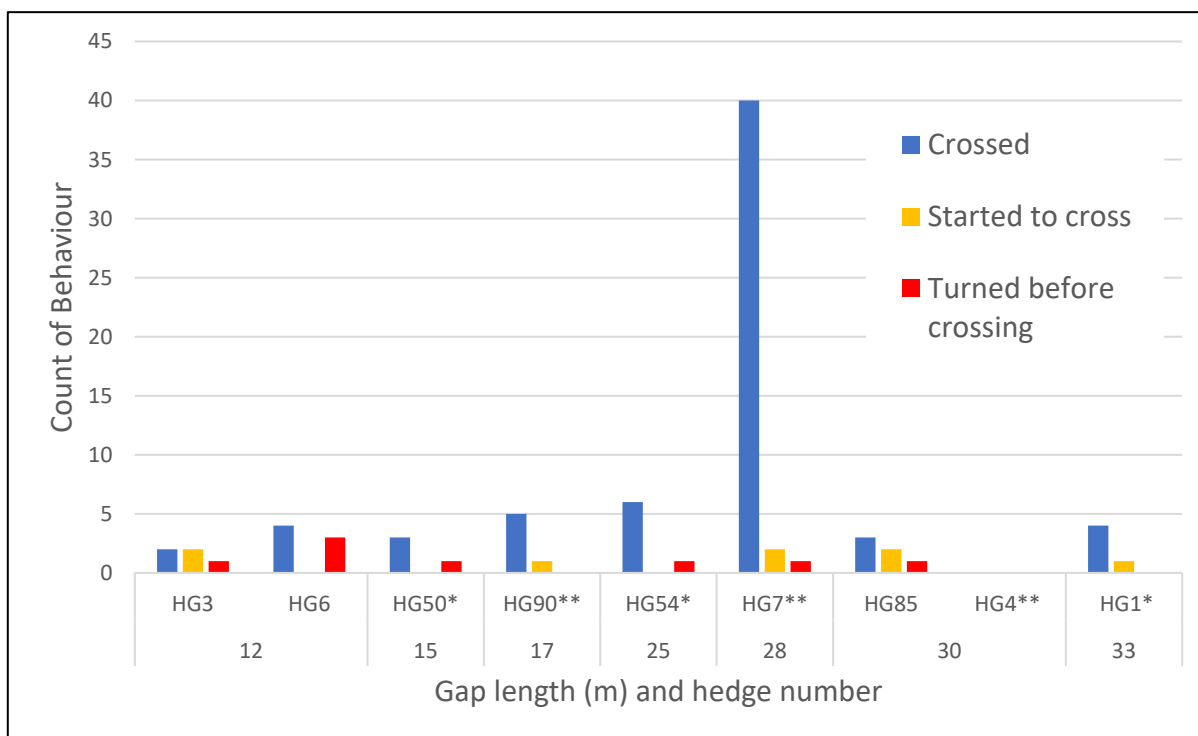


Figure 2: Bat behaviour in relation to hedgerow gap length.

*Mitigation comprised only fencing; **Mitigation comprised fencing and camouflage netting.

The minimum and maximum gap lengths were similar for each treatment type as identified in Table 1 below. Hedgerow gap length did not appear to be the primary driver for behaviour. The lowest proportion of bats successfully crossing the gap was recorded at Hedgerow 3, a gap of 12m (the shortest monitored); and Hedgerow 85, a gap of 30m (the second largest monitored). The highest proportion of bats successfully crossing the gap monitored was at Hedgerow 7 (the fourth largest gap), followed by Hedgerow 54 (which was the median length gap monitored).

Table 1: Length of gap covered by mitigation.

Treatment	Minimum hedgerow gap length (m)	Maximum hedgerow gap length (m)
Steel fencing and camouflage	17	30
Only steel fencing	15	33
No fencing (control)	12	30

Most bats (all species combined) crossing the gaps were recorded during surveys at locations where fencing with camouflage netting was in place. The ANOVA test showed this to be a statistically significant result with a P value of 0.01.

Most observations of bats starting to cross the gap before turning back, and of bats turning before crossing were made during surveys at locations where no mitigation was in place.

The ANOVA test showed this to be statistically significant with P values of 0.01 when considered individually or combined into a figure showing the number of observations of bats turning back at some point.

As a proportion of total observations fewest bats were recorded turning back at locations with fencing and camouflage netting (8% of total observations). Locations with just fencing were next (23% of total observations). Locations with no mitigation recorded the highest proportion of bats turning back (50% of total observations).

Common pipistrelle was the most recorded species and the only bat species recorded during surveys at all three treatments. The common pipistrelle results mirrored the results for all bat species (most were recorded crossing at locations with fencing and camouflage netting; most turned back at locations where no mitigation was in place). The ANOVA tests showed that these results were all statistically significant with P values of 0.01.

Myotis species and brown long-eared bats were only recorded at locations with fencing and camouflage netting. Barbastelle were only recorded at locations with only fencing and soprano pipistrelle were not recorded at locations with fencing and camouflage netting. All of these results are statistically significant. However, it is pertinent that no observations were made of these species starting to cross then turning back or turning before starting to cross at these locations.

Discussion

The use of standard steel fencing means this mitigation can be easily put up by contractors that are familiar with installing standard construction site boundary fencing. It also allows the inclusion of vehicle gates that are made from the same style of fence minimising the disruption required to maintain these connective features across the working area.

The proportion of observations of bats turning back without crossing gaps were similar to those recorded in other research (Bennett and Zurcher, 2013).

These initial trial results suggest that the use of fencing with camouflage netting is likely to be beneficial in helping to retain connectivity and reduce the proportion of crossing attempts that result in failure. While even a single line of fencing without camouflage netting may be of some use in reducing severance of bat habitat, a more complex fence structure with camouflage netting appears to have a significantly greater benefit.

Common pipistrelle is a species which was thought to be relatively untroubled by the presence of gaps in linear habitat. However, this trial has shown that the provision of fencing with camouflage netting across a gap makes it significantly easier for this species to cross gaps in hedgerows. Because the provision of fencing and camouflage netting works for common pipistrelle it is likely to work for other species with similar flight preferences and ecology.

The presence of *Myotis* species and brown long-eared bats crossing at locations with fencing and camouflage netting is also encouraging for the project. However, because no observations of these species turning back were made, it is impossible to state whether this

is because the fencing with camouflage netting facilitated the bats crossing the gap. The results could alternatively be because these fences were located in the right location for these two target species.

Similarly, because of the lack of records it is impossible to draw any conclusions about the effect of the mitigation on barbastelle and soprano pipistrelle. The ecology and known flight behaviour of these species means it is less likely that severance and fragmentation will be a serious issue.

Additional monitoring to identify the proportion of crossing attempts that resulted in these species turning would be useful in order to confirm the optimal mitigation solution for bat species other than common pipistrelle. However, this trial provides encouraging indications on the effectiveness of this mitigation and demonstrates the value of such trials to inform mitigation for projects like this.

Acknowledgements

Many thanks to Anglian Water for commissioning the monitoring of this experimental mitigation and allowing the publication of the results. Too much mitigation is installed without evidence that it is likely to work. Additionally, much mitigation monitoring that is carried out goes unreported/unpublished. Thanks to the SPA construction team, particularly Phillip Crossman, Craig Fisher, Jamie Crosby, James Parry and Simon Emmott for accommodating the monitoring surveys.

Thanks to Mark Norriss, Laura Roche, Alicia Logan, Harri Lee, Dan Wildsmith and James O’Leary. These surveyors completed a challenging schedule of surveys in order to complete the monitoring over a single week. Often the teams also completed other office tasks and the video and sound analysis during the day.

Final thanks to Robert Bell, Beth Ellis, Liz Allchin, Ric Sandifer and Kier Dawson for their suggestions and review of this document.

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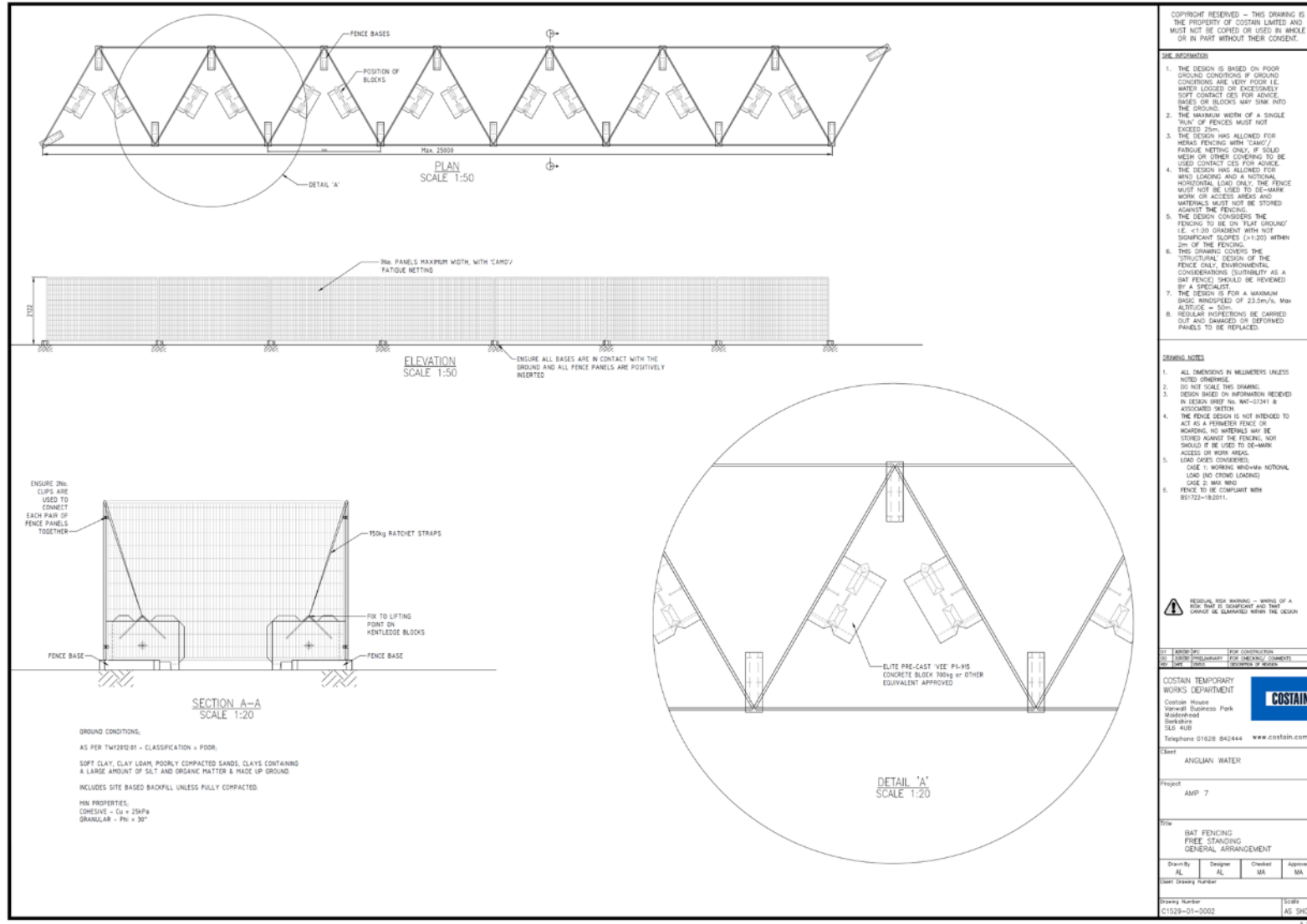
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Appendix A – Bat fencing free standing general arrangement

The plan below shows the free-standing arrangement for the steel fencing with camouflage netting. Note the drawing scales apply only to the original A1 size plan.



Herefordshire Bats and Swifts in Churches: 2014 to 2021

Denise Foster-Plume and David Lee; Herefordshire Bat Research Group

sweetchildofmine77@yahoo.com; davidlee_malvern@hotmail.com

Introduction

There are about 265 historic churches in the country of Herefordshire of which 247 are owned by the Church of England. Many of these churches provide a safe haven for wildlife, particularly for bats and swifts *Apus apus* both of which have closely similar ecological needs and return to their traditional roost/nest sites every year to breed.



Figure 1: Mathon Church which has a vibrant swift population.

Largely due to urban sprawl and development, particularly barn conversions, churches represent one of the few remaining constant resources for bats. The age of many of these buildings means that bats have been associated with particular churches for decades - perhaps even for hundreds of years - and many churches have resident colonies of bats. Whilst these often go unnoticed, serious problems sometimes occur and when they do, they can be exceptionally difficult to resolve. Reactions to these issues can be quite extreme for example anti-bat campaigner Catherine Ward (the wife of a Norfolk vicar whose churches supported large colonies of bats) started the Movement Against Bats In Churches (MABIC) back in the 1990s. Fortunately, in most cases clergy and congregation are at least

reasonably tolerant of their bats and sometimes actively supportive, although emotions can run high over droppings and urine splashes - particularly amongst volunteer cleaners! Bat species that commonly use churches include Natterer's bat *Myotis nattereri*, brown long-eared bat *Plecotus auritus*, *Pipistrellus* species, serotine *Eptesicus serotinus*, greater horseshoe bat *Rhinolophus ferrumequinum* and lesser horseshoe bat *R. hipposideros*.

In 2011/2012, Natural England (NE) and the Church of England joined forces to create a Bats in Churches Working Group to raise awareness of these issues. The aim was to provide those responsible for church buildings with guidance and advice on how best to manage resident bats, including how to deal with legal obligations.

The Church of England produced its own guidelines on bats (one in a series of many guidance documents, ranging from storage of chairs to churchyard maintenance and conservation of artefacts that can be found under Churchcare on the Church of England website). However the present authors considered these bat guidelines to be unclear and confusing. A much better resource was the NE guidance document *Bats in Churches: a management guide* (NE Technical Information Note TIN043 - unfortunately this document no longer appears to be officially available although it is still obtainable from some third-party websites).

Project background

Concerns were raised in 2014 in Herefordshire about disruptive repair works being carried out to churches where bats were known to be roosting but where no prior surveying had been carried out. Consequently, the Herefordshire Bats and Swifts in Churches Project was started with the twofold aims of identifying and recording evidence of bats and swifts using historic church buildings in the county and to provide advice and assistance to church communities who may be experiencing, or perceiving, problems (including promotion of the NE Voluntary Bat Roost Visitor (VBRV) service). Swifts are also heavily reliant on church buildings and their nest sites are frequently in danger of being lost during repair works, so they were included in the Herefordshire project as honorary bats.

A survey of available bat records held by the Herefordshire Biological Records Centre (HBRC) in February 2014 revealed churches to be very poorly represented. Church of England Dioceses are responsible for their own planning under the Faculty system, which is independent of county planning control. This means that planning related ecological surveys of church premises do not at present come readily into the public domain. Since a large proportion of HBRC bat records were abstracted from survey reports this would account for the paucity of records in churches.

In order to recruit volunteer assistance, a protocol for the new project was presented to the Herefordshire Mammal Group (HMG). HMG could see training opportunities for members, such as traditional building and bat detector survey skills, VBRV training and general public engagement, so the proposal was positively received.

Project aims and objectives

- To provide churches with important information about bats and swifts that use church buildings and provide advice and assistance where bats are causing concern.

- To increase the understanding of bat behaviour and reasons why bats target church buildings.
- To continually monitor bat boxes (where applicable) and carry out annual counts of bat colonies in churches where they are causing issues.
- To provide general advice about wildlife management in the churchyard.
- To involve local group members and the church community in the project and to share good practice.
- To provide a range of training opportunities to volunteers, especially those training to be Volunteer Bat Roost Visitors.
- To generate comprehensive bat records for the Herefordshire Bat Atlas and local biological record centre.
- To work with conservation partners for the benefit of bat conservation.
- To try to reduce the amount of damage to church furnishings and precious artefacts by providing alternative roosting opportunities for bats where possible.

Pilot Project (2014)

The project officially started in April 2014 and contact was made with local parish priests, via the A Church Near You website; this clearly was not the best option. Unfortunately there has been some history of confrontation between church communities and well-meaning but misguided bat workers so our approaches were initially viewed with some suspicion. In hindsight, initial contacts should have been made through the Archdeacon of Hereford and a few email exchanges with the Archdeacon led to a positive turning point for the project. Permission was given by the Archdeacon to contact local clergy directly, provided that they were willing to collaborate. The Archdeacon also requested that we also made contact with a Rural Dean who was a member of the National Bats in Churches Working Group.

Unfortunately that approach was not so successful due to his previous experiences with consultant ecologists during repairs to several churches in his group of parishes. His story was the familiar one of exorbitant fees being charged to confirm that no bats were present. Whilst we cannot comment directly on those assertions it would appear that at least some of the work should have qualified for the free Bat Advice Service and that the ecologist engaged was also a licensed roost visitor. Since then we have personally encountered a number of situations related to both churches and domestic properties where consultant ecologists, some of whom are licensed roost visitors, have taken on paid work where the works could have been covered free of charge by a VBRV.

The general perception is that the Church of England is a wealthy organization and it came as a shock to learn that individual churches are required to fund their own upkeep and maintenance. Clearly this can be a tremendous problem for a parish with a small and dwindling congregation. Repair works alone can run into many thousands of pounds and require extensive fund-raising efforts, so it is understandable that the additional costs of professional ecological surveys may be considered to be an unnecessary expense. Since both the authors were licensed VBRVs and in a position to carry out NE roost visits, covering repair works in many cases, we have made every effort to encourage churches to make use of this service by raising awareness with the diocese and architects as well as individual churches.

The Churches project ran as a pilot for one year and resulted in ten local churches being surveyed over the summer and leading to good relationships being established with clergy and churchwardens. Informative documents about bats and swifts and survey reports were provided to all participating churches.

The information pack included the following documents:

- *Bats in Churches: a management guide*, NE Technical Information Note TIN043
- *Bat roosts and timber treatment products*, NE Technical Information Note TIN092
- *Roof Repairs and Re-Roofing with Swifts*, Swift Conservation
- *How to be a bat-friendly church*, A Rocha UK
- Summary of the NE VBRV Service
- *Focus on Bats*, a publication produced by NE
- *Bats in Churches*, a publication produced by the Bat Conservation Trust (BCT)
- *Herefordshire Churchyards*, a publication produced by Caring for God's Acre

Church Survey Protocol

A church survey protocol was developed with three levels of survey effort:

1. Basic Survey

Volunteers are asked to visit their local church, and any other churches they may be passing, and report any signs of bat activity. The visit can be undertaken in about half an hour and does not require any specialized experience or training. A checklist is provided containing key points to record; including details of construction, surrounding habitat, churchyard management, bat and swift nesting/roosting potential, evidence of swift presence etc. Most Herefordshire churches are kept unlocked during the day so, wherever possible, volunteers are encouraged discreetly to look inside for evidence of bat activity such as droppings, urine splashes, grease marks and damage to artefacts. Observations are limited to the public areas of the buildings; volunteers do not venture into towers, vestries or undercrofts etc.

2. Full survey

Where moderate to high levels of bat activity are reported, churches are offered a more comprehensive survey led by experienced bat workers who are also licensed VBRVs. If maintenance or minor building works are planned then this may be combined with an official NE roost visit. All accessible parts of the building are inspected for bat or swift activity, including tower, vestry and any undercrofts. This is followed by an evening swift-return/bat-emergence survey. Additional volunteers with hand-held bat detectors are positioned around the church and static recording bat detectors are deployed both inside and all around the building. A full report is prepared and copies submitted to the church representatives, the Parochial Church Council (PCC) and the Diocese.

3. Extended surveys

Additional dusk and dawn surveys are carried out at churches where high levels of bat activity are recorded. Annual monitoring and emergence counts, including monitoring of known roost exits using IR cameras, are carried out at the small number of churches experiencing problems due to bat activity after which reports are issued to the local church contact.

However, these survey reports, including recommendations, frequently failed to generate any response, which was disappointing, so from the start of the project it was apparent that time and effort would need to be expended if we were to win over the confidence and trust of the Church communities.

At the end of the pilot phase, our findings and future plans were presented to a meeting of the Diocese Advisory Committee (DAC) held at Hereford Cathedral in December 2014. The response was very positive and valuable contacts were made for the future, particularly since several church architects were present at the meeting. Following the meeting the DAC added us to the diocesan list of approved advisers for wildlife issues. This has resulted in timely requests for advice and VBRV visits where maintenance works are being planned.

Bats and Swifts in Churches Project 2015 to 2021

Following the success of the pilot, the project continued into 2015 and beyond. Survey reports continue to be sent to key people in the churches and diocese, although there is still limited response to some of our recommendations.

One of our recommendations that does not require any funding is to allow bats access to less sensitive areas of the church, particularly into towers, by making simple modifications such as creating small openings in meshed apertures. On the other hand, provision of long-lasting boxes for bats and swifts does require significant funding and, since every church is self-funded, money is always tight so finance for the supply of boxes generally has to come from elsewhere.

The purchase of bat and swift boxes for ten Herefordshire churches was made possible by a grant of £4,900 received from the Heritage Lottery Fund (HLF) in 2015. As with all HLF grants, community involvement and public outreach is important so a budget for educational material, project booklets, display posters and display boards was included. A1 display boards and a project poster, designed by James Bisset, were placed in all churches participating in the HLF project.

Project booklets still continue to be distributed widely to churches, both by the Diocese and the authors themselves. This publication is also available to download from the Diocese website:

[www.hereford.anglican.org/content/pages/documents/DAC Bats and swifts in Hereford Churches.pdf](http://www.hereford.anglican.org/content/pages/documents/DAC_Bats_and_swifts_in_Hereford_Churches.pdf)



Figure 2: A1 posters were displayed in ten churches which were part of the HLF funded project.

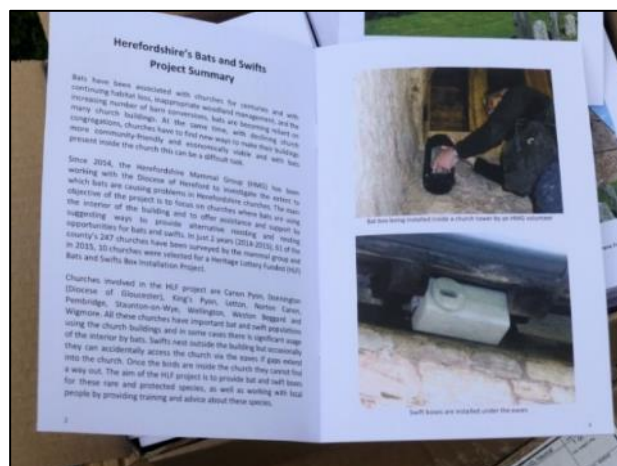


Figure 3: 1500 project booklets were produced and a PDF copy can still be downloaded from the Diocese website.



Figures 4 and 5: Modifications were carried out by folding back mesh and removing any sharp edges in various churches to allow bats access into areas where they would not cause the congregation any issues, particularly in the bell tower. These modifications allow access for bats but not problematic bird species such as jackdaws and pigeons.

In 2016, Docklow Church was also included in the project, because increasing numbers of bats using the interior of the church were causing concern. Whilst the HLF funded project had ended, the church community was happy to fund its own bat boxes, which the authors installed in the tower and around the churchyard and continue to monitor. The boxes installed in the church tower have continued to be in regular use by bats.

Ten churches (Table 1) were allocated bat and/or swift boxes, courtesy of the HLF grant. The positioning of all these boxes required approval from the Diocese and the local PCC prior to installation, particularly as many boxes were to be installed on the fabric of the church building.

Table 1: 14 Churches with Bat and Swift Boxes installed. Churches 1-10 were part of the HLF funded project 2015/2016. Churches 11-14 funded their own boxes.

No.	Church Name	Quantity	Bat/Swift Boxes
1	Canon Pyon	7	Bat Boxes
2	Donnington (In Herefordshire but within the Diocese of Gloucestershire)	7 2	Bat Boxes (2 wooden) Swift
3	King's Pyon	2	Swift
4	Letton	5 2 1	Bat Boxes Swift Bird
5	Norton Canon	4 2	Bat Boxes Swift
6	Pembridge	8 2	Bat Boxes Swift
7	Staunton-on-Wye	2 8	Bat Boxes Swift Boxes
8	Wellington	5 4	Bat Boxes Swift
9	Weston Beggard	5 2 1	Bat Boxes Swift Barn Owl Box
10	Wigmore	5 4	Bat Boxes Swift
11	Docklow	6	Bat Boxes
12	Weobley	3 2	Bat Boxes 2 Swift
13	Coddington	2	Swift
14	Cradley	2	Swift

Community outreach and media coverage

Public events such as bat talks and walks were arranged at churches where there was sufficient public interest, as well as publication of a series of articles about the project, which appeared in various community magazines and newspapers, such as the Church of England's Reflections, British Wildlife, the Hereford Times, Malvern Gazette/Ledbury Reporter. Unfortunately, some of the articles originally written by us were amended by editors and contain glaring ecological errors -particularly a persistent and annoying tendency to refer to bat roosts as nests!

The North Herefordshire MP, Mr Bill Wiggin, lent his support to the project and was keen to receive regular updates. In fact he has been instrumental in speaking up for bats in Parliament on our behalf on a couple of occasions, for which we are very grateful. Also, at our request, he later met with management staff of BCT to discuss issues of bats in churches.



Figure 6: Despite the misspelling of the author's name plus other editorial anomalies, this was one of two articles that were published by the local press.



Figure 7: Article in the Church of England publication Reflections (Summer 2016).

Local events included:

- Local Village Days (Wigmore and Hampton Bishop)
- Bat and Swift Walks and Talks (Putley, Wellington and Staunton-on-Wye)
- Talks to local Bat Groups (Herefordshire, Warwickshire, Midlands Bat Conference)

The authors were fortunate to have a long-term captive common pipistrelle *Pipistrellus pipistrellus*, called Princess, who was unable to be released due to a wing joint injury. Princess was instrumental in changing many people's perceptions about bats, particularly people who previously had phobias or just didn't like them. She was very placid and proved to be very popular at outreach events (Figure 8).

The National Bats in Churches Workshop Conference, organised by the Bats in Churches Project Group (Historic England, BCT, the Cathedral and Church Buildings Division of the Church of England, the Churches Conservation Trust and NE) was held in Coventry in May 2015. The purpose of the conference was to discuss the outcome of recent research and to share practical ideas about the needs of the bats using church buildings whilst preserving the buildings themselves. The conference was open to professional ecologists, bat group members and the church community and others who were actively interested in bats in churches.

We considered this event to be an important milestone to publicise and present the achievements in Herefordshire so far. There was good representation at the meeting with at least 200 delegates in attendance. Representing the church community for Herefordshire was Rev. Michael Cluett, vicar of the Wellington, Canon Pyon and King's Pyon group of parishes, two church wardens from Pembridge Church and members of the Hereford DAC. Whilst there was some fervent anti-bat sentiment expressed at the meeting, the overall positive attitude of the Herefordshire delegates was very encouraging - particularly since this included the vicar of our most affected church!



Figure 8: David Lee showing members of the church congregation Princess during a bats and swifts evening held at Staunton on Wye Church.



Figure 9: Denise Foster presenting at the National Bats in Churches Workshop conference in 2016.

Swift survey results

About swifts

Swifts were included as part of this project mainly because their ecological requirements are very similar to bats and the species is also in sharp decline. Swifts pair for life; they migrate individually but return to the UK in April/early May to meet up each spring at the same nest site. Swifts' nest sites are found high up under tiles, in holes in walls or under the eaves and they are very reliant on church buildings. They are faithful to their old nest sites and fail to breed if they lose them so it is essential to retain them during any repair works. Whilst bats are likely to have alternative roosting sites, this is not the case for swifts. If a nest site is destroyed then this will have a severely detrimental effect on that animal and may even result in its death.

Swift surveys

Swifts arrive in the UK at the end of April/early May and leave as early as mid-July/early August so the window of opportunity for surveying for these animals is extremely narrow. Consequently baseline surveying for swifts' required additional effort and the Herefordshire Ornithological Club (HOC) was recruited to help. At a meeting in 2017, the British Trust for Ornithology (BTO) representative and County Bird Recorder agreed that HOC would provide assistance to survey Herefordshire's churches for swift activity (additionally some HOC members with bat detectors were able to survey for bats as well).

HOC was keen to be involved and managed to recruit 18 members to carry out surveys during 2017. HOC members carried out 71 swift surveys and, together with our own efforts, a total of 92 swift surveys were performed that year, including at 39 churches that had not previously been surveyed. Overall a total of 128 churches were surveyed for swifts, some of which were surveyed more than once (Figure 10 and Appendix 1).

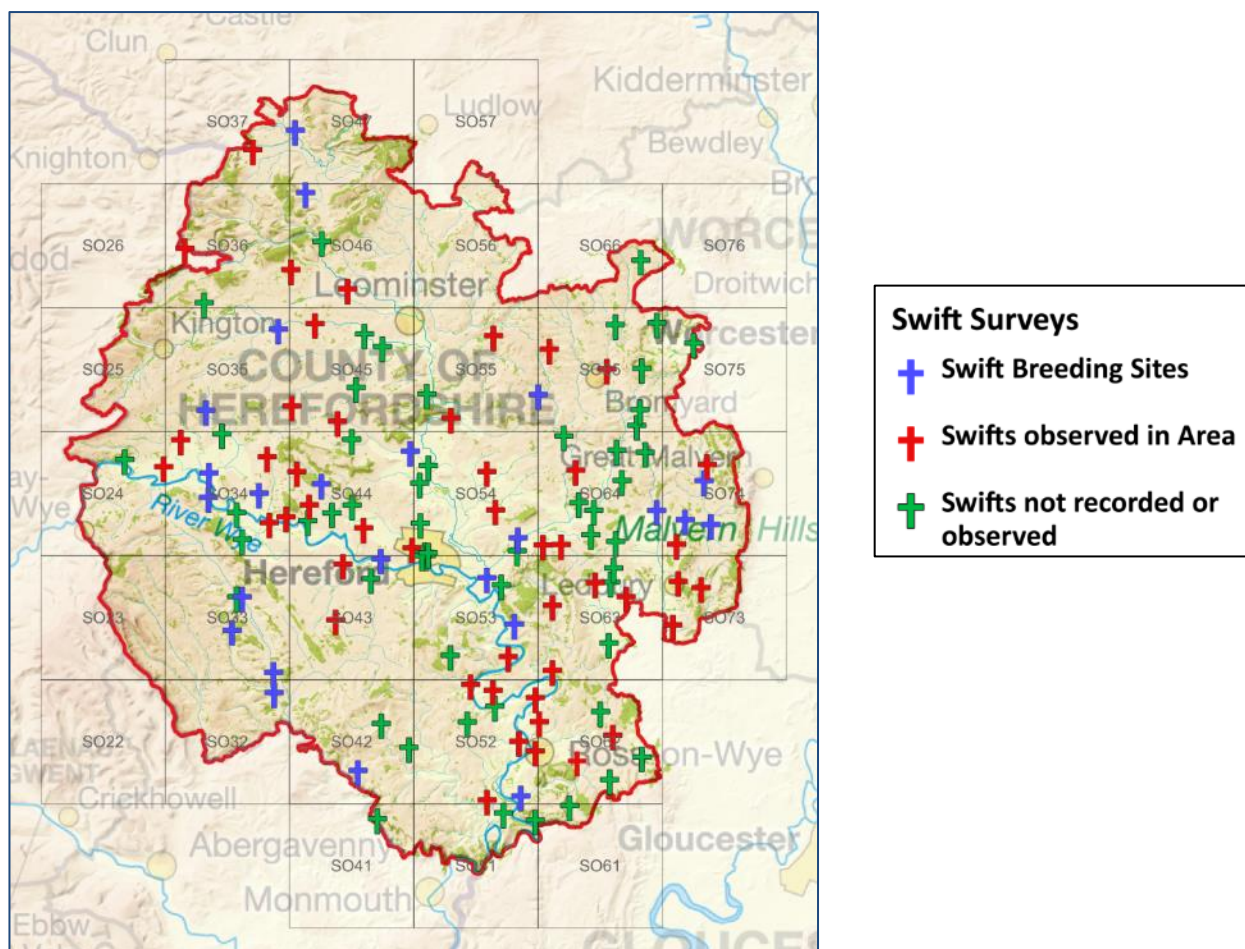


Figure 10: An overview of churches surveyed for swifts in Herefordshire between 2014 and 2017.

Swift Boxes

Schwegler Type 17 swift boxes were selected, mainly because they resemble a stone block and blend in well with existing masonry (Figure 11). A total of 34 swift boxes were installed between 2015 and 2020 at 12 Herefordshire churches; 20 boxes were part of the official HLF-funded Bats and Swifts in Churches Project and 14 were funded separately, eight by Severn Waste Services (supplied via HOC), two were self-funded and four were provided as enhancement during tower repair works at Staunton-on-Wye in 2018/2019. So far swift presence has been recorded in seven out of 22 boxes inspected. However, four boxes remain to be checked and a further eight boxes in three churches have been installed high up in bell tower louvres and so are not readily accessible so checking for occupancy will need to be carried out by visual observation during the breeding season.



Figure 11: Schwegler Type 17 Swift box - the box of choice for the Church.

Swifts at Staunton-on-Wye Church – a success story

This 13th century church was first surveyed in 2014. Seven natural swift nest sites were recorded; four in the cavities in the masonry of the tower wall, due to displaced mortar, and three under the eaves of the chancel roof. This church is very important for swifts, so emphasis was put on providing more nesting opportunities for future generations of birds. In 2015, four swift boxes were installed on the church building: three under the eaves on the north side and one under the eaves on the south side.

In 2016 and 2017, swift surveys were carried out and a total of 12 swift nest sites were mapped and recorded (rising to 16 if we include the four new swift boxes installed in 2015). In 2017, ten swift nests were active but they all were within the fabric of the building (Figure 12).

In 2017, the Church was planning major repair works to the building, particularly the tower, so every effort had to be made to save swift nesting sites. Funding for remedial works was granted in 2018 and tenders were being drawn up!

Meetings about the swifts were held with the church warden, the architect and the authors. Unfortunately there is currently no legal protection of traditional swift nest sites whilst they are unoccupied. However, since swifts are in such a steep decline, we felt an obligation to make every effort to retain their current nest sites. Fortunately the ecologist appointed was well known to us and all our reports, photographs and church plans were sent to him, so he was able to pinpoint and retain every nest site during the works, as well as adding further swift boxes high up in the tower. If a less vigilant ecologist had been appointed it is highly likely that these important nest sites would have been overlooked and destroyed.



Figure 12: Ten active swift nest sites on the south and west side of the church in 2017. Nest site no.12 on the north side was also active but out of view in this photo. ©Mike Bailey.

In 2021, a return visit to the church was arranged, following completion of the works to the tower. As promised by the ecologist, all the swift nest sites had been retained in the tower walls (Figure 13) and four additional swift boxes had been installed in the louvres of the tower (one on each side of the building, funded as part of the remedial works). The church warden informed us that swifts had returned in high numbers the previous year, so it was no surprise to find that three of the four swift boxes that we installed in 2015 now contained evidence of nesting swifts.

This was a win-win situation for the birds, the church congregation and the authors who strived to retain these nest sites. We are very grateful to both Richard Lamb of Hook Mason Architects and Mike Worsfold (consultant ecologist) for their help in conserving our local swifts.



Figure 13: The circled gaps in the masonry were retained during repointing works in 2021, saving existing swift nest sites. Nest sites between the corbels under the eaves were also retained.

Bat survey results

Bat surveys and roost visits

A total of 145 surveys was carried out between 2014 and 2020 at 108 out of 247 historic Herefordshire Churches (Appendix 2). Of these, only 18 churches showed no signs of bat activity within the building (Figures 16 and 17). The presence of bats is generally tolerated in the majority of churches and so far there has only been serious conflict in four churches - the main culprits being Natterer's bats (Figure 14).

Collaboration and forward planning between the Diocese of Hereford, church architects and the authors has improved over time, resulting in more NE VBRVs/bat emergence surveys being requested, particularly where remedial works were being planned.

A total of 33 full inspections/bat activity surveys was carried out between 2014 and 2020; 19 of which were official NE VBRVs (one visit was carried out in the County of Worcestershire - only just over the border, Figure 16). We estimate that the VBRV system must have saved each church that has made use of the service in the region of £500 to £1000 plus VAT (based on an estimate supplied by one of the church architects in 2016).

Surveys reveal that at least 11 species of bat make use of Herefordshire churches; with brown long-eared bat being the highest recorded (in 40/108 churches), followed by common pipistrelle and soprano pipistrelle *P. pygmaeus* (Figure 18).



Figure 14: Four churches in Herefordshire have maternity colonies of Natterer's bats using the interior of the church.



Figure 15: Brown long-eared bats were recorded in 40 out of a total of 108 churches.

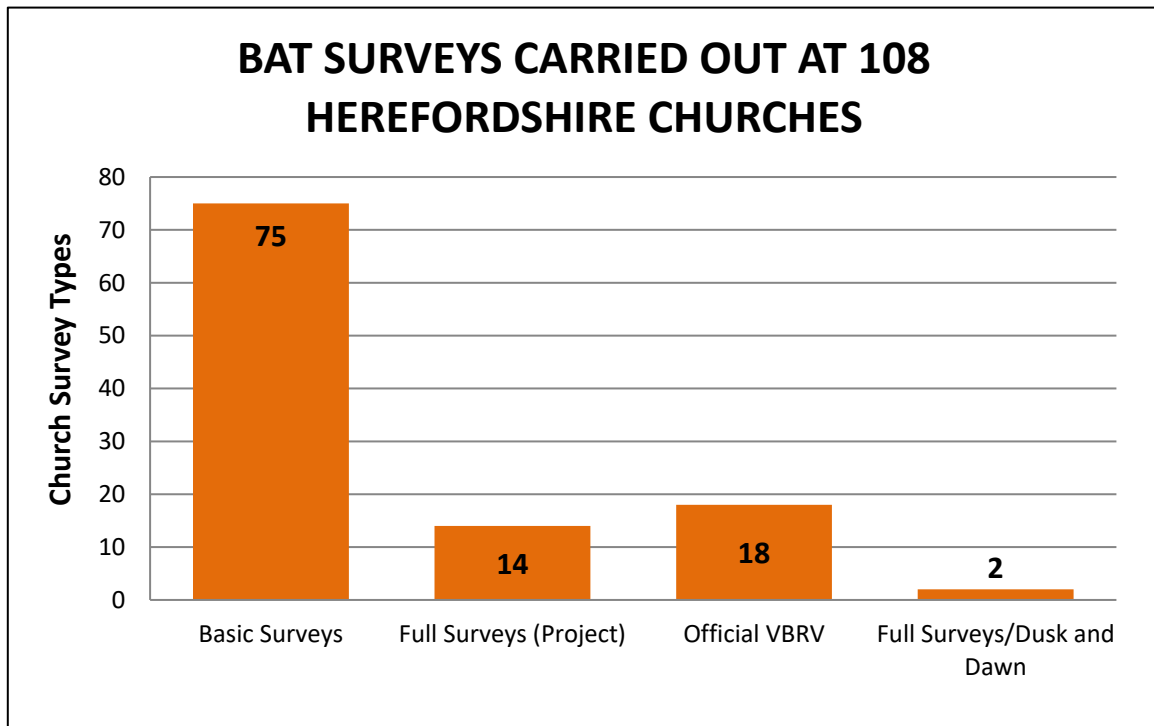


Figure 16: Survey types carried out at 108 Herefordshire churches from 2014 to 2020. A second VBRV visit was carried out at one church taking the total number of NE roost visits to 109. This graph shows the number of churches surveyed - not the total number of surveys performed.

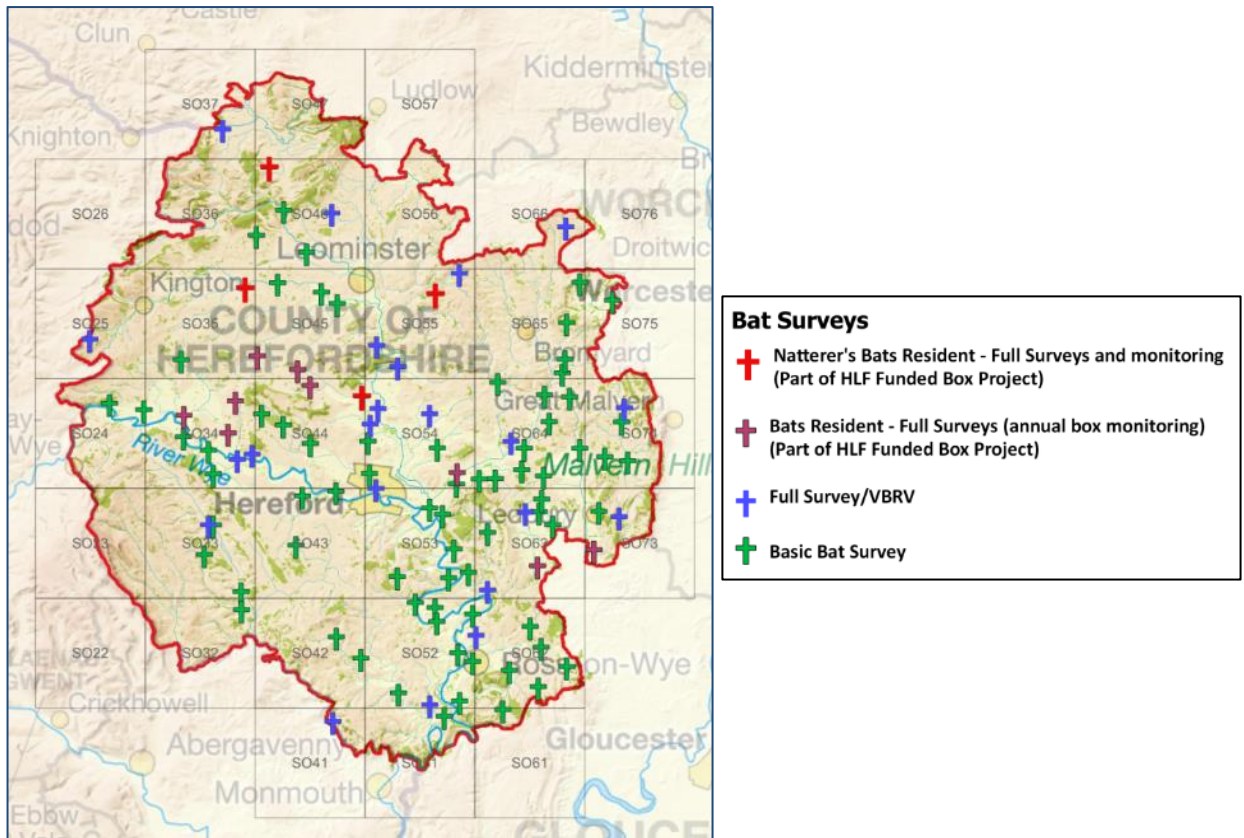


Figure 17: An overview of churches surveyed for bats in Herefordshire between 2014 and 2021.

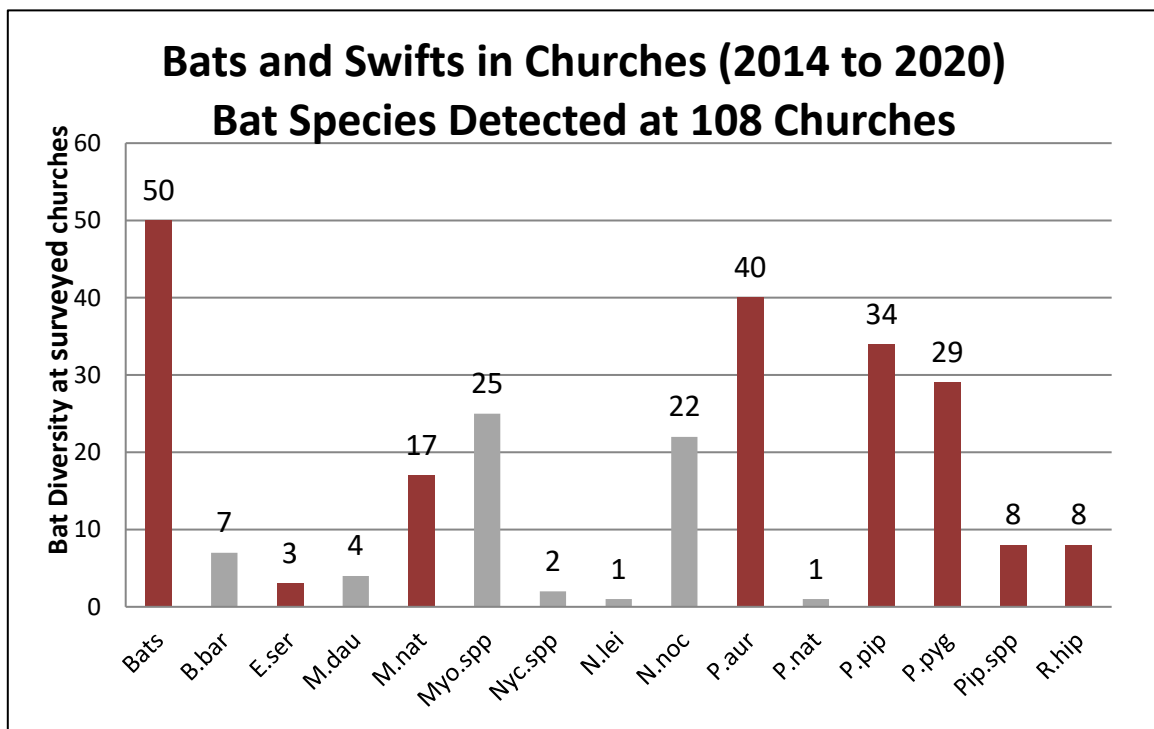


Figure 18: Bats species recorded in and around the church building at 108 Herefordshire churches. Red: Species using church buildings (externally and internally). Grey: Species recorded only during night-time bat activity surveys.

Bats were previously under-recorded in Herefordshire churches and this project has to date generated a total of 301 new records.

Bat Box Monitoring at Herefordshire Churches

A mix of Schwegler 1FS colony boxes and 2FN domed bat boxes was purchased with the aid of HLF grant funding (Figure 19). In 2015, 72 bat and swift boxes (48 bat, 22 swift, one bird and one barn owl box) were installed at ten Herefordshire churches. Since 2015, a further 22 boxes (14 swift and eight bat) have been installed at four Herefordshire churches (with funding from other sources).



Figure 19: Schwegler 2FN and 1FS boxes - the choice of bat boxes for the HLF-funded project.

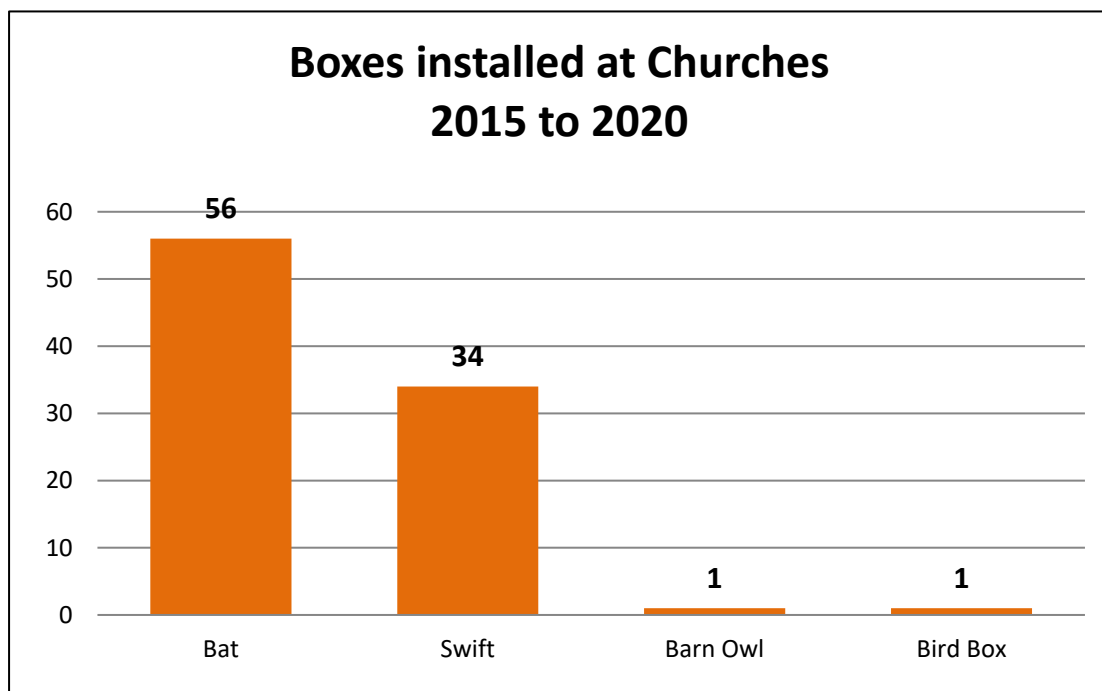


Figure 20: 92 bat and bird boxes were installed at 14 Herefordshire churches between 2015 and 2020.

Bat box results

Routine monitoring of bat and swift boxes installed at 11 churches has continued since the beginning of the project to the present. Particular attention is given to bat boxes installed inside bell towers (Figure 21).

Bell Towers: Bat boxes were installed in seven church towers. Since 2015 a total of 13 out of 15 boxes have been routinely used by bats - mainly *Myotis* species or brown long-eared bats.

Church Buildings: Permission was given to install bat boxes on the exterior fabric of eight church buildings. Since 2015, seven out of 22 of these boxes have been used by *Pipistrellus* species.

Churchyard: Bat boxes were installed on ash and yew trees in eight churchyards. Since 2015, six out of 20 boxes have been used by several species of bats: *Pipistrellus*, brown long-eared bats and unidentified *Myotis*.

Colony boxes (1FS) have generally been utilized by blue and great tits for nesting and roosting; only two out of ten of these boxes have been used by bats; one of which was inside a bell tower.

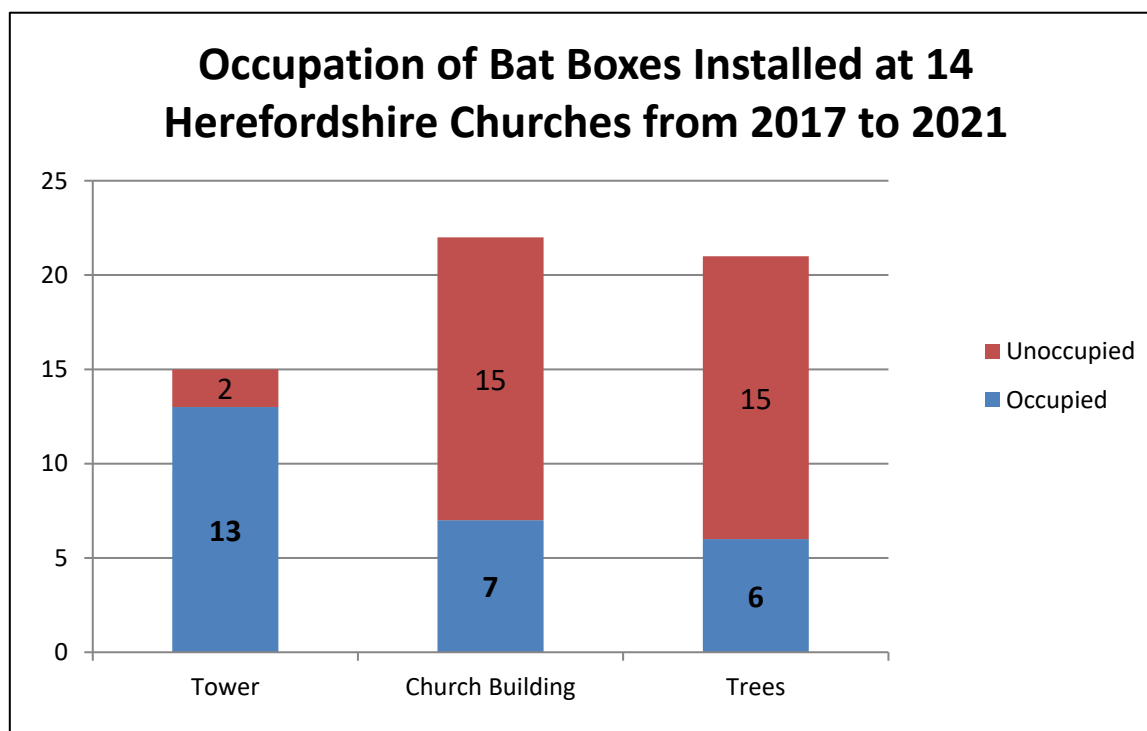


Figure 21: Graph showing bat box usage at 14 Herefordshire churches from 2017 to 2021.



Figure 22: Bat boxes sited inside the bell tower at Staunton-on-Wye are being used by brown long-eared bats.



Figure 23: Three brown long-eared bats roosting in a 2FN bat box sited in Letton churchyard.



Figure 24: All three boxes installed inside the bell tower at Docklow regularly contain bat droppings (*Myotis* or *Plecotus*).



Figure 25: *Pipistrellus* bats in a bat box sited on the church building at Weston Beggard.

Pembridge and Wellington churches

Very early on, Pembridge and Wellington churches were identified as having serious issues arising from maternity colonies of Natterer's bats roosting inside the church. In 2014, when the project started, both churches were extensively surveyed and were routinely monitored with annual emergence surveys until 2018. At this time both churches became part of the National Bats in Churches Project and professional consultants were employed to introduce measures to deter bats from using the church interiors. Despite these two churches being added to the National Project at our request we have so far not been involved in or informed about the outcome of these measures. However we have continued to monitor our own bat and swift boxes at both these sites.

Wellington

Wellington church has a large maternity colony of Natterer's bats (between 55 and 60 females) that roost inside the nave, causing considerable anguish to the church community. During the summer months the pews and other artefacts have to be covered due to the huge amount of faecal droppings and urine spotting that the bats produce when they fly around the roof space prior to emergence.

Originally the church hosted a small colony of brown long-eared bats that caused no significant problems, however the colony of Natterer's bats appeared at about the same time that barns and other agricultural buildings in the village began to be converted into dwellings (about 2009 - personal conversation with the parish priest). Wellington village contained an unusually large number of barns and one of the present authors has personally assisted with commercial bat emergence surveys prior to conversion of four of these sites! In addition a large old barn immediately opposite the church was completely demolished to make way for a new housing estate and the site remained completely empty for several years. Several more agricultural buildings remain unconverted within the village and the church has been advised to monitor planning applications to ensure that adequate surveys and compensation measures are specified in any future conversions.

A large number of surveys were carried out at the church, including an overnight stay for a dawn survey. The dawn survey identified four access points, including an open window in the Lady Chapel which is frequently open for ventilation during the summer months. Until 2018, this church was routinely monitored for bats and swifts by the authors.

Recommendations were made to the PCC and the Diocese to open up the bell tower to allow bat access. Unfortunately this suggestion was vetoed by the bell ringers. Ringing is carried out by the Hereford Cathedral team and the bell chamber is fully carpeted, the bell-frame freshly painted and the bells polished, so bats are definitely unwelcome! However we were permitted to open up access into the void above the timber barrelled ceiling above the chancel via a meshed lancet aperture (Figures 26 and 27). Whilst this showed great promise, unfortunately a new LED lighting fixture was subsequently installed in the car park opposite the church, which spilled too much light on the south and east side of the building. Following our advice, the church was in discussions regarding mitigation of this disturbance at the same time the responsibility passed to the National Bats in Churches Project consultants. At present we are not aware of the outcome - unless the light fixture was

suitably adapted there would be little chance that bats would investigate this new roost site, since Natterer's bats are more sensitive to light than other species.



Figure 26: There is an enclosed void above the timbered barrelled ceiling in the chancel (indicated by red line). The meshing of the lancet aperture has been opened to provide a potential alternative roost site for the colony of Natterer's bats currently using the church interior.



Figure 27: The modified aperture as it looks today.

A total of five bat boxes and two swift boxes were placed at the site, three 2FN bat boxes were already in situ on churchyard trees; although at a box check in 2021 it was noted that two of these bat boxes had gone missing during the COVID lock-down. LaFarge Tarmac (a local company) provided funding for two 1FS maternity boxes for installation on the church building near the bats access points (as well as permitting us to carry out a trapping survey at their gravel extraction site, about a kilometre from the church). A further two swift boxes were installed in 2021, funded by a local waste management company.

Pembridge church

Bat surveys revealed common and soprano pipistrelles and a maternity colony of Natterer's bats using the interior of Pembridge church. Based on emergence counts the size of the maternity colony of Natterer's bats was estimated to be approximately 45 females; somewhat smaller than the colony using Wellington church. As at Wellington, at least six surveys were carried out at the church, including dusk and dawn surveys, to determine where the bats were emerging. Whilst we would not consider the overall issue with Natterer's bats to be as severe as that at Wellington church, droppings and urine are concentrated in particular areas and along flight lines. Unfortunately the main maternity roost is directly over the children's play area, with a second major concentration of droppings scoring a bulls-eye on the priest's stall in the crossing. Understandably the priest and congregation considered this to be a problem!

Unusually, Pembridge has a very large, historically important, ancient, detached bell tower, which is separately in the care of a village amenity group, rather than the church. Whilst there was no evidence of Natterer's bat activity we did record a small maternity colony of brown long-eared bats roosting in the tower at the time of our surveys. In an attempt to encourage Natterer's bats to use the bell tower we installed five 2FN bat boxes within the tower, one high up amongst the bells.

Pembridge has the largest allocation of bat boxes from the HLF project (two 1FS, seven 2FN and two swift boxes). Since we installed the bat boxes, there has been evidence of bats using them, particularly those in the bell tower although all droppings in these boxes have so far been consistent with brown long-eared bats. Surprisingly the box closest to the bells is always found to contain droppings, despite regular bell-ringing and continual chiming of the clock great-bell! As with Wellington, this church has been monitored for both swifts and bats every year from 2015 to 2018 until it became part of the National Bats in Churches Project. Our monitoring checks in 2021 have continued to reveal evidence of brown long-eared bats using the bat boxes inside the tower.

Bats in Churches national project

The National Bats in Churches HLF bid, submitted by the NE/BCT partnership was successful in 2017 following rejection in 2015. The national project targeted 100 churches worst affected by the presence of large numbers of bats. Initial bat surveys at 100 churches nationwide were carried out by professional consultants including two Herefordshire churches (Pembridge and Wellington). Brimfield church in Shropshire was also included due to issues with Natterer's bats. Following these preliminary surveys, the worst affected churches were to be selected for mitigation measures to persuade the bats to use new roosting sites. At our suggestion, Wellington and Pembridge were selected and accepted in Herefordshire. In 2021, visits to Wellington and Pembridge revealed mitigation works in progress within both churches; however at present we are not aware of the state of completion of these works or their success or otherwise.

Shropshire

Since the Diocese of Herefordshire extends northwards into Shropshire, the Herefordshire Bats and Swift's in Churches Surveying Project was extended into Shropshire in 2016 and preliminary/basic surveys were carried out in partnership with Shropshire Bat Group. 38 Shropshire churches were surveyed as part of the project: 27 in the Diocese of Hereford and 11 in the Diocese of Lichfield. We are hoping that Shropshire Bat Group will be able to continue with the project within their county.

Conclusions

The main success of this project has been the raising of awareness of bats and swifts in local churches and the breaking down of barriers between bat workers and local church communities and getting them thinking about their local wildlife, particularly in relation to scheduled repair works. Project booklets, produced as part of the project, are an informative guide and contain information about promoting wildlife. Some churches have already made some small changes, particularly leaving areas of grass unmown in the churchyard.

It takes a long time for bats to find new roost sites, so the educational and promotional part of the project was deemed the most successful at the beginning. This project has built bridges with the local people and church congregations and they now feel they have some support.

One church (Wigmore) asked to retain their display board indefinitely. However, other churches have insufficient space to accommodate these large displays so they have been replaced by permanent laminated A4 posters (bearing the HLF logo). These are still present on the notice boards of most participating churches.

Project Booklets continue to be distributed to churches within the Diocese, both in Herefordshire and Shropshire. We have sufficient stock to distribute to new churches and other interested non-church groups if requested.

Church surveys have greatly increased our knowledge not only of how bats and swifts use our church buildings but also of the architecture and history of the buildings themselves. This has allowed us to engage more effectively with church communities and our volunteers have learned new skills along the way. The walks and talks that were part of the HLF project have also provided information and knowledge about bats and swifts to local church communities and we have received requests from some churches to repeat them in 2022.

Overall, working together with the Diocese, PCC, church wardens, architects and local church communities has been a very positive and rewarding experience for all concerned. Particularly encouraging has been the positive attitude towards bats developed by the vicar of our worst affected church - despite his continuing concerns over the high-level disturbance and distress caused by the Natterer's bats in his church.

Going forward, churches that have bats using the interior should be encouraged to open up bell towers, disused under-crofts and enclosed roof voids to allow bats access into less sensitive parts of the building. Access for bats can readily be created whilst continuing to exclude problem species. If bell towers are too draughty then bat boxes can be installed inside towers as this has shown promising results in Herefordshire.

Overall achievements of the project

- VBRV visits are now frequently requested prior to church repair work - one architect's estimate of potential saving to churches is between £9,500 and £19,000 + VAT.
- More churches now think about bats in good time when planning remedial works.
- Churches actively monitor local planning applications - particularly nearby barn conversions.
- Churches feel they have more support, which helps to reduce anxiety about bats.
- There is full support for this project both from the Diocese of Hereford and a local MP.
- The present authors are on the Diocesan list of approved advisers for wildlife in churches.
- Requests are still being received from churches for new bat/swift boxes.
- More churches are leaving areas of grass uncut for wildlife.

- Retention of particularly important swift nesting sites at Staunton-on-Wye Church.
- Creation of valuable roosting and nesting sites for target species.

Acknowledgements

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Last but by no means least: RIP Princess - the common pipistrelle!

Appendix 1 Swift surveys carried out from 2014 to 2017

Churches surveyed	Churches surveyed	Churches surveyed	Churches surveyed
All Saints (Hereford)	Cradley	Lea	St. Peter (Hereford)
Abbeydore	Credenhill	Ledbury	St. Margaret's
Acton Beauchamp	Docklow	Leintwardine	St. Weonards
Almeley	Donnington	Letton	Stanford Bishop
Ashperton	Dormington	Linton	Staunton-on Wye
Aston Ingham	Eardisland	Little Dewchurch	Stoke Edith
Aylton	Eardisley	Little Marcle	Stoke Lacy
Aymmestrey	Eastnor	Llanrothal	Stretton Grandison
Ballingham	Eaton Bishop	Mansell Lacey	Stretton Sugwas
Birley	Edvin Loach	Marden	Tarrington
Bishops Frome	Evesbatch	Marstow	Tedstone Delamere
Bishopstone	Ewyas Harold (Baptist)	Mathon	The Lea
Blakemere	Ewyas Harold (CofE)	Moccas	Tenbury Wells (Worcs)
Bodenham	Fownhope	Monkland	Thrupton
Bosbury	Foy	Mordiford	Titley
Brampton Bryan	Garway	Morton-on-Lugg	Turnastone
Bredenbury	Goodrich	Much Cowarne	Upper Sapey
Bredwardine	Hampton Bishop	Much Marcle	Upton Bishop
Breinton	Hentland	Munsley	Vowchurch
Brampton Abbots	Hoarwithy	Norton Canon	Walford
Bridge Sollars	Holy Trinity (Hereford)	Orcop	Wellington
Bridstow	Holmer	Pembridge	Wellington Heath
Bromyard	Holme Lacy	Pencombe	Weobley
Brockhampton Estate	Hope Mansell	Pixley	Weston Beggard
Byford	Hope-Under-Dinmore	Presteigne	Weston-Under-Penyard
Canon Pyon	How Caple	Preston Wynne	Whitbourne
Canon Frome	Ivington	Preston on Wye	Whitney-on-Wye
Castle Frome	Kenchester	Putley	Wigmore

Churches surveyed	Churches surveyed	Churches surveyed	Churches surveyed
Cathedral	Kingsland	Ross-on-Wye	Winforton
Cleohonger	King's Capse	Selleck	Withington
Coddington	Kings Pyon	Shobdon	Woolhope
Colwall	Kinnersley	St. Nicholas (Hereford)	Yazor

Colour Key

	Swifts seen in area
	Swift breeding sites at church
	No swifts observed at time of survey

Appendix 2 Bat surveys performed from 2014 to 2021

Churches surveyed	Churches surveyed	Churches surveyed
Abbeydore	Foy	Preston on Wye
Acton Beauchamp	Goodrich	Preston Wynne
Almeley	Hatfield	Putley
Ashperton	Hampton Bishop	Ross-on-Wye
Aston Ingham	Hoarwithy	Selleck
Aylton	Holme Lacy	Shobdon
Aymmestrey	Hope Mansell	Stanford Bishop
Ballingham	Hope-Under-Dinmore	Stoke Lacy
Bishops Frome	How Capse	Stoke Edith
Blakemere	Huntington	Staunton-on Wye
Bodenham	Ivington	Stretton Grandison
Bosbury	Kingsland	St. Margarets
Brampton Bryan	King's Capse	St. Weonards
Bredwardine	Kings Pyon	Tarrington
Breinton	Lea	Tedstone Delamere
Brampton Abbots	Ledbury	Tenbury Wells (Worcs)
Bridstow	Letton	Thrupton
Brockhampton	Linton	Turnastone
Brockhampton Estate	Little Dewchurch	Upper Sapey
Byford	Little Marcle	Upton Bishop
Canon Frome	Llangarron	Vowchurch
Canon Pyon	Llanrothal	Walford
Castle Frome	Mansell Lacey	Wellington
Cathedral	Marden	Wellington Heath
Coddington	Marstow	Weston Beggard
Colwall	Mathon	Weston-Under-Penyard
Cradley	Moccas	Whitbourne
Credenhill	Monkland	Whitney-on-Wye
Docklow	Mordiford	Weobley
Donnington	Morton-on-Lugg	Wigmore
Dormington	Much Marcle	Winforton

England – Midlands

Churches surveyed	Churches surveyed	Churches surveyed
Eardisland	Munsley	Withington
Eastnor	Norton Canon	Woolhope
Eaton Bishop	Orcop	Yarpole
Evesbatch	Pembridge	Yazor
Ewyas Harold	Pike Cum Lyde	
Fownhope	Pixley	

Colour Key:

	Full Surveys or VBRV
	Full surveys and Bat boxes
	Full surveys and Bat boxes (issues with Natterer's bats)

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Winter Bat Activity in a Suburban Garden

Alan Roe, Derbyshire Bat Group

records@derbyshirebats.org.uk

Introduction

Over the winters of 2019/20, 2020/21 and 2021/22, I left a static bat detector out in my South Derbyshire garden to see just how often bats were on the wing during their hibernation period. In 2019/20 it was an Anabat Express zero-crossing detector and in the following two winters a Wildlife Acoustics MiniBat full spectrum detector. The detectors recorded from sunset to sunrise every night throughout the winter, with data being analysed manually using AnalookW and Kaleidoscope software respectively. Identifications were made by comparing call parameters to reference values in Russ (2012) and Barataud (2015), although no attempt was made to identify *Myotis* bats to species level based on echolocation calls alone. Temperatures were recorded using the internal thermometers in the detectors.

The garden is on the edge of a suburban village and would best be described as moderate to high quality commuting and foraging habitat following the guidelines set out by Collins (2016); in addition to the surrounding gardens there are mature broadleaved and coniferous trees, a species-rich unmanaged hedge, a stream and an agriculturally improved grassland field all within 20m of the detector placement. There are known roosts of common pipistrelle *Pipistrellus pipistrellus* and brown long-eared bat *Plecotus auritus* in the village whilst soprano pipistrelles *P. pygmaeus* and Leisler's bats *Nyctalus leisleri* use bat boxes on the other side of the village. All 12 of the bat species on the Derbyshire list (Derbyshire Bat Group, undated) except Brandt's bat *Myotis brandti* have been recorded in the village over the last 20 years.

Results

Results for the core winter months of December to February in each winter are presented in Figures 1 to 3 below which show the number of passes by each species/genus per night and the temperature at sunset. Occasionally it was obvious from the sonograms that two bats were present together but usually only one was recorded at a time. The number of passes per night tells us nothing about the number of bats but does give an indication of how prolonged or intense the activity was on any given night.

Table 1 shows the percentage of nights when bat passes were recorded for each month in the three winters. Overall, bats were recorded on the wing on 49.4% of all 271 nights over the survey period.

In Figure 4 the percentage of nights when bat passes were recorded across the whole study period is shown as a function of temperature at sunset.

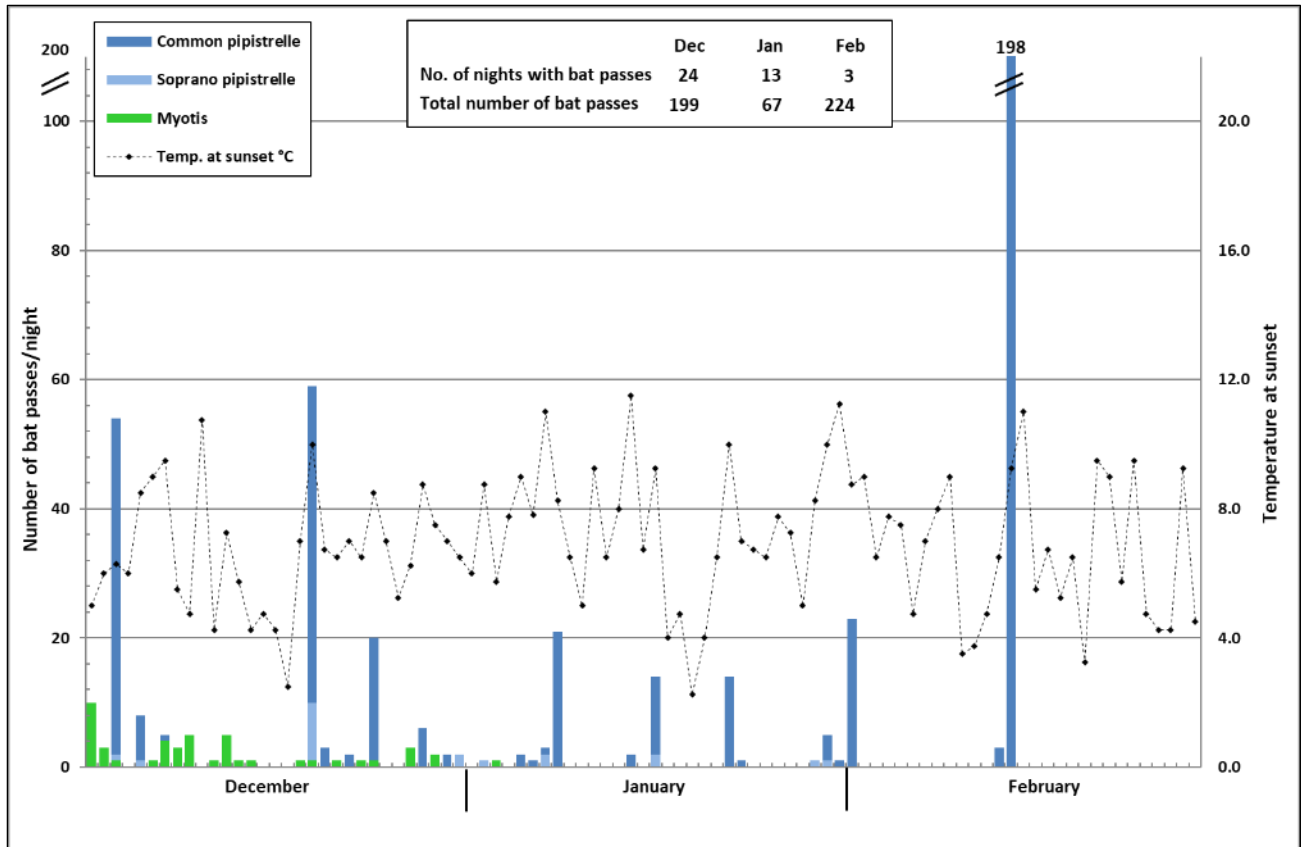


Figure 1: Nightly bat activity, South Derbyshire - December 2019 to February 2020.

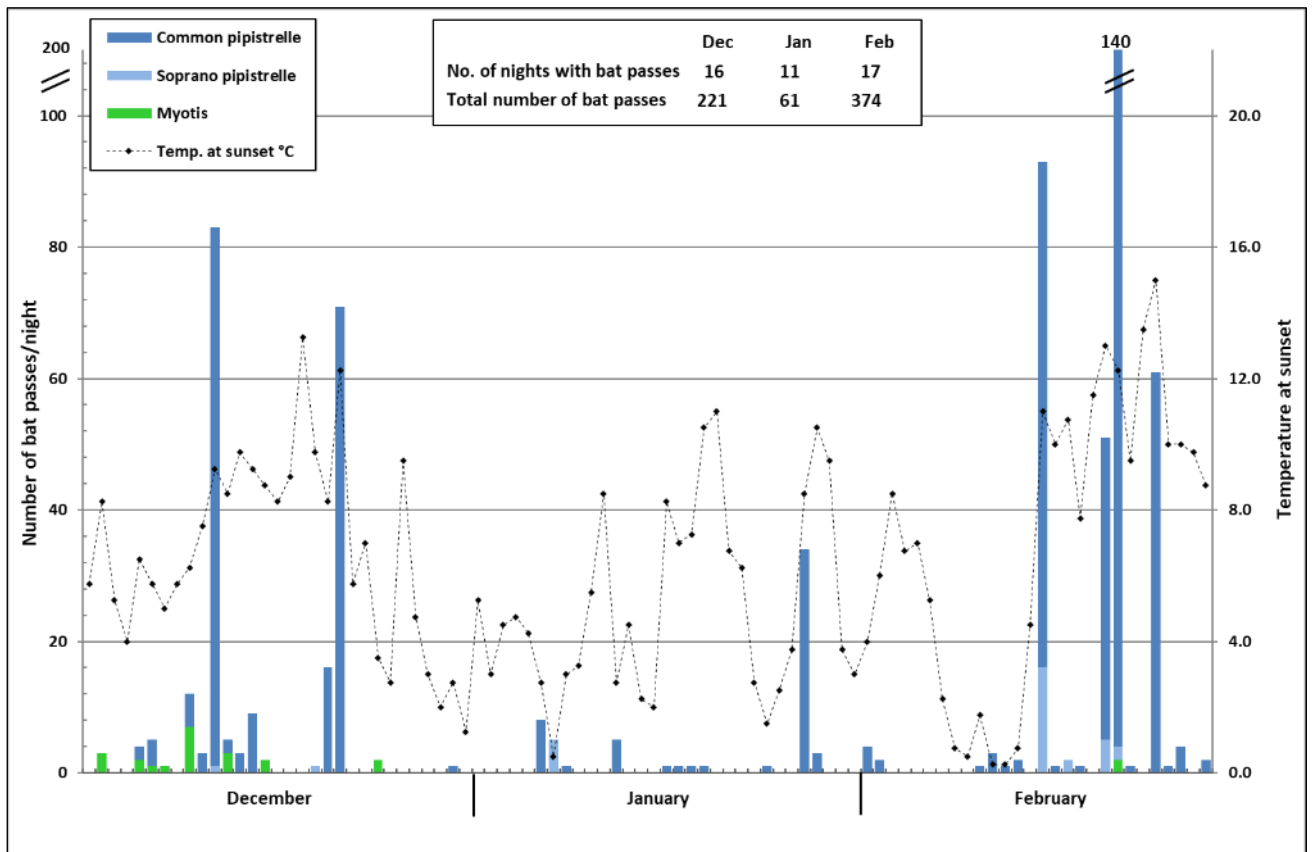


Figure 2: Nightly bat activity, South Derbyshire - December 2020 to February 2021.

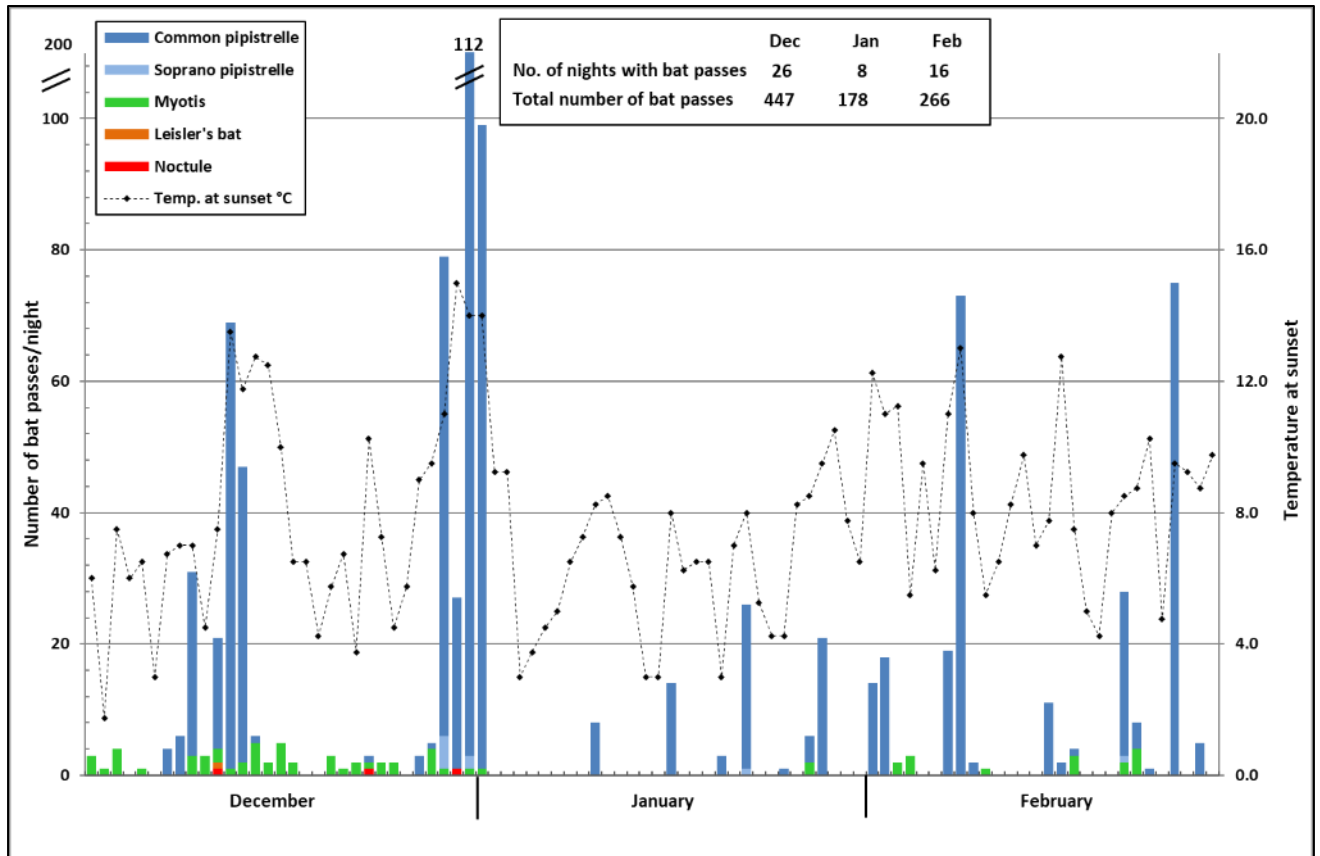


Figure 3: Nightly bat activity, South Derbyshire - December 2021 to February 2022.

Table 1: Percentage of nights with bat activity recorded-all species.

	December	January	February
2019-20	77	42	10
2020-21	52	35	61
2021-22	84	26	57
Average	71	34	43

Discussion

The first thing that is striking from Figures 1-3 is that bats are active, on and off, throughout the winter. Mostly the number of passes recorded per night is low but with occasional peaks of activity when multiple passes are recorded. These peaks tend to last for a period of 30 minutes or more and are often associated with social calls. For instance, on 14th February 2020 a common pipistrelle was persistently social calling from sunset until midnight, during which time the temperature fell from 9.3°C to 7.0°C. Echolocation calls were interspersed with regular type D social calls (Pfalzer and Kusch, 2003) at the rate of about one per second. The following night was even milder, with a temperature around 11°C from sunset until midnight but no bats were recorded that night or for the rest of the month. In the winter of 2019/20, the longest period without any bats was 16 nights over the second half of February (bats reappeared on 2nd March that year and were then present on most nights through the rest of the month) whilst in the 2020/21 and 2021/22 winters seven and eight nights respectively were the longest periods with no bats recorded.

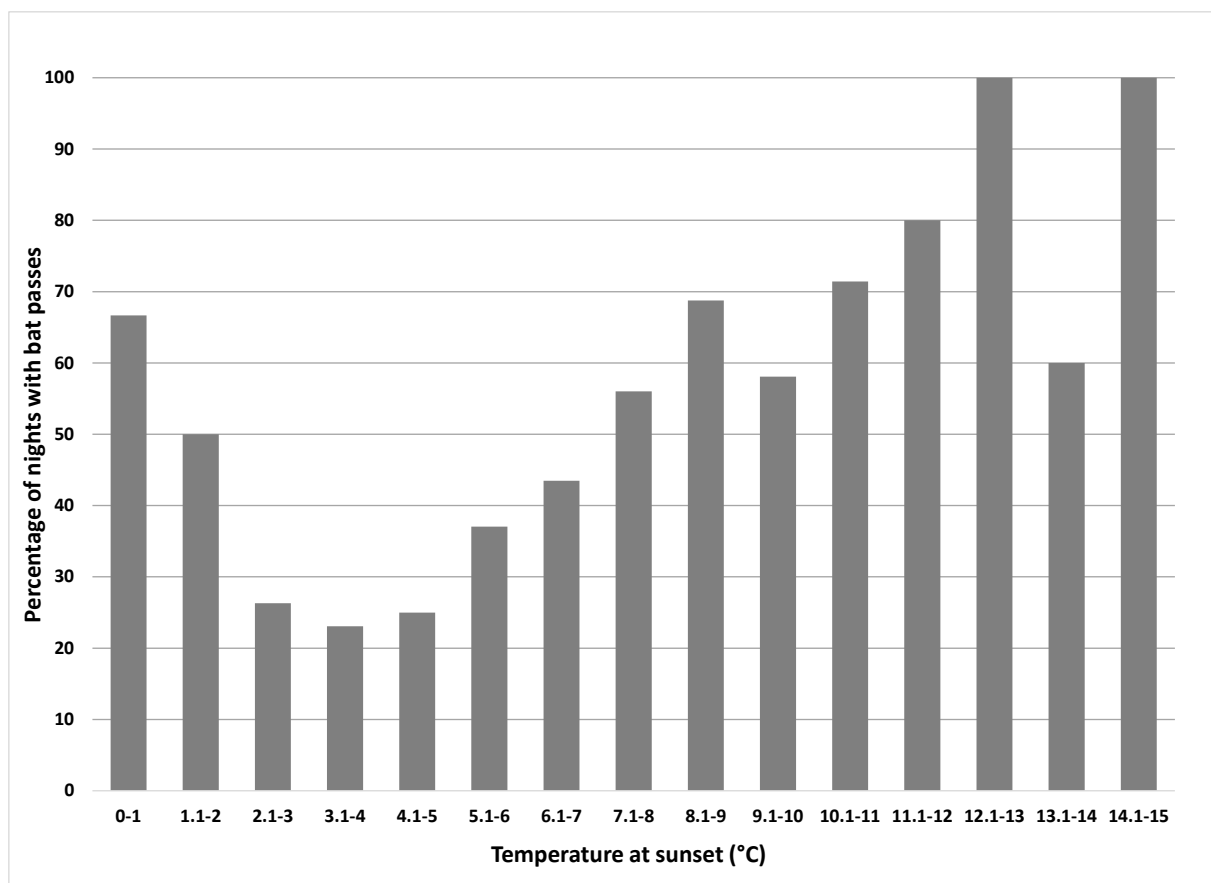


Figure 4: Effect of sunset temperature on winter bat activity.

Another noticeable feature is that *Myotis* bats tend to be active throughout December but then appear much less frequently. Common pipistrelles and the occasional soprano pipistrelle account for most of the activity through January and February each year. This may indicate that *Myotis* enter a more continuous period of hibernation in January and February, or it may be that my local individuals move to a more distant hibernation roost and are less likely to be detected flying past.

Although I regularly record noctules *N. noctula* over the garden and adjacent field during the summer months along with the occasional Leisler's bat, these species hardly showed up during winter, with the last records usually being in late November and the first in mid- to late March. The exception was December 2021 with single passes by a noctule on three nights and a Leisler's bat just once on the 11th. Similarly brown long-eared bats were not recorded in any of the three winters, although even in summer these 'whispering bats' are picked up only occasionally when they fly particularly close to the detector.

On average bats were recorded on more than two-thirds of December nights and over one-third of nights in both January and February, with February showing the greatest variation across the three winters (Table 1).

It is tempting to try and find a correlation between sunset temperature and bat activity. Many other factors including precipitation, wind and antecedent conditions might be expected to have a bearing on bat activity on any given night and would need to be accounted for in any predictive model. Nevertheless, nights with multiple passes tend to be

milder (Figures 1-3) and while bats do not appear on every mild night, as shown in Figure 4, bats are more likely to appear as the temperature at sunset increases above 4°C.

The high likelihood of bats appearing on nights when the sunset temperature is below 2°C (50% or better) would at first sight seem to be anomalous but may be due to bats switching roosts when conditions are very cold, as described by Korsten *et al.* (2016) and Bell (2019). Of course, in winter temperatures can fall quickly after sunset particularly on clear nights. Occasionally bats were detected flying in very cold temperatures, such as a *Myotis* bat on the wing in a temperature of -0.5°C at 02:17 on 10th December 2019 and a common pipistrelle flying in a temperature of -4.8°C at 07:15 on 11th February 2021; these may be examples of bats undertaking this roost switching behaviour.

Overall, our winters are getting milder, as evidenced by the long-term temperature anomaly charts published by the Met Office (Met Office, undated). Data for the three winters is shown in Table 2. Only January 2021 was colder than the 30-year average for England over the period 1961-1990.

Table 2: Mean temperature anomaly. Differences from 30-year average for period 1961-1990 (°C).

England	Dec	Jan	Feb
2019/20	+1.4	+2.8	+2.8
2020/21	+0.6	-0.4	+1.4
2021/22	+1.8	+1.2	+3.1

Is this tendency for milder winters resulting in an increase in winter activity? Fortunately, at least one person was investigating winter bat activity in the 1980s, environmental campaigner Mark Avery. His PhD thesis 'Winter Activity of Pipistrelle Bats' (Avery, 1983) was based on field work over the winters of 1980/81, 1981/82 and 1982/83.

Avery studied the winter activity of *Pipistrellus* over a three-year period at a nature reserve in Cambridgeshire and published his results in the Journal of Animal Ecology (Avery, 1985). He used a hand-held heterodyne detector, starting 30 minutes before sunset and finishing an hour after sunset or 30 minutes after the last bat contact. He didn't visit the site every night through the three winters but one of the charts he presents shows the percentage of survey nights on which *Pipistrellus* were active. I have compared Avery's results over three winters with mine over a similar period almost 40 years later to see whether *Pipistrellus* activity levels in the mid-winter months are comparable or strikingly different.

Several factors need to be borne in mind when viewing this comparison:

- The two sites are different. Habitat quality may have been higher on the nature reserve in Cambridgeshire which is around 135 km south-east of my South Derbyshire garden.
- Avery didn't stay out all night, unlike my static detector. On some nights I first detected bats much later than an hour after sunset, which Avery's methodology would have missed.

- Although Avery did detect noctules sometimes, the subject of a separate chapter in his thesis and another paper (Avery, 1986), he didn't detect *Myotis* bats and makes no mention of them.
- Avery's study took place before the separation of common and soprano pipistrelles into two species. I have therefore included both species from my results under *Pipistrellus* although most of my winter activity did relate to common pipistrelles.

In spite of these caveats, I think the comparison is worth making and is shown in Figure 5. It is immediately apparent that the amount of winter *Pipistrellus* activity I have recorded is not unprecedented and Avery saw similar levels nearly 40 years ago. Results for January are virtually identical and, in both studies, remarkably consistent. February activity varied much more between years within both studies.

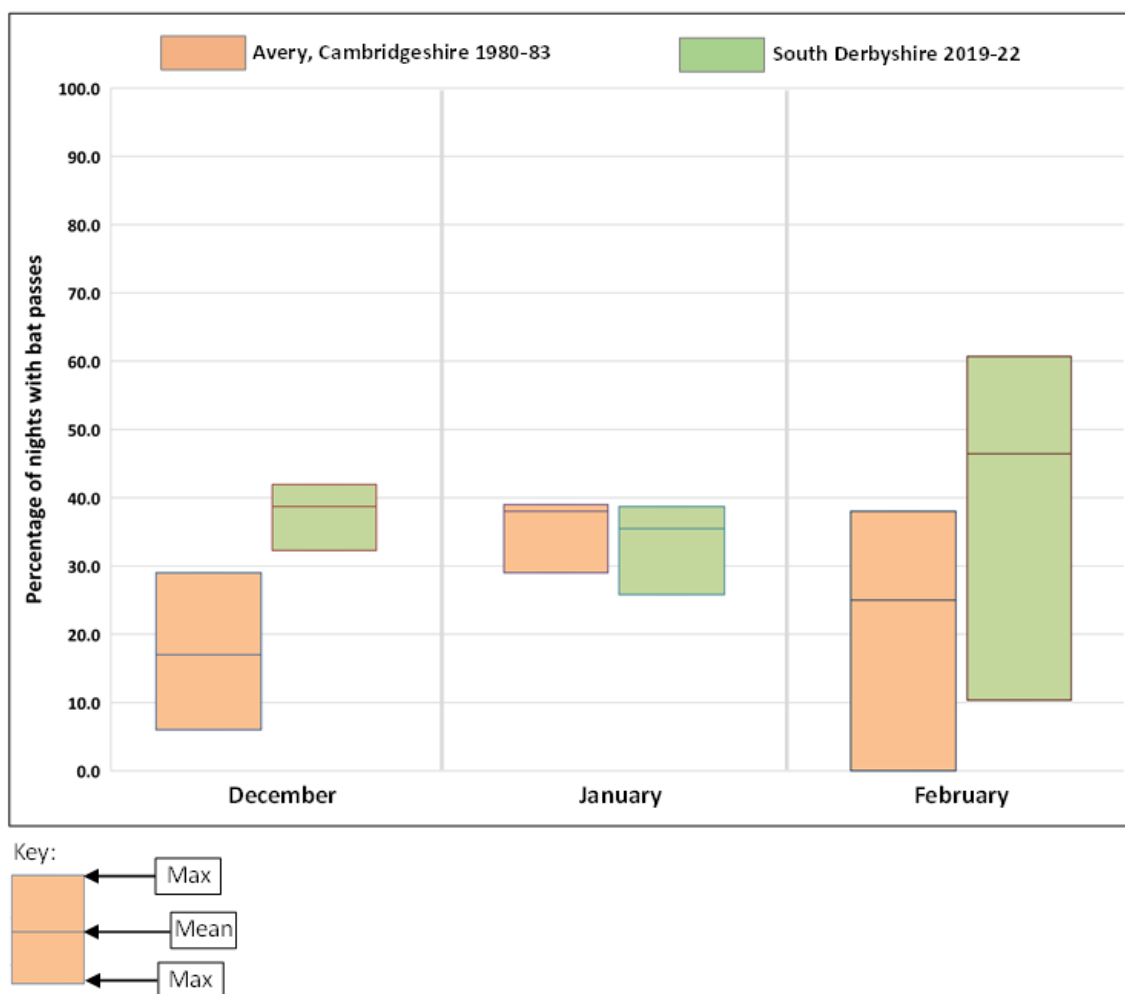


Figure 5: Comparison of winter *Pipistrellus* activity, 1980-83 and 2019-22.

Avery's conclusion from his study was that *Pipistrellus* were emerging in winter principally to feed although his PhD supervisor, Paul Racey, suggested in a paper six years later (Speakman and Racey, 1989) that the primary function of winter emergence is to drink in order to combat dehydration which remains the generally accepted view. Like Avery, I recorded feeding buzzes on some nights that *Pipistrellus* were active but by no means all. On some nights with extended periods of activity, persistent social calling consistent with song flight activity was noted, such as on 14th February 2020. Similar episodes were noted

in February 2021 and February 2022. Overall, I noted social calling by common pipistrelles on 45% of the nights that they were active and feeding buzzes on 23% of nights when they were recorded.

Over the three winters I recorded bats of all species on an average of 49% of nights during December, January and February. Common and soprano pipistrelles were on the wing on 37% of nights on average. This level of winter *Pipistrellus* activity is comparable with a study made almost 40 years ago. Avery recorded *Pipistrellus* flying on 25% of nights during the same months but the difference is mainly down to lower levels of activity in December. During January and February the amount of activity is remarkably similar in the two studies.

One possible conclusion from this comparison is that the high frequency of bat activity I recorded in winter, which was more than I anticipated, is not elevated as a result of warming winter temperatures but represents a level required to meet the need to feed and drink. Some winter flights may also be undertaken to switch roosts as temperatures drop, while prolonged activity by *Pipistrellus* on certain nights accompanied by persistent social calling (including, each year, deep into the hibernation period in February) may be associated with mating behaviour.

A repeat of Avery's work at the same site using similar methodology to provide a more direct comparison would be a worthwhile investigation for any bat workers living in the Cambridge area.

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Comparison of Visual and Emergence Count Methods at a South Yorkshire Tunnel

Peter Middleton and Robert Bell

robert.andrew.bell@gmail.com

Summary

Rockley Tramway Tunnel has been subject to extensive, albeit intermittent, bat study since Arthur Whitaker recorded the first roost there in 1905. In order to better characterise the tunnel's use by roosting bats, it was decided to undertake emergence surveys during each month of the year, coupled with pre- and post-emergence visual checks. We were curious what light the undertaking of emergence survey may shed on the number of bats roosting, with historic survey comprising almost exclusively visual inspections.

During eight of the twelve survey months, the number of bats recorded during emergence counts exceeded the number counted during the pre-emergence visual inspection, with the number the same according to both survey methods during only one month. Over the three remaining monthly surveys, the number of bats counted during visual survey exceeded the number emerging. Bats were recorded emerging from the tunnel during all monthly surveys, including during a cool, windy and damp January survey visit.

The study showed the value of winter emergence surveys on an underground site, highlighting another method that could be employed on all underground sites to provide additional confidence in the true number of bats roosting within, whatever the season. The use of both survey methods in combination was particularly effective in increasing the total count of bats roosting within the tunnel during the periods of apparent highest use, which in the case of this tunnel appears to be during the spring-flux, mating and autumn-flux periods.

Introduction

The bats of Rockley Tramway Tunnel near Barnsley in South Yorkshire have been surveyed almost annually for the Bat Conservation Trust's (BCT) National Bat Monitoring Programme (NBMP) since 1987. Indeed, the study of roosting bats at this site dates back to Arthur Whitaker's investigations, beginning in 1905 (Whiteley, 1987). An article documenting the tunnel's history and the findings of visual roosting bat counts made over a prolonged period within the tunnel were published in *The Naturalist* (Middleton and Bell, 2017).

Like many underground sites it is difficult to accurately count the true number of roosting bats present within Rockley Tramway Tunnel, with the vaulted dry-stone walls providing potential roosting opportunities for bats both between and behind stones. It is well understood that in most underground sites only a proportion of the bats roosting are likely to be seen during visual inspections (Mitchell-Jones and McLeish, 2004; Dietz and Kiefer, 2014). On this topic, the *Bat Worker's Manual* states '*as the size and complexity of the hibernation site increase, the probability that all bats will be observed and counted decreases*' (Mitchell-Jones and McLeish, 2014).

The purpose of this study was to compare visual inspections and emergence surveys, undertaken during all months, as a method of counting the bats roosting within Rockley Tramway Tunnel.

Rockley Tramway Tunnel is 25m in length and a little over 2m wide with an inside height of 2m at its highest point. It is built of the local sandstone in the drystone method by which structures are constructed without mortar. Consequently, there are an abundance of roosting features such as vertical and horizontal crevices and voids between stones at all heights across its length. The entrance was rebuilt and grilled by the Local Authority in 1978 with the opposite end having been sealed off with the exception of a ventilation hole (it was open ended at both sides prior to this). Limited repairs to the roof were undertaken by South Yorkshire Bat Group members in 2017.



Figure 1: The interior of Rockley Tramway Tunnel.

Methodology

The tunnel was surveyed once during each month of the year, although the survey visits were spread over a two-year period from October 2017 to August 2019 (Table 1). Each survey visit comprised an internal visual inspection undertaken by two surveyors, followed by an emergence survey beginning at sunset and continuing for a period of two hours. Following the emergence survey, a second visual inspection was undertaken to count any observable bats which had either failed to emerge, or which had entered the tunnel during the emergence survey.

Visual inspections were undertaken by experienced and licensed surveyors using torches only (no endoscopes were used). The species and number of bats were recorded during these inspections. Where a confident species identification was not possible, then the bat/s were recorded to genus only.

The emergence surveys were undertaken by one or more surveyors assisted by an infrared video camera (various models were used). The surveyors were positioned approximately 5m from the grilled entrance portal and when light levels were low, surveyors viewed the video camera/s to assist with observation. Segments of recorded video, during which bat activity had been observed were then reviewed on a computer screen to confirm observations

made in the field. During emergence surveys the number of emerging/returning bats was recorded, together with their species, where confident identification was possible. If bats returned prior to other bats emerging, then this was accounted for to give the minimum number of roosting bats present prior to the survey commencing.

Findings from the three survey approaches (pre-emergence visual inspection, emergence survey and post-emergence visual inspection) were then considered together to calculate the minimum total number of bats roosting within the tunnel that day. For example, to give a more complex example, if four Natterer's bats *Myotis nattereri* were counted during the pre-emergence visual inspection, with three Natterer's bats observed emerging (assuming none returned) and a further two Natterer's bats counted during the post emergence visual inspection; then the minimum total present the preceding day would be five Natterer's bats.

Basic weather information was also recorded prior to, and at the end of, each emergence survey (Table 1).

Table 1: Weather conditions during surveys.

Date	Temperature at start (°C)	Temperature at end (°C)	Wind (Beaufort Scale)	Precipitation
20/10/2017	13	12	3	
15/01/2018	6	4	4/5	Showers
09/04/2018	7	7	1	Light rain
24/07/2018	18	17	1	
29/09/2018	11	7	1	
26/11/2018	6	4	2	
21/12/2018	6	6	1	Drizzle
28/02/2019	5	5	1	
31/03/2019	7	3	1	
27/05/2019	10	10	1	
30/06/2019	17	15	3	
26/08/2019	16	15	3	

Results

The full findings of each survey visit are detailed in Appendix 1. Figure 2 shows the number of bats recorded roosting within the tunnel as measured using each of the three survey approaches (pre-emergence visual inspection, emergence survey and post-emergence visual inspection) and using all methods combined.

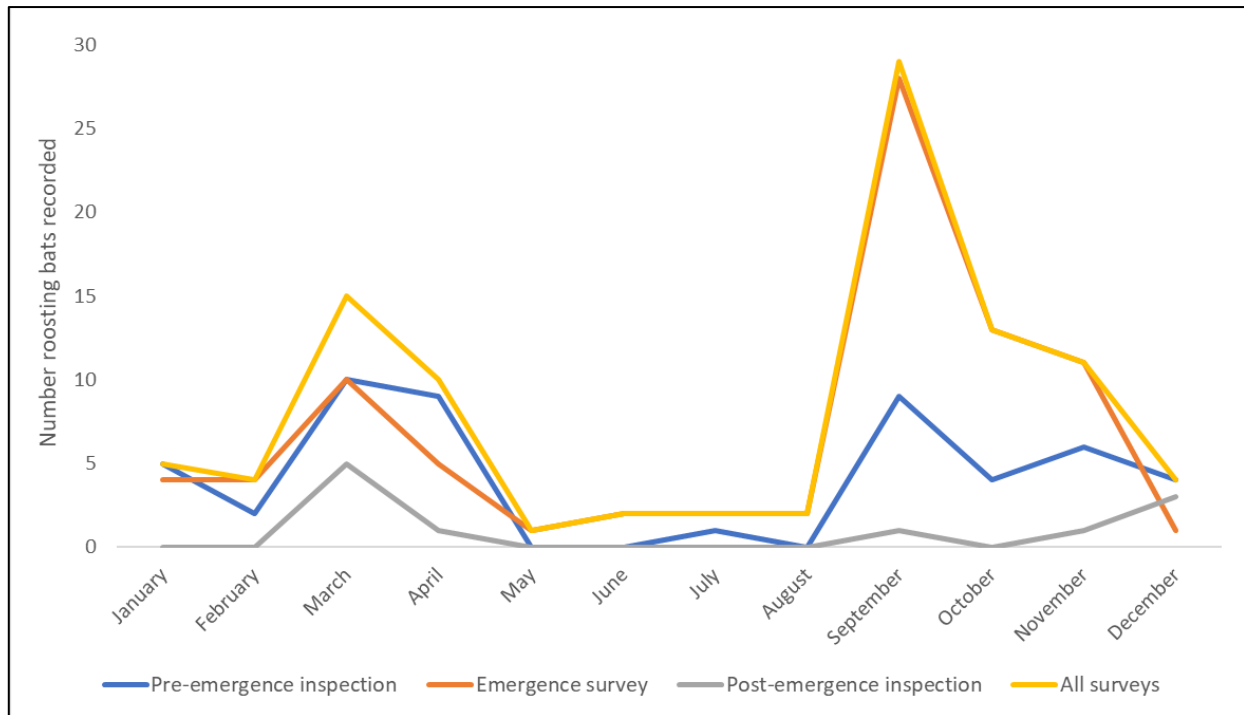


Figure 2: Comparison of number of bats recorded during each survey approach.

Three species of bat (brown long-eared bat *Plecotus auritus*, Natterer's bat and Daubenton's bat *M. daubentonii*) were recorded roosting within the tunnel, with roosting bats present in all months. At least one bat was recorded emerging from the tunnel during each of the 12 monthly survey visits, although in three months (May, June and August) no bats were visually observed roosting within the tunnel.

During eight of the 12 survey months (February, May, June, July, August, September, October and November), the number of bats recorded during emergence counts exceeded the number of bats seen during the visual inspections. During three of the survey months (January, April and December), the number of roosting bats recorded during visual inspections exceeded that recorded during the emergence surveys. The same number of bats were recorded during the pre-emergence visual inspection and emergence survey during the March survey. Visual counts of bats were much less than emergence counts during the September visit, when relatively large numbers of roosting bats were present within the tunnel, with this occurring during the autumn/mating period of the year. This later result was due largely to the difficulty of visually counting bats roosting in a cluster.

During five of the survey months (March, April, September, November and December), the post emergence visual inspection showed that at least one bat known to be roosting within the tunnel had not emerged. This was also the case during the January visit, although the bat which had not emerged could not be seen within the tunnel during the post-emergence inspection.

Surveys appear to show the highest level of roost use of the tunnel during the spring-flux, mating and autumn-flux periods (BTHK, 2018), although winter use may appear less partly due to a lower relative level of bat emergence activity during this period. Undoubtedly, roost use of the tunnel was lowest during the pregnancy and nursery periods.

Discussion

This study demonstrates the value of undertaking emergence surveys of underground sites during all seasons. Whilst visual inspections recorded a higher number of bats than the subsequent emergence surveys during two of the three core winter months (December and January), as would be expected, this was not the case during the February visit. We were quite surprised by the level of bat emergence activity recorded during winter survey visits, including on a notably cool, windy and showery night in January. In instances where internal inspections of underground sites cannot be safely carried out, static detector surveys present one alternative survey option and their undertaking is recommended in the current bat survey guidelines (Collins, 2016). It is however very hard to get any idea of the number of bats roosting at a site through static survey alone. Data collected during this study suggests that a valid complementary survey option comprises winter emergence surveys, with this survey type sometimes yielding useful count data, even in apparently poor weather conditions.

It was also notable that post-emergence survey visual inspections often recorded bats which had failed to emerge, particularly outside the core bat activity survey season (May-August) (Collins, 2016). Whilst not a surprise, this does demonstrate the value of such post-emergence checks, in enabling a more accurate count of the total number of bats present, where conditions allow for these post-emergence checks to be carried out.

In the case of understanding bat roost usage of Rockley Tramway Tunnel, the combined use of visual counts and emergence survey during all months has provided an increased understanding of tunnel's use by roosting bats, particularly in terms of more accurate roost counts. However, the most effective survey method depends to some extent upon the season.

It is notable that when bat roost usage appears to be highest (during the spring-flux, mating and autumn flux periods), the advantage of using both methods in combination was most apparent. This study shows that Rockley Tramway Tunnel, which superficially appears to be a classic hibernation site, actually appears to be used most outside the core hibernation season. This pattern of use is likely to be the case in many other similar situations.

Acknowledgements

Thank you to Greg Slack and Amanda Murphy who helped with these surveys. Greg Slack's comments on the draft of this document were also much appreciated.

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Appendix 1 Survey results.

Key to abbreviations used in table: Mn - Natterer's bat, Md - Daubenton's bat, M? - unidentified *Myotis* species, Pa - brown long-eared bat

Monthly repeat	Date	Num. of bats during pre-emergence visual inspection	Visual observations during pre-emergence visual inspection	Min. num. bats emerging during activity survey	Emergence survey results [#]	Num. of bats during post-emergence visual inspection	Visual observations during post-emergence visual inspection	Min. num. of bats roosting during preceding day	Seasonal period (BTHK, 2018)
January	15/01/2018	5	x2 Mn, x2 Pa, x1 M?	4	Emerged: x4 M? Returned: x1 M?	0	No bats observed	5	Winter
February	28/02/2019	2	x1 Mn, x1 Md	4	Emerged: x4 M? Returned: x1 Pa	0	No bats observed	4	Winter
March	31/03/2019	10	x6 Md, x2 Mn, x2 Pa	10	Emerged: x6 Md, x4 Mn Returned: no bats	5	x3 Pa, x1 Mn, x1 Md	15	Spring-flux
April	09/04/2018	9	x6 Mn, x2 Md, x1 Pa	5	Emerged: x5 M? Returned: x5 M?	1	x2 Pa	10	Spring-flux

England – North East

Monthly repeat	Date	Num. of bats during pre-emergence visual inspection	Visual observations during pre-emergence visual inspection	Min. num. bats emerging during activity survey	Emergence survey results [#]	Num. of bats during post-emergence visual inspection	Visual observations during post-emergence visual inspection	Min. num. of bats roosting during preceding day	Seasonal period (BTHK, 2018)
May	27/05/2019	0	No bats observed	1	Emerged: x1 Pa Returned: x5 Mn	0	No bats observed	1	Pregnancy
June	30/06/2019	0	No bats observed	2	Emerged: x2 Mn Returned: x3 Mn	0	No bats observed	2	Pregnancy
July	24/07/18	1	x1 Pa	2	Emerged: x1 Mn, x1 Pa Returned: no bats	0	No bats observed	2	Nursery
August	26/08/2019	0	No bats observed	2	Emerged: x2 Mn Returned: x1 Mn	0	No bats observed	2	Nursery

Monthly repeat	Date	Num. of bats during pre-emergence visual inspection	Visual observations during pre-emergence visual inspection	Min. num. bats emerging during activity survey	Emergence survey results [#]	Num. of bats during post-emergence visual inspection	Visual observations during post-emergence visual inspection	Min. num. of bats roosting during preceding day	Seasonal period (BTHK, 2018)
September	29/09/2018	9	x9+ Mn*	28	Emerged: x35 Mn Returned: x7 Mn	1	x1 Pa	29	Mating
October	20/10/2017	4	x4 Mn	13	Emerged: x13 Mn Returned: no bats	0	No bats observed	13	Mating
November	26/11/2018	6	x5 Mn, x1 Pa	11	Emerged: x10 Mn, x1 Pa Returned: no bats	1	x1 Pa	11	Autumn-flux
December	21/12/2018	4	x2 Mn, x2 Pa	1	Emerged: x1 Mn Returned: no bats	3	x1 Mn, x2 Pa	4	Autumn-flux

*Minimum estimate number of bats roosting in cluster

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Crank Caverns Monitoring Results 2000-2020

Stan Irwin; Merseyside and West Lancashire Bat Group (MWLBG)

bat.man47@talktalk.net



Figure 1: One of the hibernation teams inside Crank Caverns.

Background and introduction

Crank Caverns is the common name of the remains of the sandstone Rainford Delph Quarry; it is located near Crank, St. Helens, Merseyside (Figure 2). The mines are an example of pillar and stall mining, with the roof being supported by pillars of stone left in place when mining was taking place (Figure 3). There are two sections of the mine, lower and upper; the lower level (Figures 4 and 5) is more extensive than the upper. It is highly probable that at one time the entire system was more extensive but over time deeper tunnels/chambers have been effectively sealed or collapsed. There are numerous myths and legends associated with the caverns including the presence of aggressive dwarves, missing children, human bones, presence of a Cathedral chamber and in 1547 persecuted Catholics taking refuge from the rampaging Henry VIII despite the fact that mining at the quarry only began in about 1730! For many years, and to this day, regular human disturbance and constant littering takes place along with an increase in graffiti. An attempt was made to grill the lower entrance (Figure 6) but after many attacks it was finally breached (Figure 7). The mine is located on private land but by kind permission of the landowner MWLBG have been granted access.



Figure 2: Area in which Crank Caverns is located.



Figure 3: Pillar and stall mining method.



Figure 4: Lower level plan.



Figure 5: Section of Lower level.



Figure 6: Lower entrance grille being installed.



Figure 7: Lower entrance grille after being vandalised.

Status of Crank Caverns

Currently the mine is the only ‘typical’ subterranean hibernacula in Merseyside that has been accessed. In 2012 acoustic monitoring was undertaken over the autumn swarming¹ season during which time six of the nine species currently recorded in Merseyside were identified (Table 1). In more recent years catching bats with mist nets and harp traps by South Lancashire Bat Group (SLBG) and MWLBG have confirmed those species (Figure 8). Captured bats were ringed with the use of standard lightweight forearm rings and have been recaptured during subsequent swarming surveys in addition to ringed bats being found hibernating within the mine. The mine is located amid an agricultural landscape surrounded by mix of young semi-mature broadleaf trees and is not directly linked to other woodland patches or hedgerow within the wider habitat. During the swarming season it was noted that several bat species forage along the hedgerow to the south east of the mine but to arrive at the mine bats have to cross a distance of 180m over an open field. Owing to its hibernation value the mine is designated as a Local Wildlife Site within Merseyside.

Localised bat roosts

Small common pipistrelle *Pipistrellus pipistrellus* and brown long-eared bat *Plecotus auritus* roosts are known to be present in the locality of the mine but the only recorded *Myotis* roost is located approximately 1.8km north, a whiskered bat *Myotis mystacinus* roost comprising of six bats in a residential dwelling and it is more than probable that these bats will use the mine (Tyrer Ecological Consultants Ltd, 2020). Daubenton’s bat *M. daubentonii* frequently use a large lake 1.8km south east of the mine from which there is some connectivity in the form of a brook and treeline/hedgerow, although not linearly continual to the mine.



Figure 8: Processing bats during trapping session.

Table 1: Bat species recorded in Merseyside.

¹ Swarming activity in context with these monitoring results is described as ‘the gathering of bats at the entrances of underground sites in late summer and throughout the autumn months’ (Dietz and Keifer, 2014). The practice is not fully understood but is believed to be associated with mating/social behaviour and/or investigation of hibernation opportunities.

Species	Recorded in Merseyside	Recorded in Crank Caverns
Daubenton's bat <i>Myotis daubentonii</i>	Yes	Yes
Brandt's bat <i>Myotis brandti</i>	Yes	Yes
Whiskered bat <i>Myotis mystacinus</i>	Yes	Yes
Natterer's bat <i>Myotis nattereri</i>	Yes	Yes
Noctule <i>Nyctalus noctula</i>	Yes	No
Common pipistrelle <i>Pipistrellus pipistrellus</i>	Yes	Yes
Soprano pipistrelle <i>Pipistrellus pygmaeus</i>	Yes	No
Nathusius' pipistrelle <i>Pipistrellus nathusii</i>	Yes	No
Brown long-eared bat <i>Plecotus auritus</i>	Yes	Yes

Monitoring

Monitoring for hibernating bats commenced in 1994 with just two surveyors but has since increased, however to keep disturbance to a minimal, the surveys are limited to four-five surveyors on two occasions over the hibernation season of December-March. Sample data was taken over twenty years for comparison purposes and in an attempt to quantify any population trend the sample period was divided into two ten year blocks. 2000 was selected as a start date as by then the hibernation surveys were more regularly conducted by several people, which gives a greater chance of bat detection, and that more experience and knowledge of the site was achieved since the initial survey during 1994.

Monitoring results

Similar to most hibernacula the species and numbers that utilise Crank Caverns will be subject to a number of influencing factors as described below:

- Species variable seasonal times of entering hibernation
- Ambient temperatures during or just before the hibernation season
- Temperature and humidity fluctuations within hibernaculum
- Changes to an entrance or change of features within
- Disturbance

Species and numbers

Figure 9 illustrates the species/species groups and numbers recorded over two ten-year periods, 2000-2010 and 2011-2020 and Figure 10 illustrates the percentage use of the mine by species/species groups. Table 2 lists the species/species groups considered in the analysis. Surveys have not been conducted in 2021 in accordance with the International Union for Conservation of Nature (IUCN) current guidelines in as much as human-bat close contact should be avoided wherever practical due to risk of human-bat Covid transmission.

Table 2: Key to species references in the figures within this report.

Species	Abbreviations used in Figures	
Daubenton's bat <i>Myotis daubentonii</i>	M.d	Md
Whiskered/Brandt's bat <i>Myotis mystacinus /brandti</i>	M.m/b	Wab
Natterer's bat <i>Myotis nattereri</i>	M.n	Mn
Brown long-eared bat <i>Plecotus auritus</i>	P. a	Pa

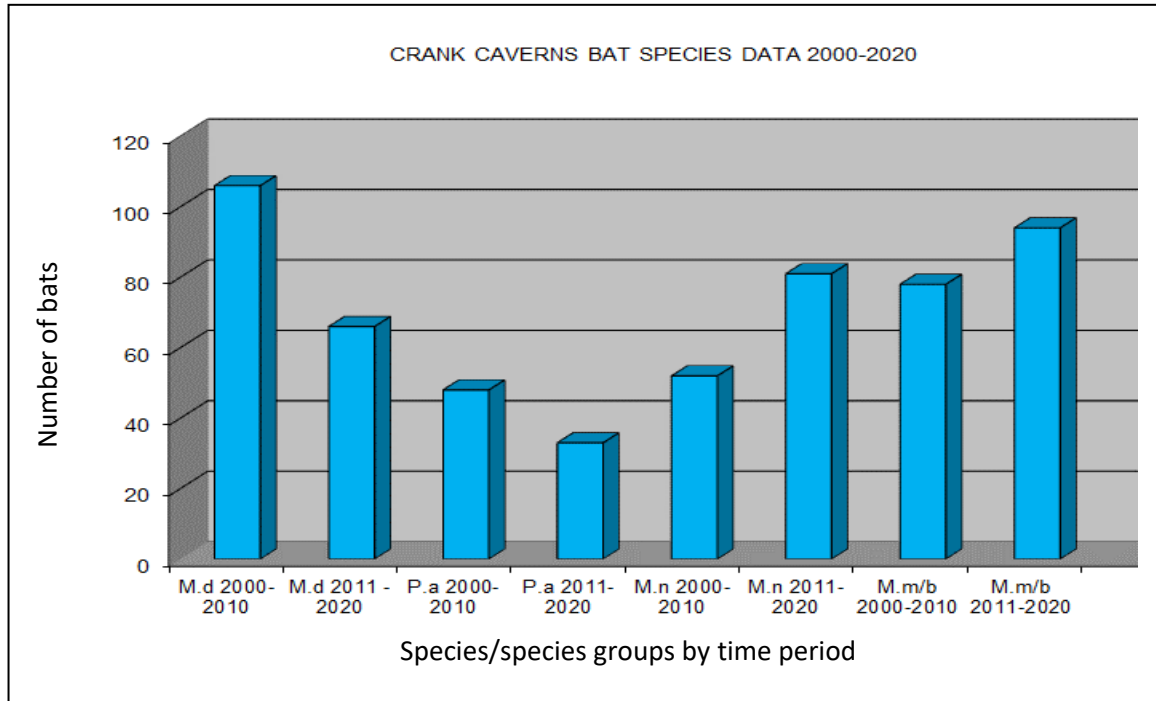


Figure 9: Total numbers of bat species/species groups for each time period.

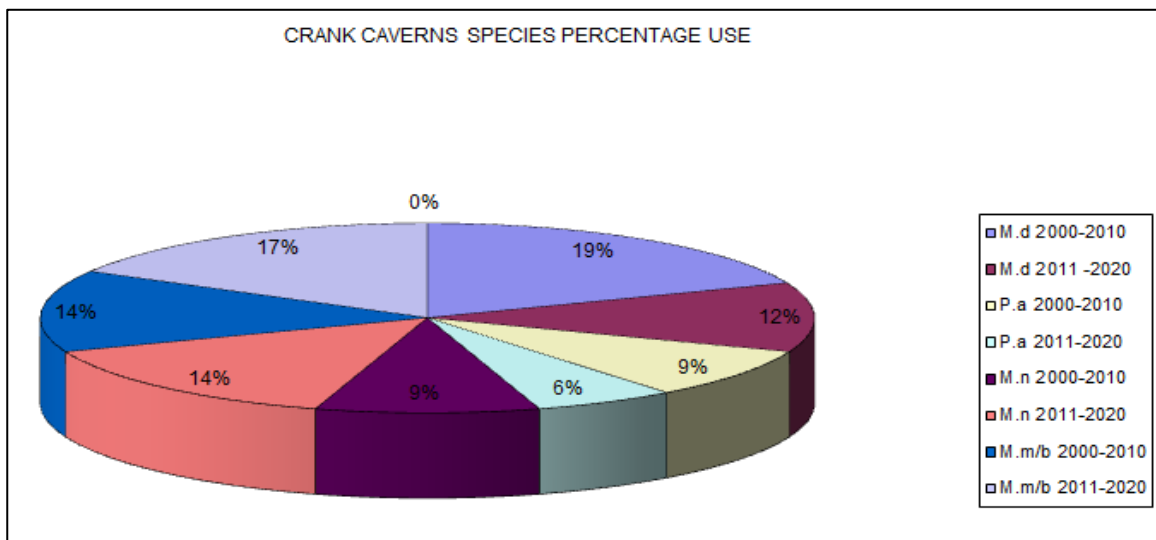


Figure 10: Total species/species groups percentage use of Crank Caverns for each time period.

Survey results

The survey results reveal several distinct trends notably a decrease in Daubenton's bats and brown long-eared bats and an increase in whiskered/Brandt's bats² and Natterer's bats. Notwithstanding these trends the influencing factors that have previously been mentioned may account for number variations, however taking into consideration the long-term survey

² Whiskered bat and Brandt's bat are very similar species which can only be differentiated in the hand (Dietz and Keifer, 2014), therefore they are generally referred to for recording purposes as whiskered/Brandt's bat.

periods it can be concluded that the data reflects a reasonably robust indication of species trends.

Whilst the data is localised it should be noted that a ringed Natterer's bat from the mine was recaptured during summer at a site over 8km away, clearly demonstrating that the mine is attracting bats outside of a localised environment.

Individual species numbers and trends

In addition to assessing the total number and species/species groups using the mine the data was interpreted to look at individual numbers and trends (Figures 11-14).

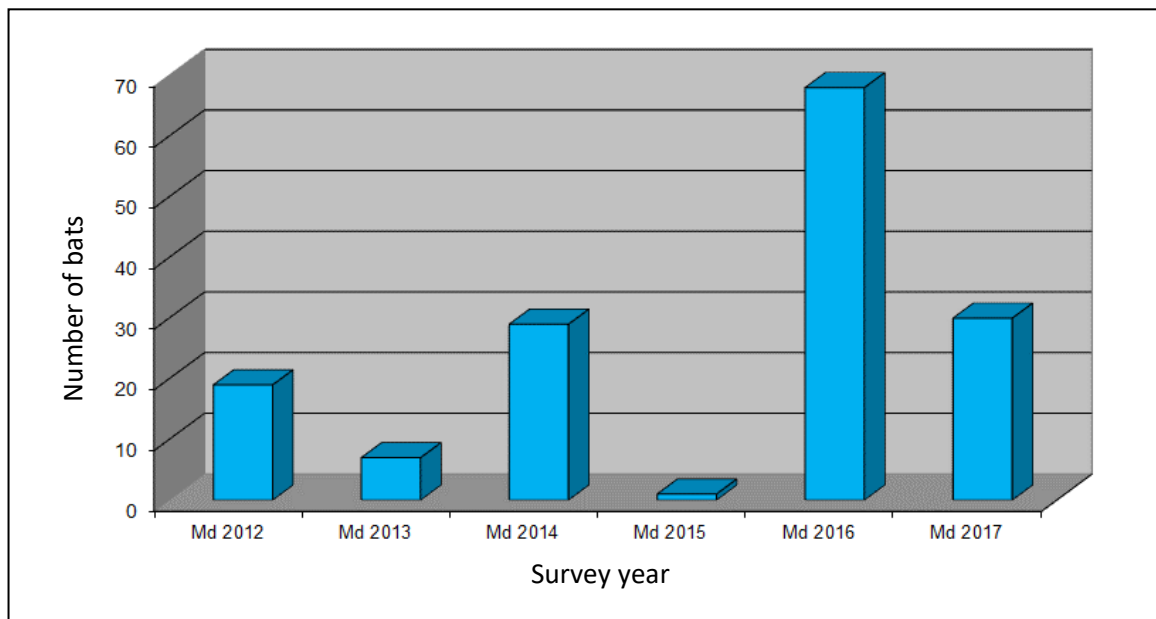


Figure 11: Numbers of Daubenton's bats at Crank Caverns per survey year 2012-2017.

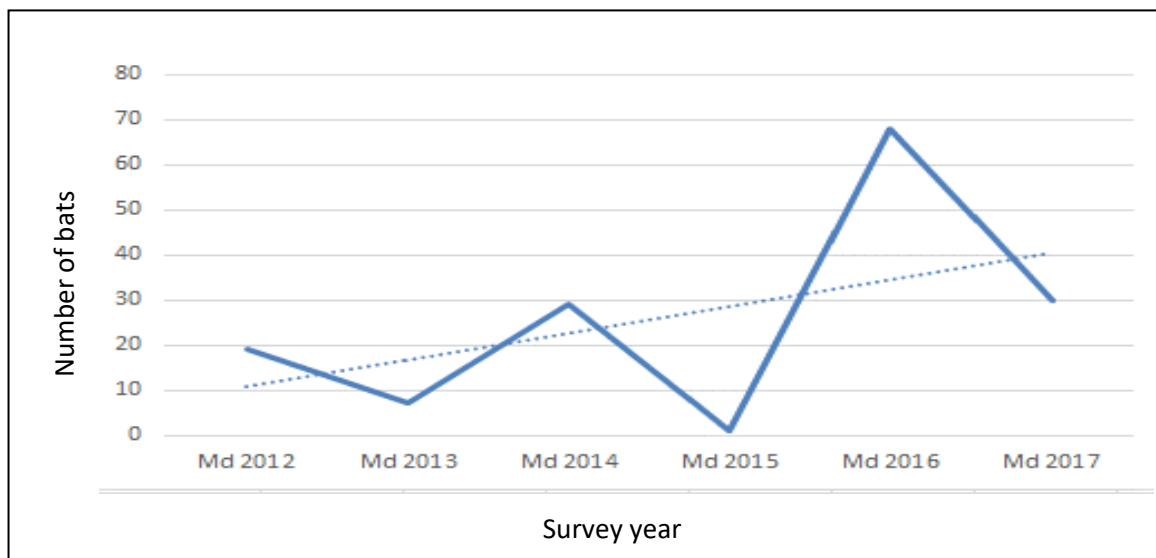


Figure 11a: Numbers of Daubenton's bats at Crank Caverns 2012-2017 (solid line) to show overall trend across years (dotted line).

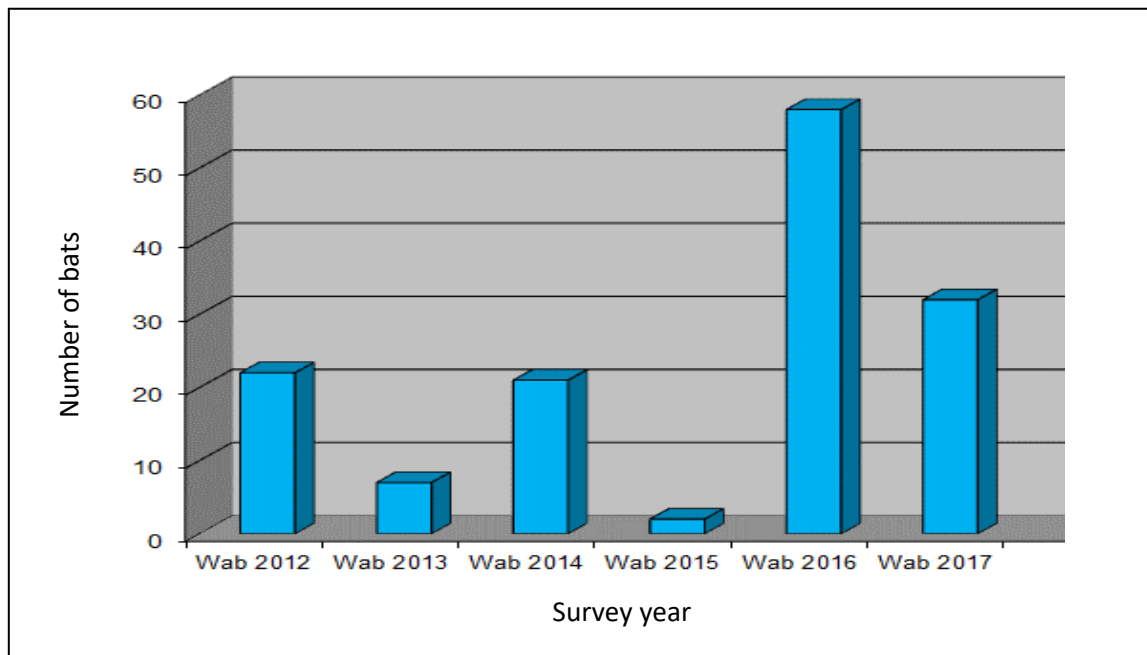


Figure 12: Numbers of whiskered/Brandt's bats at Crank Caverns per survey year 2012-2017.

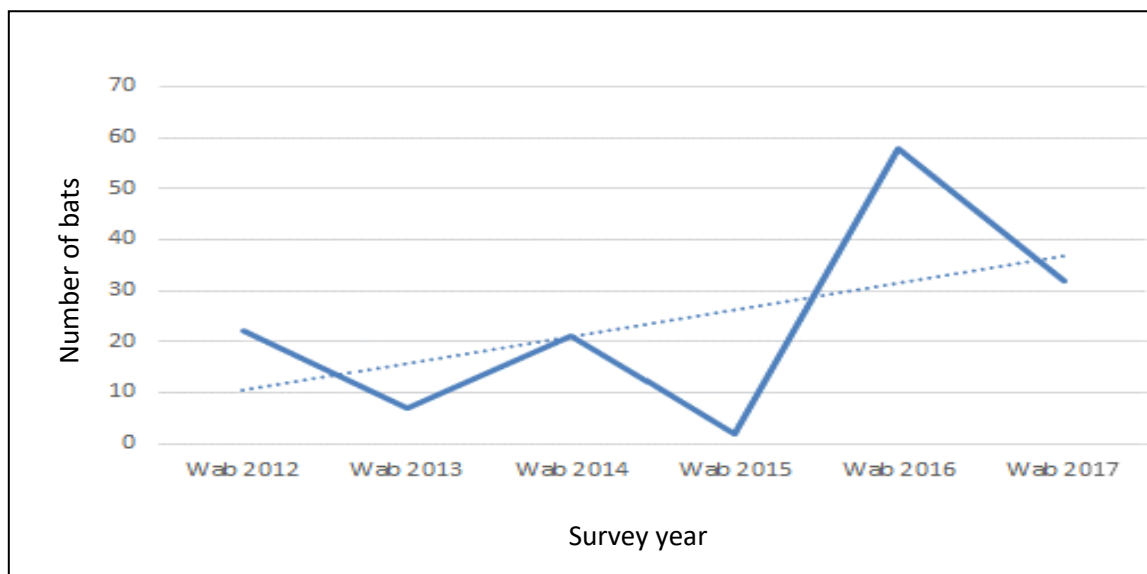


Figure 12a: Numbers of whiskered/Brandt's bats at Crank Caverns 2012-2017 (solid line) to show overall trend across years (dotted line).

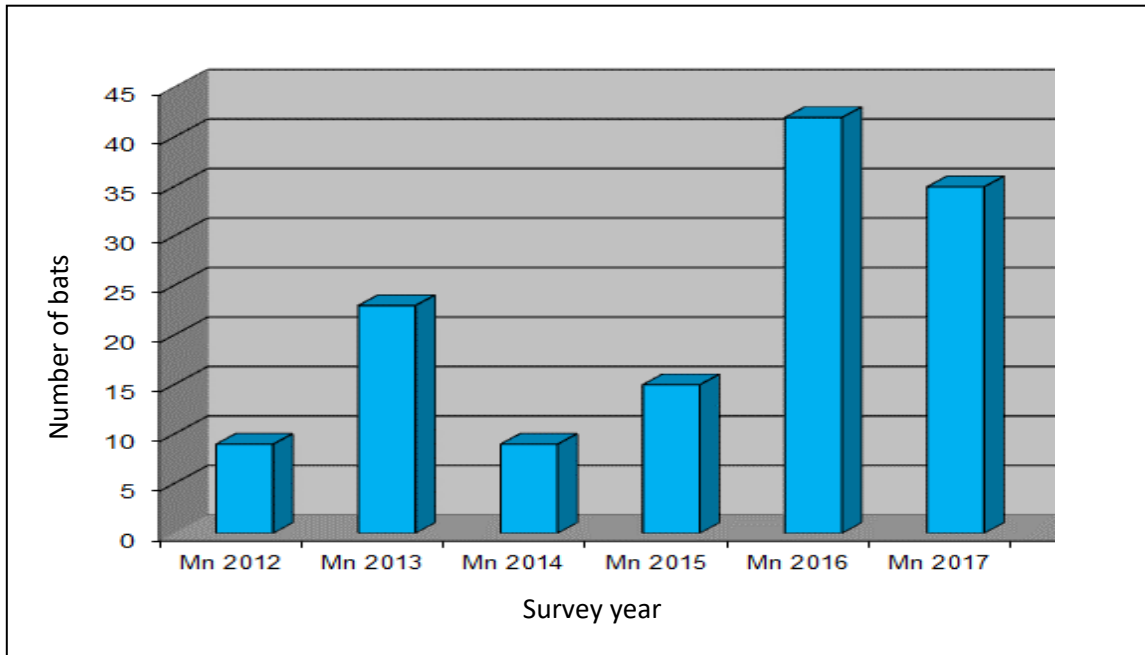


Figure 13: Numbers of Natterer's bats at Crank Caverns per survey year 2012-2017.

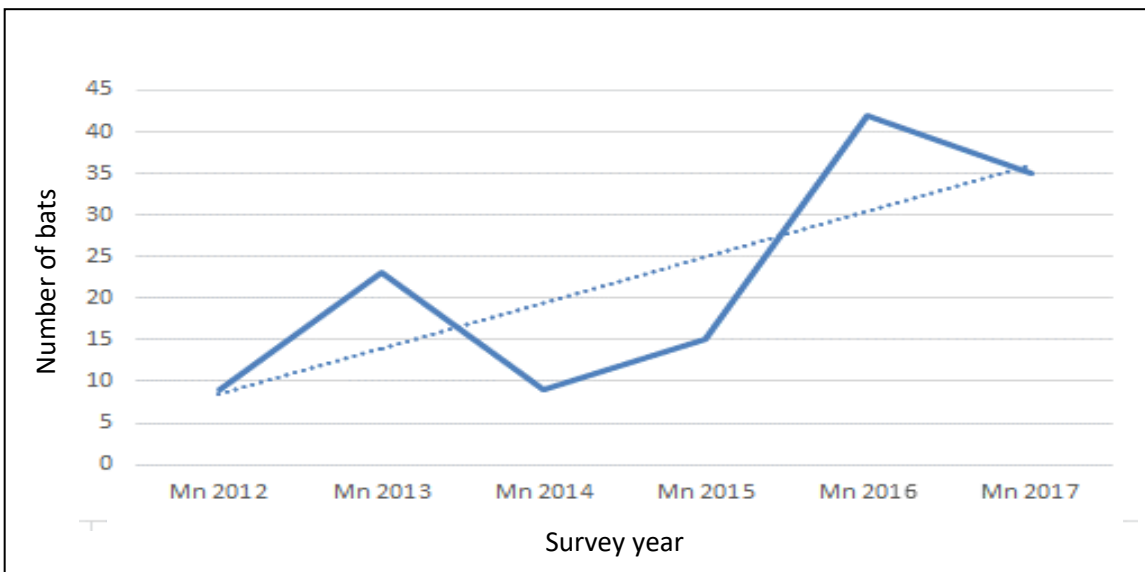


Figure 13a: Numbers of Natterer's bats at Crank Caverns 2012-2017 (solid line) to show overall trend across years (dotted line).

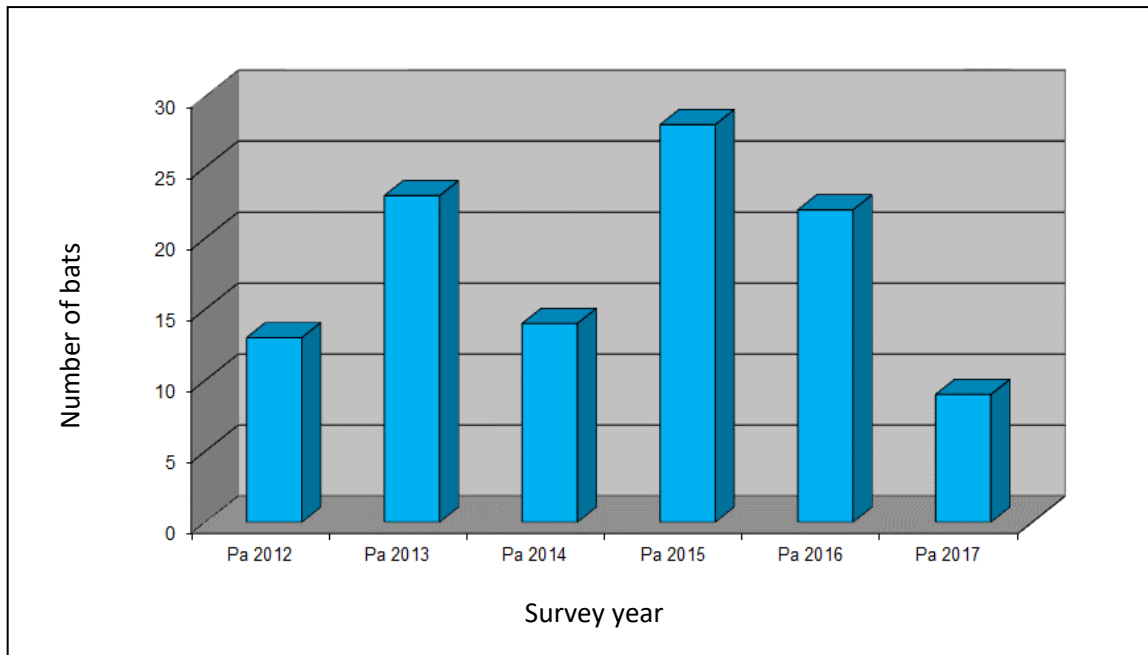


Figure 14: Numbers of brown long-eared bats at Crank Caverns per survey year 2012-2017.

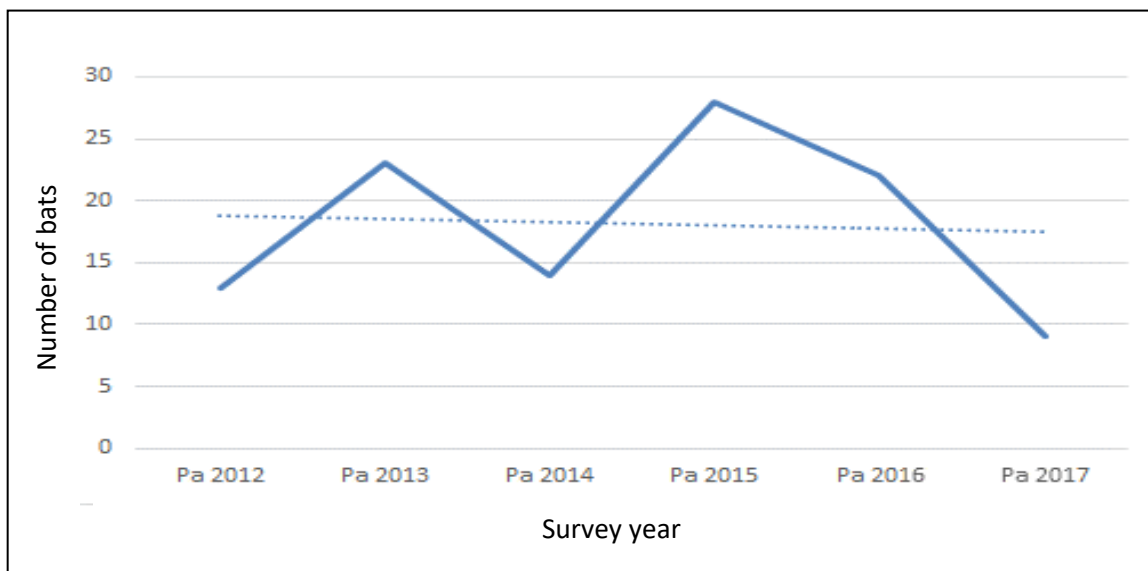


Figure 14a: Numbers of brown long-eared bats at Crank Caverns 2012-2017 (solid line) to show overall trend across years (dotted line).

In context with gender differentials during a typical swarming season the number of males in comparison to females over a sampled year is contained within Tables 3 and 4.

Table 3: Sample month Male-Female numbers.

Species/species group	Months and Year	Male	Female
Daubenton's bat	August and October 2012	11	2
Whiskered/Brandt's bat	August and October 2012	12	4
Natterer's bat	August and October 2012	13	4
Brown long-eared bat	August and October 2012	5	1
		Total 41	Total 11

Table 4: Total Male-Female numbers.

	Year	Male	Female
All Species	2012 - 2017	338	83

The disproportionate numbers of males to females concurs with data that has been recorded at other swarming sites in Europe and the UK (Glover and Altringham, 2008).

Summary of Crank Caverns hibernation data 2000-2020

Species included within the data represent the most frequently recorded species, brown long-eared bat, whiskered/Brandt's bat, Natterer's bat and Daubenton's bat; *Pipistrellus* species, whilst present on occasions, were excluded from the data results due to low numbers. The records are over two comparable ten-year periods. Although during the surveys temperature and humidity was recorded, these are not included in detail within this report; however, from the average temperature and humidity readings over the survey period (Table 5) it can be seen that conditions within both systems are representative of what is considered to be favourable for hibernating bats (van Schaik *et al.*, 2015). Table 6 illustrates species/species group numbers and percentage change between the two time periods. Figure 15 represents Bat Conservation Trust (BCT) Species Population Trends.

Table 5: Average temperature/humidity readings.

Upper System	Lower System
Average External Temp 6.7°C	Average External Temp 6.7°C
Average Internal Temperature 5°C	Average Temperature Internal 6.5°C
Average Internal Humidity 50-80%	Average Humidity 80-95%

Table 6: Species/species group numbers and percentage change between time periods.

Species	Year	Number	Percentage Change
Daubenton's bat	2000-2010 2011-2020	106 66	Net decrease of 40 = 37.7% decrease
Whiskered/Brandt's bat	2000-2010 2011-2020	78 94	Net increase of 16 = 21.51% increase
Natterer's bat	2000-2010 2011-2020	52 81	Net increase of 29 = 55.7% increase
Brown long-eared bat	2000-2010 2011-2020	48 33	Net decrease of 15 = 31.25% decrease

Apart from Daubenton's bat, BCT data for English hibernation sites appear to show an increase/decrease in the same species as Crank Caverns (Figure 15), particularly relative to an increase in Natterer's bat, although it should be noted that BCT data is derived from a number of sites unlike the Crank Caverns data. A decrease in brown long-eared bat numbers may be linked to warmer winters, as traditionally this species tends to enter hibernation late in the hibernation season when temperatures are reaching their coldest (Swift, 1998).

Table 6. England bat species population trends summary table (results up to 2020)

Species	Survey type	No. sites trend analysis	Base year	Long-term trend since base year (%)	Average annual change and 95% CI (%)
Greater horseshoe bat	Hibernation	119	1999	146.6*	4.4 (0.5 to 9.0)
	Roost	34	1999	160.3*	4.7 (3.2 to 6.0)
Lesser horseshoe bat	Hibernation	164	1999	133.4*	4.1 (2.4 to 5.8)
	Roost	123	1999	116.4*	3.7 (2.5 to 5.0)
Daubenton's bat	Waterway	703	1999	-5.5	-0.3 (-0.9 to 0.3)
	Hibernation	326	1999	24.8	1.1 (0.01 to 2.5)
Whiskered/Brandt's bat	Hibernation	173	1999	38.6	1.6 (-0.4 to 3.6)
Natterer's bat	Hibernation	396	1999	149.1*	4.4 (2.0 to 5.9)
	Roost	74	2002	-3.9	-0.2 (-2.2 to 1.5)
Common pipistrelle	Field	536	1999	109.2*	3.6 (2.7 to 4.6)
	Roost	428	1999	-52.1*	-3.4 (-4.9 to -2.0)
Soprano pipistrelle	Field	535	1999	34.0	1.4 (-0.2 to 3.1)
	Roost	279	1999	-44.0*	-2.7 (-4.6 to -1.2)
Serotine	Field	408	1999	4.7	0.2 (-2.4 to 2.8)
	Roost	98	1999	-3.0	-0.1 (-1.7 to 1.7)
Noctule	Field	534	1999	21.9	1.0 (-0.8 to 2.4)
Brown long-eared bat	Hibernation	371	1999	-20.8	-1.1 (-2.9 to 0.5)
	Roost	118	2001	5.4	0.3 (-2.0 to 2.0)

Notes: * indicates statistically significant result at 5% level. **Bold** indicates the survey method considered to be most robust, in instances where survey indices show statistically significant but differing trends (see *Robustness of Monitoring and individual species accounts* for further details).

Figure 15: Extract from The National Bat Monitoring Programme Annual Report 2020 (BCT, 2021).

It is difficult to draw any firm conclusion for the reasons for the discrepancy in Daubenton's bat trends between Crank Caverns and BCT data; however BCT data for Daubenton's bat hibernation trend also notes:

'The smoothed index is currently 24.8% above the 1999 base year value, equivalent to a mean annual increase of 1.1% (95% CI 0.01% to 2.5%). The value of the smoothed index was relatively stable between 1999 and 2011. From 2011 it began to increase, reaching a peak in

2016, before falling again in recent years. The index was significantly higher than the baseline year between 2000 and 2002, and again more recently from 2013. Currently the smoothed index is just significantly higher than the 1999 base year value, however this result is provisional and could be revised up or down as further years of monitoring data are added, so this finding should be treated with caution' (BCT, 2021).

Based on the above it will be of interest to see the trend results of BCT's future monitoring in comparison to Daubenton's bat trends within Crank Caverns.

Future surveys

Subject to Covid requirements MWLBG will continue to monitor this important hibernaculum in Merseyside and possibly aim to establish in more detail how bats arrive at the site. The data thus so far is being used as part of the Liverpool Region 'State of Nature' report whereby its aims are to assess future wildlife trends within the region and will act as baseline data for inclusion within reports.

Future objectives

- Identify from what direction bats arrive at the mine
- Continue to monitor numbers and species
- Continue to monitor trends
- Continue to monitor climatic conditions
- Work with landowner to enhance and protect habitat around the mine

Acknowledgements

Mr J. Parr, Landowner for allowing access.

All the survey teams over the years.

H and Phil Green, (Figure 5), for the help with the grille installation.

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Tyrer Ecological Consultants Ltd, for providing whiskered bat roost details.

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The role of golf courses as habitats for bats within an urban setting and the effect of their features on bat activity and species composition

Catriona Mann; University of Salford

21424996@stu.mmu.ac.uk

Abstract

Global urbanisation has major impacts on a number of different animal groups, specifically causing concern for many bat species. Recreational activities, such as golf, have increased dramatically over the past century and are often regarded as negative for the environment due to the modification of local habitats and large-scale pesticide use. However, golf courses provide habitats for varying wildlife and are observed to possess many landscape features attractive to bats. In this study, acoustic monitoring was used to measure bat activity and species richness on golf courses within Greater Manchester to identify if golf courses are suitable habitats for bats in urban settings and whether the golf courses' features such as their size, vegetation and water bodies increased their suitability. Passive acoustic sampling was used for three nights at ten golf courses within the region using an SM4 bat detector. Five of the eight species observed in Greater Manchester were present in this study, with large variation of species richness and abundance across each golf course. Common pipistrelle *Pipistrellus pipistrellus* activity was seen to dominate nearly all sites tested. Although none of the results were significant, there did seem to be a trend of increased bat activity on golf courses with higher vegetation density. Golf course size and water body size did not have any impact on bat activity or species richness. These results confirm that multiple bat species are using golf courses as habitats within urban areas and show that vegetation density may play an important role. Further research into this topic may provide more insight into which golf course features impact on bat activity and species composition. This study, alongside future research, can be applied to golf course management and conservation decisions to protect Britain's bat species.

Introduction

Global urbanisation

In the past century, there has been an exponential growth in the amount of people living in urban areas compared to rural areas; where urbanisation in the United Kingdom has amounted to 84% (World Bank, 2020). This increase in urbanisation has led to environmental degradation causing problems such as air pollution, noise pollution and land insecurity (Zhang, 2016). Urbanisation has also had major impacts on biodiversity and has often caused it to decline (Concepción *et al.*, 2015). Due to the growth of towns and cities, habitats are destroyed or fragmented, causing some species to become endangered or even extinct, therefore naming urbanisation as the most damaging threat to biodiversity (Hardman, 2011). The increase in urban development was seen to be the cause of 35% of plant species extinctions within the UK (Thompson and Jones, 1999) and is directly responsible for the endangerment of at least 275 species within the United States (Czech *et al.*, 2000).

Wildlife has also been greatly impacted by urbanisation, where it has been observed to cause large changes in species assemblages and there has often been recorded increases in generalist species replacing specialist species (Concepción *et al.*, 2015). In the same study it was also documented that urbanisation reduced the number of highly mobile specialist

species within the area, therefore expressing the harmful ecological impacts of urbanisation. Due to the expansion of urban areas, there has been an increased number of human-wildlife interactions and conflicts (Soulsbury and White, 2016). Many human-wildlife conflicts have caused negative impacts on specific species, in turn affecting ecosystems. These conflicts have led to the extinction of numerous species and have been held accountable for large numbers of human deaths and economic loss (Nyhus, 2016). Urbanisation has also been suggested to have played a considerable role in climate change issues, alongside the other major components such as greenhouse gases (Maheshwari *et al.*, 2020). However, there have also been observations of positive effects, such as benefits to human health and wellbeing through wildlife interactions (Soulsbury and White, 2016).

Urban green spaces have become increasingly common as a result of urbanisation and are often an important factor in sustainable development, including areas such as community woodland, urban parks, gardens, golf courses, farmland and street trees (Haq, 2015). Increased urban green space is thought to have positive impacts on human health, where one study found that urban tree canopy, in particular, may be beneficial in the promotion of community mental health (Astell-Burt and Feng, 2019; Kondo *et al.*, 2018). These urban green spaces also contain rich flora communities that contribute significantly to biodiversity and create important networks and corridors of habitats that help in conserving local inhabitants (Kong *et al.*, 2010). Each urban green space type has been observed to be vital for many fauna species, where each space contributes differently, however, as a collective proves to be extremely important for conserving biodiversity within cities (Gallo *et al.*, 2017). A study on native bee communities by Threlfall *et al.* (2015) showed that urban green spaces such as public parks, golf courses and front gardens were particularly important in the conservation of pollinator species and provided the resources necessary for diverse bee communities.

Golf courses and wildlife

An increase in urbanisation and recreational activities has resulted in an increase in the demand for the number of golf courses and it is expected to continue to incline over the coming years (Colding and Folke, 2009). With 1888 golf courses as of 2018 (KPMG, 2019), the UK has the highest number of registered golf courses in Europe, occupying just under 1% of total land cover (Tanner and Grange, 2005). Golf courses are often seen as extremely damaging to the environment due to their construction resulting in the modification of habitats and their large uses of water, excessive chemicals and irrigation (Tanner and Grange, 2005). The large-scale use of chemicals in the form of fertilisers and pesticides on golf courses can be extremely damaging to organisms that are exposed to them. The construction of golf courses can involve the clearing of natural vegetation, deforestation, destruction of natural landscapes and local topography and hydrology changes. Furthermore, erosion due to the clearing of trees and other vegetation has been shown to damage nearby fauna and flora of lakes and streams (Wheeler and Nauright, 2006). Golf course construction has also led to the loss of biodiversity, for example, a site in Wyoming, USA saw the loss of bald eagles from the local habitat (Wheeler and Nauright, 2006).

Although golf courses are often viewed as negative for the environment, there have been a few studies that have shown that they may be an appropriate substitute for other environments in supporting animal and plant diversity. A study by Tanner and Grange (2005)

showed that there was a higher abundance and species richness of both bird and insect taxa on golf courses than within the surrounding farmland areas. The golf courses also showed a higher diversity of tree species than farmland and it was concluded that golf courses were actually able to enhance the local biodiversity of the area. In another study by Colding and Folke (2009), golf courses were seen to have a 64% higher ecological value than green-area habitats used for other purposes such as nature-protected sites, pasture grassland and farmland. Many of these golf courses also contributed to the preservation and conservation of various fauna. It is suggested that when managed correctly, golf courses can enhance biodiversity in more simplified landscapes and promote ecosystem services such as pollination. Furthermore, a study that measured species diversity over time on a golf course showed an increase in bats, amongst other mammals and amphibians, with these observed changes in biodiversity perhaps giving potential for the site to be used for biodiversity banking offsets (Burgin and Wotherspoon, 2009).

A survey by Lyman, Throssell, Johnson, Stacey and Brown (2007) measured the average land-use of golf courses; it was found that 67% consisted of maintained turf, with the remaining land consisting of non-turfgrass landscape, bunkers and buildings. They observed that these non-turfgrass areas, including shrub, woodland and water bodies could potentially be important for wildlife communities. Furthermore, golf courses have been seen to provide a very similar understorey habitat to those observed in woodland patches (Threlfall *et al.*, 2016). Although on average vegetation within golf courses is more species rich than other urban green spaces, they do tend to use a number of non-native plant species (Threlfall *et al.*, 2016).

Golf course land use types have been identified as specific habitats for a variety of species. Woodland habitats on golf courses have provided habitat for salamanders, birds and bats (Hedblom and Söderström, 2012; Marsh *et al.*, 2004; Wallrichs, 2019). Ponds and other water bodies found on golf courses have been observed as habitats for waterbirds and other aquatic species, including turtle populations (Winchell and Gibbs, 2016; White and Main, 2005). Additionally, open green spaces on golf courses were identified as suitable habitats for urban coyotes (Wurth *et al.*, 2020).

Effects of urbanisation on bats

Urbanisation radically changes the habitat structure, ecology and land cover of an area. These changes in land cover directly affect bat species because of the break-up of previous habitats and the destruction of commuting corridors (Threlfall *et al.*, 2012). Due to the bats native to Britain being insectivorous, they are a secondary consumer and are therefore impacted indirectly from urbanisation because of the possible loss of insect communities (Threlfall *et al.*, 2012). Bats are more susceptible to anthropogenic changes to the environment than many other animal groups because of their low reproductive rate, longevity and high metabolic rates (Jung and Threlfall, 2016). Although urbanisation is highly damaging, many studies have suggested that the impacts are not always negative, and bats can sometimes adapt to these new environments. Some families of bat have been seen to better adapt to urbanisation than others and were able to utilise urbanised habitats for foraging, roosting and commuting (Russo and Ancillotto, 2015). Furthermore, some bat species have adapted to urbanised areas well, dependent on tree coverage, however others have not (Dixon, 2012). Even within species, individuals have been seen to respond

differently to urbanisation, proving it hard to assess how adaptable a species is (Lintott *et al.*, 2015).

A large amount of research has been conducted on how birds react to an urbanised environment in comparison to the number of equivalent studies on bats (Dixon, 2012). Upon conducting a literature review, many studies were found on the effects of golf courses on a variety of taxa. In one study, evidence was found that golf courses are able to support and conserve wetland fauna including amphibian species and macroinvertebrates. This was proposed to be particularly useful for golf courses in an urban setting, where the golf course can contribute to the creation of wetland habitats (Colding *et al.*, 2009). Another study has shown that golf courses in New Mexico may be a suitable habitat for riparian birds and have the potential to support breeding communities (Merola-Zwartjes and DeLong, 2005). Some studies have looked at golf courses' effects on biodiversity as a whole, where it has been shown that there has been greater tree species diversity, and bird, insect, frog and reptile taxa diversity on golf courses than in other nearby habitats (Burgin and Wotherspoon, 2009; Tanner and Grange, 2005). However, only one thesis by Wallrichs (2019) looked specifically at the suitability of golf courses as habitats for bats.

Golf courses contain many landscape features that can make for an appropriate habitat for bats (Wallrichs, 2019). All British bat species use woodland for commuting and roosts, therefore, dense patches of vegetation and tree corridors act as important features within their habitat (Holderied *et al.*, 2006). Golf courses often have a variety of dense vegetation patches and tree corridors that have been proven to provide habitat corridors and important vegetation cover in urban areas (Nguyen *et al.*, 2020). Water bodies, often referred to as water hazards in golf, are another common feature of golf courses. Golf course water bodies are found in many different forms including streams, lakes and ponds (Graves and Cornish, 1998). These varied water bodies can be an important source of drinking water and can provide foraging opportunities for bats (Wallrichs, 2019). Within 10km of Manchester city centre there are 22 registered golf courses, excluding driving ranges, in a mosaic of urban, suburban, grassland and woodland areas (Google, 2020). These golf courses could be home to fauna communities, including some of Greater Manchester's bat species, however, no research has been done on this thus far.

Study aims and objectives

This study aims to identify if golf courses are suitable habitats for British bat species living within urban surroundings through monitoring bat activity levels and species richness. In addition, the study will assess whether specific features of the golf courses, such as size, water body size and vegetation density influence bat activity and species richness. I predict that a variety of bats will be found at each site tested, where it is probable that the most commonly found species will be common pipistrelle and soprano pipistrelle *P. pygmaeus* due to their widespread ranges across Britain (Mathews *et al.*, 2018). Furthermore, I expect that bats will prefer larger sites with greater vegetation density and a larger water presence. Results of this study could possibly be used to identify golf courses and their features as suitable habitats for UK bat species and therefore aid in the conservation of urban bat populations. With this data, recommendations may be able to be made on future construction of golf courses, regarding their features, to produce suitable bat habitats and may also be taken into account for already established courses.

Methods

Site selection

Using Google Maps, golf courses within a 10 mile radius of Manchester city centre were researched and contacted, with a total of ten golf courses within the North and South of Greater Manchester being chosen due to the timeframe of this study. The head greenskeeper at each site was contacted and the project was explained thoroughly before asking for their involvement. Each of these golf courses agreed to be part of the study: Blackley Golf Club, Bury Golf Club, Chorlton-cum-Hardy Golf Club, Ellesmere Golf Club, Prestwich Golf Club, Stand Golf Club, Swinton Park Golf Club, Whitefield Golf Club, Withington Golf Club and Worsley Golf Club (Figure 1). Due to the timing of the ethics application and the start of the third year of university, this study was undertaken from the beginning of September to mid-October. Although this is not the optimal timing for a bat study (Collins, 2016), it allowed all ten sites to be completed before the bats entered hibernation in November.

The size of each golf course was provided by the management teams of each golf course in acreage. The vegetation density was gauged through satellite imagery from Google Maps on each course. Water body presence was also viewed using this same method. A scoring system of either 1 or 2 was given to the vegetation density of each site, with 1 representing thin corridors of vegetation over the course and 2 representing multiple patches of dense vegetation across the course. Similarly, for water body presence, 1 represented either no presence of water or a small body of water such as a pond or stream and 2 represented a large body of water such as a lake or river. All scores and area sizes recorded can be seen within Table 1.

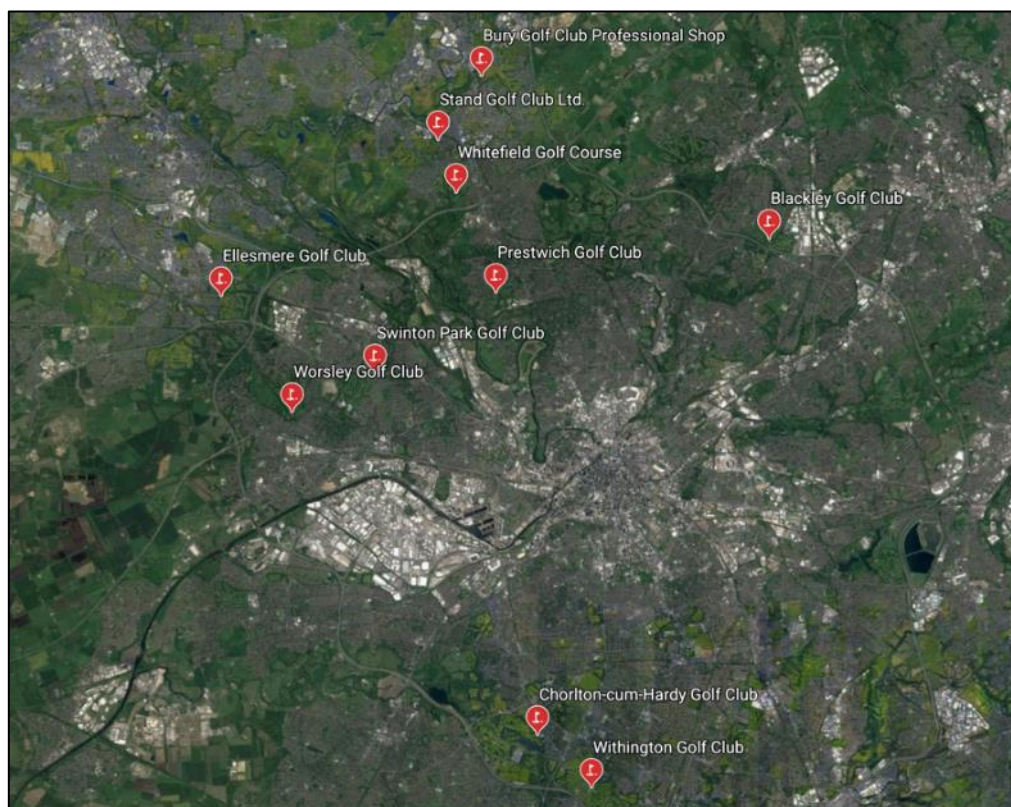


Figure 1: Map of each study site (Google, 2020).

Table 1: Summary of species richness, vegetation density, water hazard size, acreage and bat activity for each golf course.

Golf Course	Species Richness	Bat Activity (Bat Passes)	Vegetation Density	Water Body Size	Area (Acreage)
Blackley	1	46	1	1	112
Bury	3	416	1	2	90
Chorlton	3	3186	2	2	98
Ellesmere	4	335	2	2	120
Prestwich	5	2865	2	1	60
Stand	3	280	1	1	43
Swinton	2	15	1	2	99
Whitefield	4	3949	2	2	86
Withington	4	52	1	2	94
Worsley	4	63	2	2	105

Acoustic surveying

Passive acoustic surveying was chosen for this study as it allowed a way to record bat activity and species identification without the need for being present at the survey at all times and also avoided direct contact with the bats. The acoustic survey was conducted using the Wildlife Acoustics SM4 Bat Detector and the Wildlife Acoustics External A2 Acoustic Microphone, alongside a 64GB SD card. At each of the ten golf courses an appropriate position for the bat detector was chosen with help from the greens staff. Each time, the detector was located in the centre of the course on a sturdy tree within a patch of vegetation. Recordings at each site were taken for three consecutive nights in order to ensure enough repeats and a large enough dataset for each course. Once a location was picked on the golf course for the bat detector, it was tied to the tree at chest level to capture as many bat passes as possible without creating a risk by climbing further up the tree. The bat detector was programmed to the relevant time zone, in this case it was GMT, and set to record each night from 30 minutes before sunset to 30 minutes after sunrise the following morning. The detector recorded files with a maximum length of 15 seconds when triggered by a sound higher than 18dB, with each of these sound files converting into WAV audio files. After three nights of recording at a golf course, the detector was taken down from the tree and the scheduling of the detector was stopped. The data recorded onto the SD card was downloaded onto a hard drive and then the SD card was wiped and placed back into the detector. The bat detector was then moved to the next site, repeating the process for each golf course.

The files from each golf course were separated into folders for each site and processed using Kaleidoscope Pro Analysis Software version 5.3.9. The files were processed through the Kaleidoscope bats of Europe, United Kingdom (5.2.1) classifier on the most accurate (conservative) setting. A bat pass within this study is defined as a call of one species within a 5 second timeframe, therefore when running the files through Kaleidoscope, each file was cut down into 5 second clips. All files were checked over manually after auto identification using the full spectrum calls and the British Bat Calls Identification Guide by Russ (2013). All files that Kaleidoscope identified as 'Noise' were also manually checked, where if it was clear that a bat pass had occurred in the noise file it was manually identified and unmarked

as noise. All files that had been manually verified as noise were not used within the data analysis for this study. Due to it being extremely difficult to identify some species only through bat calls, *Myotis* species were only identified down to genus. After every bat pass had been automatically and manually identified, the number of passes for each species or genus group for each site were put into an Excel spreadsheet.

Statistical analysis

As there was an insufficient amount of data for some species, no statistical analysis were performed for *Myotis* species, noctule *Nyctalus noctula*, and brown long-eared bat *Plecotus auritus*. As previously stated, any noise files were not used within the data and therefore no statistical analysis were performed on these. The number of species present at each course was used to represent species richness and bat activity was represented by the number of bat passes in total for each golf course.

For the statistical analysis of the data the statistical program SPSS version 26.0.0.0 was used. To investigate the difference between the effects of low vegetation density or high vegetation density on total bat activity and *Pipistrellus* activity a Mann-Whitney U test was used. After conducting a Shapiro-Wilk test, the data was seen to be non-normally distributed, therefore a nonparametric test was chosen. When choosing a nonparametric test, the Mann-Whitney U test was chosen as two unrelated groups were being compared. When investigating the difference between the effects of small or large water presence on bat activity, species richness and *Pipistrellus* activity a Mann-Whitney U test was used again. As before, both groups were unrelated and therefore classified as independent samples. The species richness dataset showed normal distribution in the Shapiro-Wilk test and therefore a parametric test was chosen. To investigate the difference of effects of water body size and vegetation density on species richness an independent samples t-test was performed.

When looking at the relationship between area and bat activity and *Pipistrellus* activity the Spearman rank-order correlation coefficient test was used. A nonparametric test was used due to the non-normal distribution of the data and the Spearman's correlation was chosen due to area being a ratio scale variable. To investigate the relationship between the golf course's area on species richness a linear regression was used. The data was distributed normally, therefore, a parametric test was used. Due to area being a continuous variable, a linear regression allows for a linear approach for modelling the relationship between continuous variables. All graphic analysis were carried out in Microsoft Excel version 16.44 and SPSS version 26.0.0.0, where a logarithmic scale was used in order to show all the data on one graph (Figure 2).

Results

Overall bat activity and species richness

Bat activity was recorded at all ten golf courses, with bat passes from common pipistrelle, soprano pipistrelle, noctule, brown long-eared bat and *Myotis* species being recorded (Table 2). In total 11,207 bat passes were recorded across the ten golf courses from the various species, where the largest amounts of bat activity by far were seen at Whitefield with 3,949 bat passes, followed by Chorlton and Prestwich (Table 2). Golf courses with lower amounts

of bat activity include Worsley, Withington and Blackley, where the lowest amount of bat activity could be seen at Swinton with only 15 bat passes (Table 2).

Although various species were recorded across all ten golf courses, their distribution differed largely. At Blackley only common pipistrelle was recorded; however, five species of bat were recorded at Prestwich, therefore being the most species rich golf course within this study (Figure 2). Common pipistrelle was the only species to be found present at each golf course, with the largest number of passes recorded at Whitefield golf course (Figure 2). They were also by far the most recorded species in this study, with 10,094 bat passes (Table 2). The highest soprano pipistrelle activity was recorded at Chorlton golf course (Figure 2), they were the second most recorded species seen within the study, however, they only made up 9% of the bat activity recorded, in comparison to 90% from common pipistrelle (Table 2). The largest amount of *Myotis* activity could be seen at Prestwich, and Ellesmere showed the largest activity of noctule (Figure 2). Brown long-eared bat was the least recorded within the survey with only nine passes in total, data for this species was only recorded at four of the ten golf courses (Figure 2).

Table 2: Total bat activity in bat passes overall and per species for all ten golf courses.

Golf Course	Common pipistrelle	Soprano pipistrelle	<i>Myotis</i> species	Noctule	Brown long-eared bat	Total
Blackley	46	0	0	0	0	46
	100%	0%	0%	0%	0%	
Bury	400	10	6	0	0	416
	96%	2%	2%	0%	0%	
Chorlton	2403	780	0	3	0	3186
	75%	25%	0%	0%	0%	
Ellesmere	224	96	0	13	2	335
	67%	29%	0%	4%	1%	
Prestwich	2766	11	83	2	3	2865
	97%	0%	3%	0%	0%	
Stand	268	5	7	0	0	280
	96%	2%	3%	0%	0%	
Swinton	13	0	0	2	0	15
	87%	0%	0%	13%	0%	
Whitefield	3917	22	7	3		3949
	99%	1%	0%	0%	0%	
Withington	2	26	22	0	2	52
	4%	50%	42%	0%	4%	
Worsley	55	5	1	0	3	63
	87%	8%	2%	0%	9%	
Total	10094	955	126	23	9	11207
	90%	9%	1%	0%	0%	

England – North West

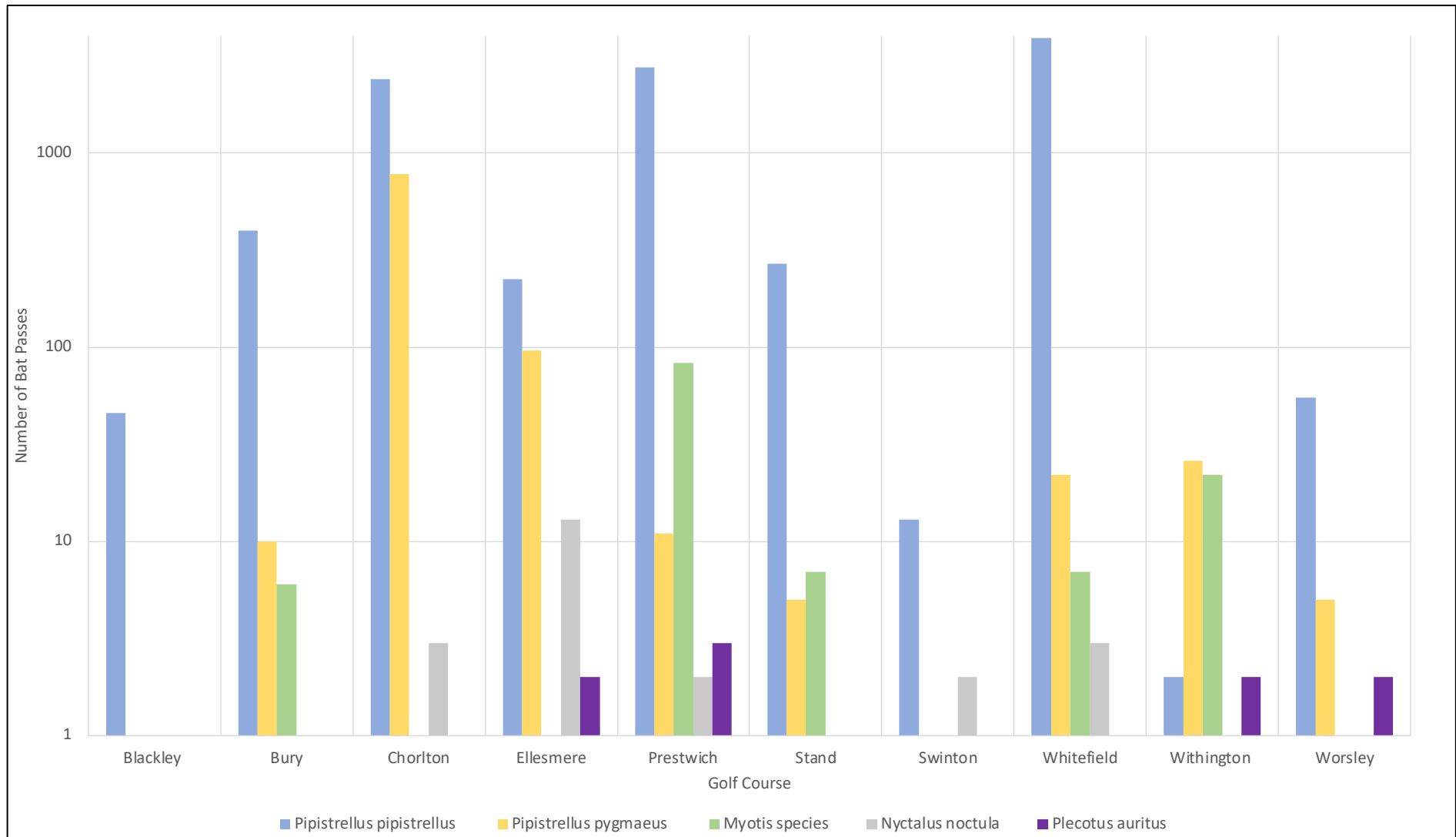


Figure 2: Species-specific activity levels in bat passes for ten golf courses in Greater Manchester, Y-axes in log scale.

Effects of vegetation density

Sites with higher vegetation density often saw a higher amount of bat activity (Figure 3), however, this result was not statistically significant ($U = 3$, $z = -1.984$, $p = 0.056$). Common pipistrelle activity was also often higher in sites with higher density vegetation (Figure 4), however, was not significant ($U = 4$, $z = -1.776$, $p = 0.095$). Furthermore, a larger amount of soprano pipistrelle activity was seen at some golf courses with high density vegetation (Figure 5), however, this was not significant and contained two outliers ($U = 4.5$, $z = -1.681$, $p = 0.095$).

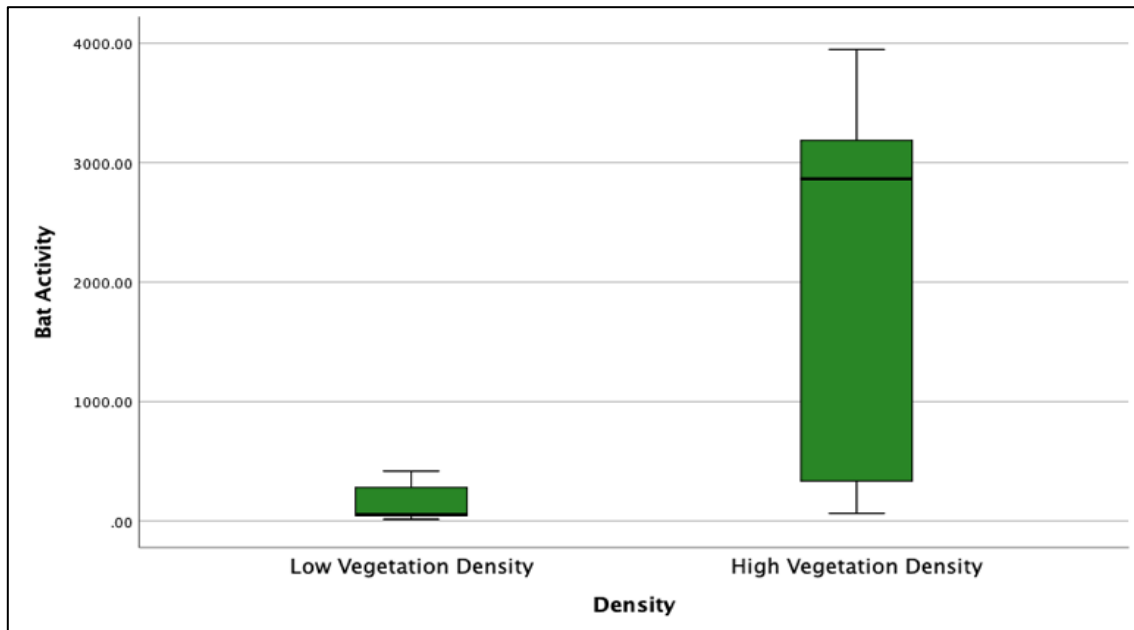


Figure 3: Bat activity difference in high or low vegetation density on golf courses.

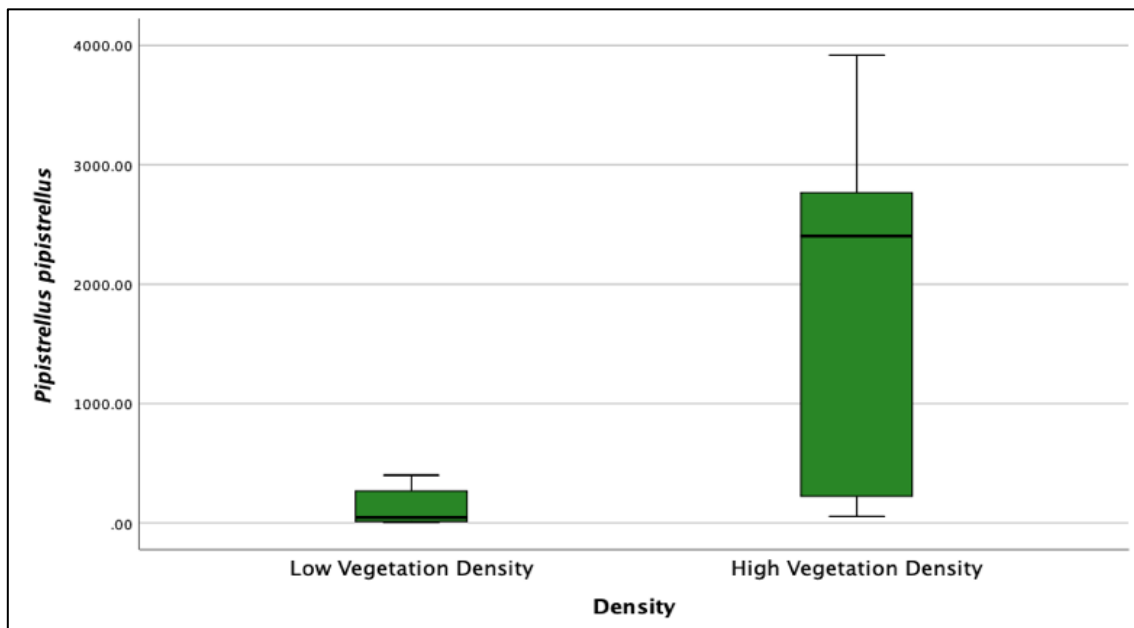


Figure 4: Common pipistrelle activity difference in high or low vegetation density on golf courses.

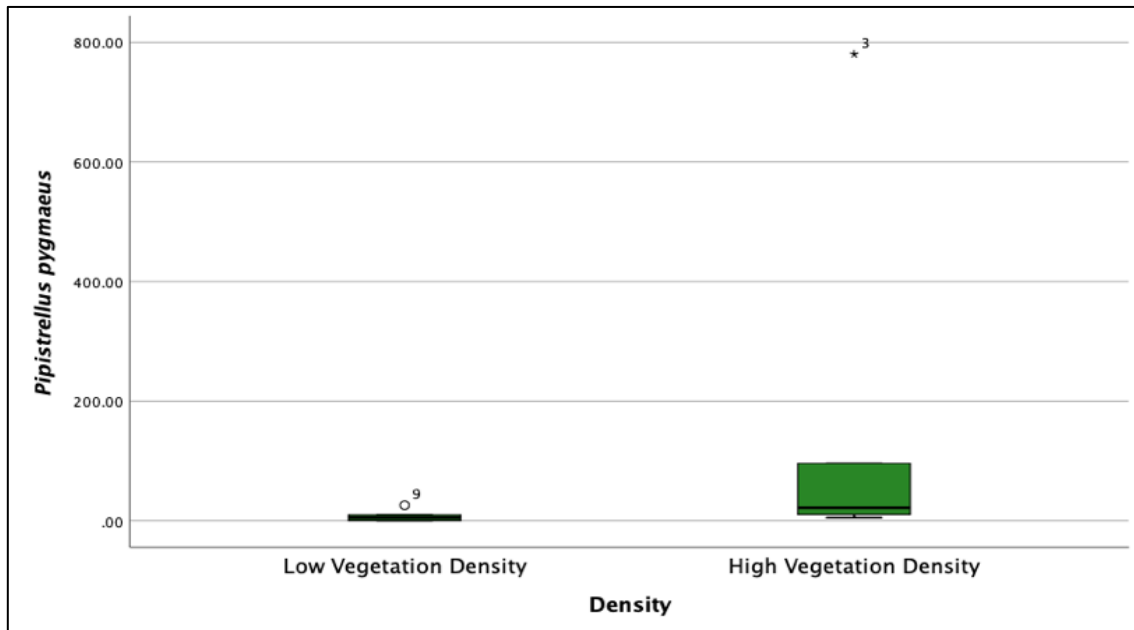


Figure 5: Soprano pipistrelle activity difference in high or low vegetation density on golf courses.

Although there is no overlap in the error bars, no significant difference was found between the vegetation categories ($t = -2.333$ $df = 8$, $p = 0.214$; Figure 6).

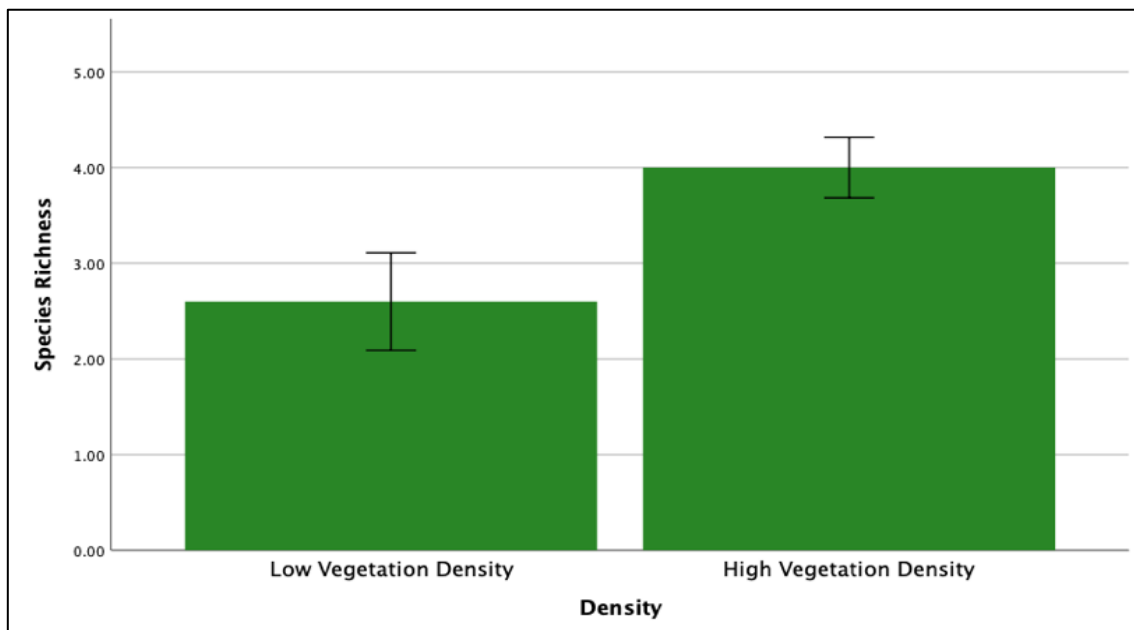


Figure 6: Mean species richness in high or low vegetation density. Error bars represent one standard error.

Effects of water body size

Small water body size and large water body size were tested against bat activity levels across the courses; however, water body size did not make a significant difference in bat activity levels ($U = 9$, $z = -0.342$, $p = 0.833$; Figure 7). Common pipistrelle activity was tested against small or large water body presence, however it was not significantly different and contained an outlier in the dataset ($U = 9$, $z = -0.342$, $p = 0.833$; Figure 8). Soprano pipistrelle

activity did not differ significantly between water body size and contained an outlier in the dataset ($U = 5$, $z = -1.261$, $p = 0.267$; Figure 9).

An independent samples t-test was conducted to test difference between water body size and species richness, however, there was no significance ($t = -0.513$, $df = 8$, $p = 0.169$; Figure 10).

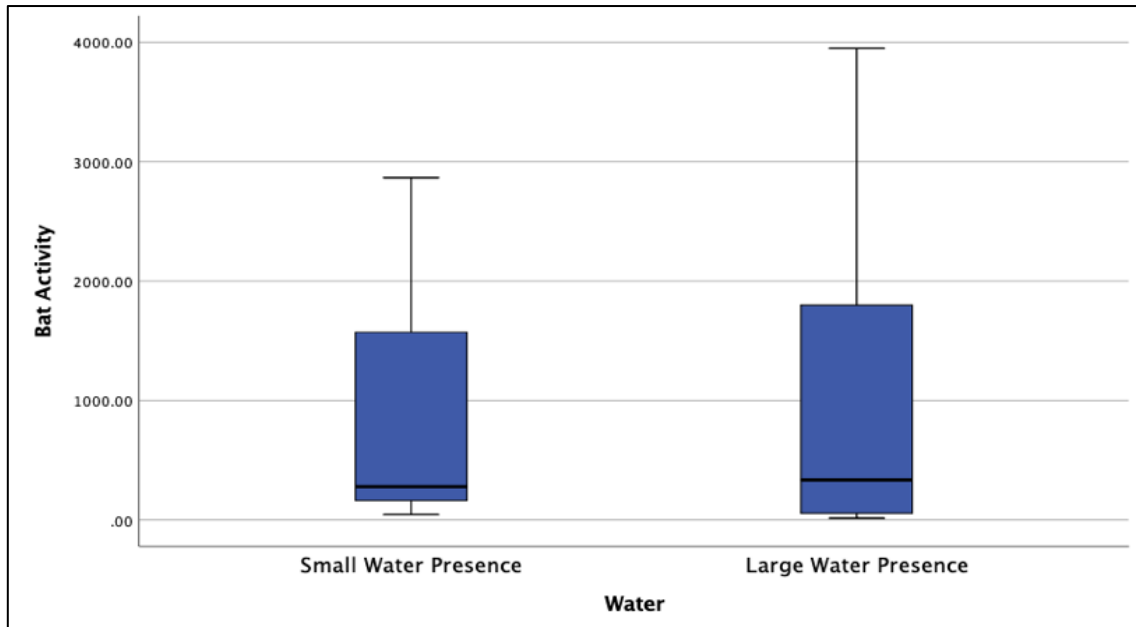


Figure 7: Bat activity difference between golf courses with small or large water body presence.

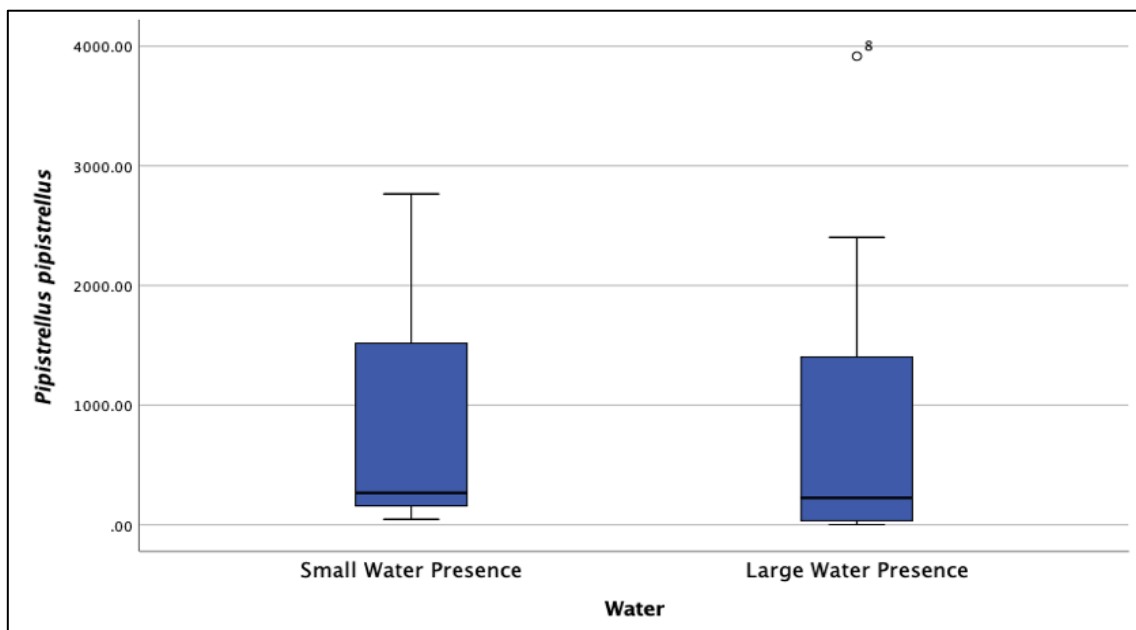


Figure 8: Common pipistrelle activity difference between golf courses with small or large water body presence.

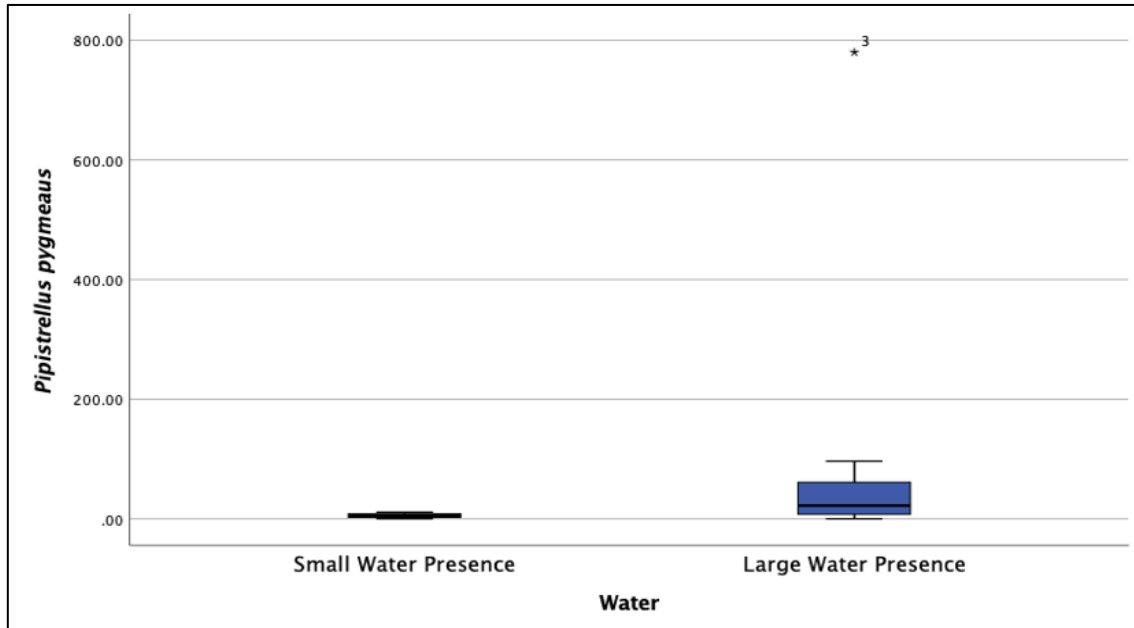


Figure 9: Soprano pipistrelle activity difference between golf courses with small or large water body presence.

An independent samples t-test was conducted to test difference between water body size and species richness, however, there was no significance ($t = -0.513$, $df = 8$, $p = 0.169$; Figure 10).

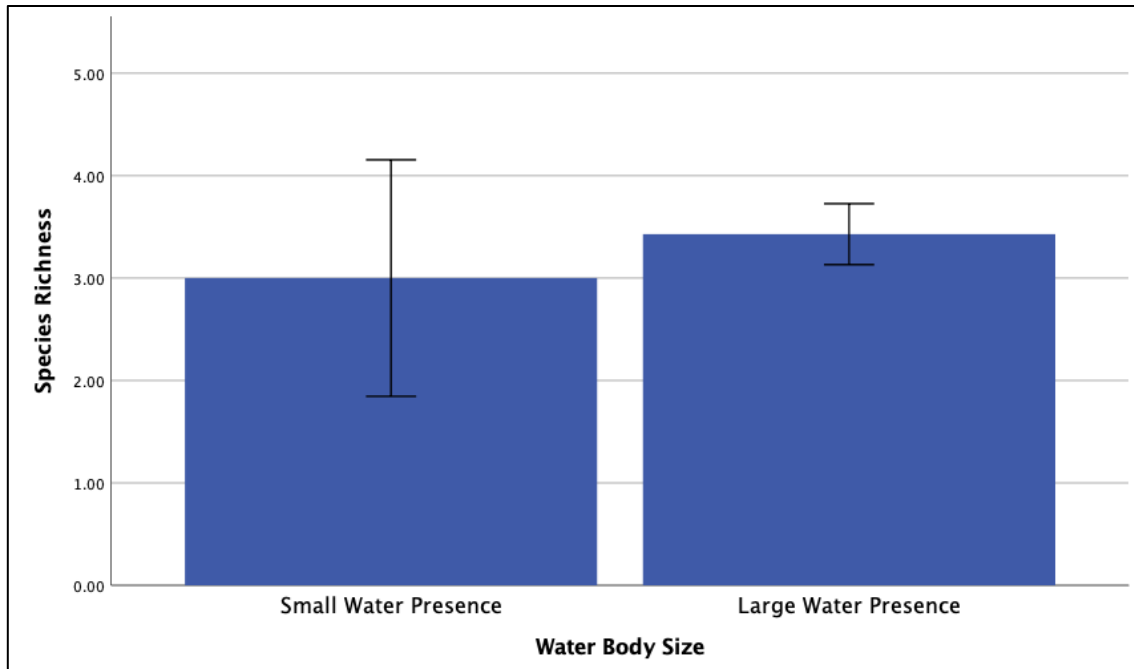


Figure 10: Mean species richness at small or large water body presence. Error bars represent one standard error.

Effects of golf course size

A Spearman rank-order correlation showed no significant relationship between area and the levels of bat activity across the golf courses ($r_s = -0.455$, $p = 0.187$, $N = 10$). There was also no

significant relationship between common pipistrelle activity and area ($r_s = -0.539$, $p = 0.108$, $N = 10$). Furthermore, soprano pipistrelle activity also showed no significant relationship to area ($r_s = -0.049$, $p = 0.894$, $N = 10$).

A simple linear regression was used to investigate the relationship between species richness and area; however, this showed no significance ($F = 0.725$, $df = 1$, $p = 0.419$, $R^2 = 0.083$).

Discussion

Species composition on golf courses

This study confirmed that a range of Britain's bat species are utilising golf courses as habitats within urbanised areas, where bat activity occurred at every golf course tested. A similar study conducted on golf courses in Delaware, USA showed the same result, where bats were seen at each golf course studied (Wallrichs, 2019). However, species richness and bat activity differed on the golf courses studied, which could represent some golf courses having greater conservation value than others. Bat activity varied greatly from golf course to golf course, with 3,949 bat passes recorded at Whitefield compared to just 15 bat passes at Swinton. This variation in bat activity between golf courses was also observed in the study by Wallrichs (2019). These results show that golf courses are an important habitat for bats living within urbanised areas in Britain and possibly internationally, where some courses may be of greater suitability than others.

In line with predictions, the sites studied showed a variation in species richness, except for Blackley, where only common pipistrelle was recorded. All bat genera present in Greater Manchester were recorded in this study and possibly all species (Varela, 2018), however this cannot be confirmed due to *Myotis* species only being identified down to genus. Prestwich was the most species rich golf course in this study, where all five species/species groups within the study were recorded over the three nights.

Common pipistrelle activity was seen to be the highest in this study, making up 90% of the recorded bat passes. Common pipistrelle was also the only species to be present at all ten golf courses. Due to common pipistrelle being the most common and widespread bat found within Britain, the data in this study is no different to studies done on other habitats (Mathews *et al.*, 2015). Various other studies on different habitats all recorded common pipistrelle to be the most common species within woodland, farmland and grassland (Lintott *et al.*, 2014; Russ and Montgomery, 2002; Walsh and Harris, 1996). Therefore, suggesting that golf courses may be just as useful as other habitats with regards to common pipistrelle conservation. Soprano pipistrelle were the second most common species to be documented within this study, and represented 9% of total bat activity, similar to results in other studies across Britain, however, were recorded much less than common pipistrelle. Soprano pipistrelle is the second most common species in Britain, found to be extremely abundant and widespread in a variety of different habitats (Rachwald *et al.*, 2016). Due to the large difference in bat activity found between *Pipistrellus* species in this study, common pipistrelle may prefer golf course habitats more than soprano pipistrelle.

Brown long-eared bat was the least recorded bat species within this study with only nine bat passes in total. Although brown long-eared bat are documented to be common in Britain, they are much less common than *Pipistrellus* species (Joint Nature Conservation Committee,

2007). In Britain, brown long-eared bat roosts are mostly within the attics of old houses and they are highly selective in the sites and areas that they choose to roost (Entwistle *et al.*, 2000), this could possibly give explanation as to why they were not recorded much on golf courses. Only 23 noctule passes were recorded in this study even though they are thought to be common and widespread within Britain (Mathews *et al.*, 2018). Noctule are selective in roost choice, normally roosting in large mature trees (Boonman, 2000). Due to the selection of trees for golf course management, often large trees are avoided or removed in golf course refurbishment (Hunter *et al.*, 2008), which may account for the lack of noctule activity on the golf courses studied.

As all bats identified as *Myotis* were only identified at genus level, therefore, no conclusions can be drawn about which *Myotis* species use golf courses as habitats. However, due to the presence of *Myotis* at four of the golf courses it is certain that at least one species utilised golf course habitats. Some *Myotis* species are extremely uncommon in Britain (Wright *et al.*, 2018), therefore, the golf courses where *Myotis* activity was recorded could be important in *Myotis* conservation.

Explaining the effects of golf course features

Due to the small sample sizes in this study, it is extremely hard to draw any robust conclusions from the results. Furthermore, as the data collected on vegetation density and water body size was categorical instead of continuous, this may have had an impact on the ease of drawing significance from the results. Although, none of the results recorded in this study were statistically significant, some trends can still be observed.

Due to the importance of vegetation cover in bat habitats (Müller *et al.*, 2013), it was hypothesised that golf courses with higher vegetation density would have larger amounts of bat activity. It seems that there was a trend in increased bat activity at golf courses with higher vegetation density. Although this result was not significant, it was extremely close and with a larger sample size may produce a significant result. Bats have often been documented to prefer habitats with higher vegetation density and cover as this provides more opportunity for foraging and roosting, however, this can differ between species (Gunnell *et al.*, 2012). Contrary to the results in this study, some have suggested that bats prefer a lower density vegetation environment due to the energy cost of flying through higher density vegetation sites, suggesting that lower density vegetation creates a better habitat for commuting (Caras and Korine, 2009). Due to the areas of high vegetation density being found in small patches on the sites tested, there were still plenty of edge habitats that the bats could use for commuting. Suggesting that the edge habitats on the course may have been used for commuting paths, whereas the higher vegetation density areas may have been used for foraging and roosting. Therefore, sites that had lower vegetation density may have only provided commuting habitats, rather than foraging and roosting.

Similarly, when observing common pipistrelle and soprano pipistrelle activity on golf courses with higher vegetation there was a positive trend in the data, however, this was not significant; but may produce a significant result with a larger sample size. Both species generally hunt along linear features and sometimes into half-open surroundings (Verboom and Huitema, 1997; Gunnell *et al.*, 2012), which does not explain for the trend in preference

for higher density vegetation sites in this study. However, they have been seen to forage in various different vegetation densities and vegetation coverage (Müller *et al.*, 2013).

Vegetation density did not have an effect on the species richness within a golf course. This could be due to British bat species having differing foraging preferences, where some prefer dense vegetation patches, and some prefer a more open space habitat (Gunnell *et al.*, 2012). Therefore, a higher or lower amount of vegetation on a site doesn't necessarily mean there will be a higher or lower amount of species richness.

Water bodies are extremely important within all insectivorous bat's habitats as a source of drinking water and for foraging, using a variety of streams, lakes, ponds, and rivers, along with artificial water bodies (Korine *et al.*, 2016). A range of these water bodies were seen at the ten golf courses in this study; however, water body size did not have an effect on bat activity, species-specific activity or species richness at the golf courses tested. In a previous study by Razgour *et al.* (2010), it was seen that both bat activity and species richness increased significantly with water body size, where size of artificial bodies also had the same impact. However, it has also been recorded that smaller pools of water can often be of extreme local importance due to their concentrations of insects for foraging (Russo *et al.*, 2012).

Water quality has been seen in some cases to be more important than water body size, where agricultural pollutants may cause reduced levels of bat activity due to decreased foraging and drinking (Korine *et al.*, 2016). Many studies have found golf courses to use similar agricultural pollutants including fertilisers and pesticides that have been seen to pollute both surface water and groundwater (Balogh and Walker, 2020; Li *et al.*, 2013; Shin *et al.*, 2011). Therefore, it may be possible that agricultural pollutants could have polluted the water bodies seen on the sites in this study. Due to this, bats may have preferred bodies of water based off water quality rather than the water body size. Thus, meaning that measuring the water quality rather than size may be more suitable when studying the relationship between bat activity and water bodies on golf courses. The source of the water may also be another important factor (Korine *et al.*, 2016). Furthermore, it may be possible that the presence of water bodies on golf courses may only have an impact on bat activity when there is a lack of water within the surrounding landscape.

There was no significant relationship discovered between the golf course area and bat activity or species richness. Bat home ranges vary greatly, for example, common pipistrelle colony home ranges have been recorded at around 1500 ha, whilst soprano pipistrelle colonies were around 487ha (Nicholls and Racey, 2006). As the golf courses recorded within this study are quite small in comparison to bat home ranges, it is likely that the golf course only makes up part of the bat's habitats. This could give reason as to why the site's area is not important in habitat selection and does not have an effect on bat activity. It is possible that the golf course's connectivity to surrounding habitats is in fact more important than the size of the golf course itself (Tournant *et al.*, 2013).

Conservation recommendations

As golf courses have been recognised in this study as habitats currently being used by British bat species within an urban surrounding, it is therefore important that bats are taken into consideration in golf course creation and management. Golf courses should be regarded as

a potential safe haven for wildlife living within built-up environments, with special consideration for local bat species. It may be possible for golf courses to work with local wildlife authorities to put conservation plans in place, for example, professionals could give advice towards vegetation cover on golf courses and put surveying schedules in place to give important insight into population trends of different species. From the results of this study, it seems that dense patches of vegetation on golf courses may be important for roosting and foraging, along with corridors of trees for commuting. Therefore, it would be favourable for golf courses to include these features. Bat boxes may be helpful to install on golf courses with lesser bat activity to aid in roosting (Forestry Commission, 2005). As education is such an important aspect of conservation (Jacobson *et al.*, 2015), it may be beneficial to inform members of the golf club and locals about the bat species found on each specific course.

Further study in this area is vital for the understanding of the effects of golf course features and their effects on bat activity and species richness. Suggestions for additional research include:

1. Surveying surrounding habitats to measure if the golf course is a more or less effective habitat than its surrounding areas.
2. If the site's connectivity to surrounding habitats has an impact on bat activity or species richness.
3. A more expansive study on the effects of vegetation density may provide a significant result.
4. If the quality of the water bodies on site affected the bat activity and species richness.

Furthermore, it is important to use a larger sample size within more optimal weather conditions and it may be beneficial to locate day roosts. It may also be useful to use a mixture of study methods such as acoustic surveying and mist netting.

Conclusion

The increase in global urbanisation has seen a general decline in suitable habitats for bat species in the past century. However, this study identified that golf courses, although often regarded as negative for the environment, are used by a variety of British bat species. Golf courses seem to be no different to the multiple other anthropogenic activities and impacts that bats have adapted to previously. The results suggest that golf courses with patches of higher density vegetation record larger amounts of bat activity than golf courses with lower density vegetation. However, contrary to predictions, water body size and golf course size did not have any impacts on the bat activity observed on the courses. Species richness on golf courses was not impacted by any of the golf course features measured in this study, therefore, the reasoning for the species composition differences on golf courses still remains unknown. Although none of the results were significant, the findings are still useful in golf course management and bat conservation.

The most important findings of this study are the potential that golf courses have for bat conservation within urbanised areas and the large amounts of remaining study that can be conducted surrounding the topic. This study along with further golf course studies could

provide vital information for future decision making in bat conservation and golf course construction and management. The application of these results to golf courses may provide opportunities for increasing bat numbers due to suitable roosting and foraging areas. There is large potential to work with golf courses to create more bat-friendly environments in Britain and internationally. Furthermore, similar concepts can be applied to other species groups suited to golf course environments. The merging of golf courses with wildlife conservation possibilities may eventually spark change in the negative perception of golf course land use for the environment and could provide a new opportunity for urban bat conservation.

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π•pistrelle: an ultra-inexpensive, handheld device for citizen bat science

Phil Atkin; Omenie Ltd

phil@philatkin.com

π•pistrelle is an ultra-affordable, self-build handheld bat science device. Initially designed to be a cheap heterodyne detector, over a year of development the design has morphed into a three-in-one device - a hybrid heterodyne/time expansion detector, a microSD card field recorder and an educational bat echolocation synthesizer. When hand-assembled in low volume the unit cost is well below £20 (May 2022 price). Sample rate, storage capacity and battery life meet or exceed those of commercially-available devices costing many hundreds of pounds. Recording quality and noise levels are very good, but fall short of commercially-produced devices, so a comparison with the Echo Meter Touch 2 is presented.



Figure 1: π•pistrelle version 1.6.

Background and project genesis

I have in recent years worked almost exclusively in the field of sound synthesis for music, and have extensive experience in software optimisation for performance-constrained real-time systems. Essentially, I like to code things that make noise. After relocating to Wiltshire during the COVID-19 lockdown of March 2021, I volunteered as a 'Bat Detective' for the Bats in Churches project, having had no previous experience with bats, but having loved them to bits for a long time. In February 2021 the Raspberry Pi Foundation had announced their first microcontroller product, the Pico, a very inexpensive embedded computer platform.¹ It seemed that bats and Pico had entered my life like a unique planetary conjunction, so I decided to design and build an educational bat detector using the Pico, with a target build cost of around £10.

¹ Pico features a dual-core 133MHz processor with integral Analog-to-Digital Converter (ADC), 2MBytes of flash memory and 264kBytes of RAM. It costs just £3.50 (May 2022).

TL;DR

If your eyes are already glazing over after just one paragraph, if the prospect of 15 more pages of hardware and software development and debugging fills you with existential dread, skip forward to the ['Comparison with Echo Meter'](#) section. You can always convince yourself that you will come back here later.

Initial specification

With such a tight budget I had to get creative to deliver an informational visual display. Instead of a dot matrix display a simple array of 10 LEDs would form a real-time spectrum display, representing 15-125kHz in 10kHz bands. The LED onboard the Pico was intended to provide some additional feedback to the user via recognisable flash patterns.

An inexpensive Micro Electro-Mechanical Systems (MEMS) ultrasonic microphone would be used, amplified to allow the Pico's built-in Analog-to-Digital Converter (ADC) to digitize and capture any bat sounds. Audio (heterodyne samples and speech synthesis) would be output to the user via one of the Pico's Pulse Width Modulated (PWM) pins. The Pico has sufficient performance to undertake real-time Fast Fourier Transforms (FFTs) on the incoming audio stream, so a key feature would be 'auto scanning' for the strongest ultrasonic signal, offering eyes-free, hands-free operation.

The majority of feedback to the user would be provided by speech synthesis and audio output from the device is via a 3.5mm headphone jack - the budget would not stretch to an amplifier and speaker.

User input was limited to two push buttons and a single rotary encoder, giving the system a command vocabulary of just seven actions - single, double and long click on each of the buttons for six commands, along with 'override heterodyne frequency' on the rotary encoder. The rotary encoder is endless and requires multiple revolutions to span the frequency compass, so any form of frequency scale printed on the device was not possible. Manually selected frequencies would require feedback, so visual feedback would be provided via a flashing LED on the spectrum display and speech synthesis feedback would indicate the current frequency.

First prototype - π •pistrelle version 1.0

Given all that, the hardware would consist of just the Pico, a microphone and associated amplification, 10 LEDs and resistors, two buttons, one rotary encoder, a headphone jack and a pack to carry three AA batteries. All of which sounds perfectly feasible on a £10 budget.

Software development began in April 2021, and by early May the first prototype was detecting bats and performing heterodyning. The prototype at this time had speech synthesis in place, and was automatically scanning for the strongest ultrasonic energy band to set the heterodyne frequency without any need for user action. This lets the user keep their eyes to the skies and visually confirm bat species. To assist complete novices - remember that I was at this point a total bat novice - the device attempted to ID bats based on their echolocation frequency and had a 'speak most recent bat' feature.

In short, virtually all the detector features were in place after the first month of development. Things were going well.

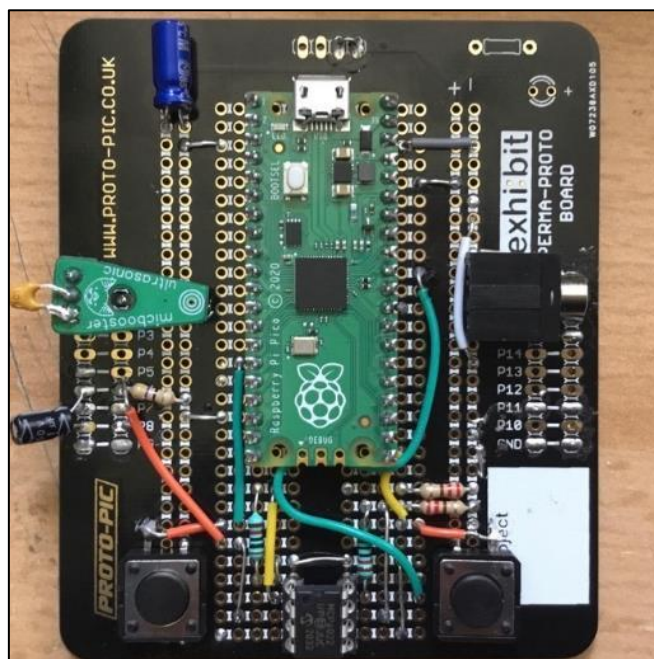


Figure 2: π •pistrelle hand-assembled prototype 3 (version 1.0).

This first prototype used a commercial microphone board from Micbooster and the microphone alone was so expensive it consumed the entire target budget. So a custom microphone interface was needed that would allow the use of MEMS microphone chips as discrete components, moving the part cost to under £1 rather than the £10 for pre-built microphone modules.

Not only that, but assembly of these first prototypes was slow, error-prone and fundamentally unpleasant. To make matters worse, the audio filter circuit was very badly designed. Analog hardware design is definitely not one of my skills, and my initial 'design' was performing half-wave rectification on the input signal, generating very strong harmonics, so it needed a complete rework and some rapid learning.

Versions 1.1 and 1.2 - first PCBs

After three prototype builds I had had enough, and decided to transition the design to a Printed Circuit Board (PCB), which could be inexpensively manufactured in China, in volume, at a number of PCB service companies. Soldering of components onto the PCB would still need to be done by hand, but the inter-component wiring would be in place, printed onto the circuit board as copper tracks, cutting out about 80% of the assembly work.

Enter the BatSignal

I took a decision early on to split the detector into two separate designs - an ultrasonic microphone module and the detector itself. The reason for splitting out the microphone function was that the microphone is extremely small and fiddly, and extremely - let me say this one more time in block capitals - EXTREMELY - difficult to solder. Because the microphone and its support circuitry can only be tested after the Pico is soldered down to

the detector PCB, the risk was very high that a large number of units would need to be scrapped if the microphone proved too difficult to solder.

The 'BatSignal' PCB holds an ultrasonic microphone chip, a Knowles SiSonic SPU0410LR5H-QB. There was enough space on the PCB to also include the operational amplifier (op amp), a MicroChip MCP622-E/SN, tasked with boosting the tiny signal from the microphone up to a level that the Pico could detect and digitize. The Microchip was chosen after prototyping and rejecting several other devices and the final selection was due to its ultrasonic performance at a high gain factor, and its relatively low cost.

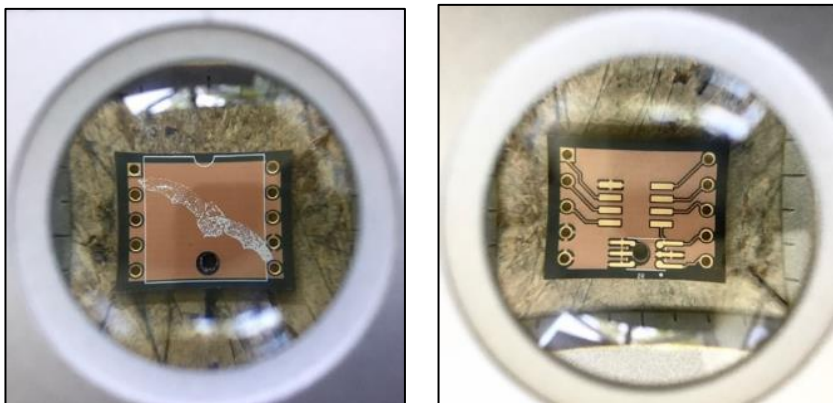


Figure 3: The first BatSignal Ultrasonic Module (orange finish, US manufacture).

The first BatSignal (Figure 3) was manufactured in the US, which gave me a very rapid turnaround time, a startling orange circuit board, but unacceptably high unit cost of around \$5 per BatSignal. I was able to very quickly confirm that the design worked and reworked it into the now-familiar black BatSignal version 2 (Figure 4). This was manufactured in China by [PCBWay](https://www.pcbway.com), a trial run for the π •pistrelle main PCB, and this module PCB costs me under 50p per unit.

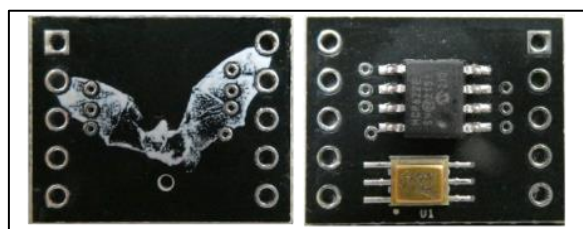


Figure 4: the current BatSignal design (black finish, shown assembled).

The version 1.2 π •pistrelle PCB - a minor bugfix after the first 1.1 PCB - was ready and running by mid-July 2021, with a much-improved audio circuit compared to the hand-wired prototype. This version operated extremely well as a detector, and at this point I was confident that the hardware side of the project was done. I could not have been more wrong!

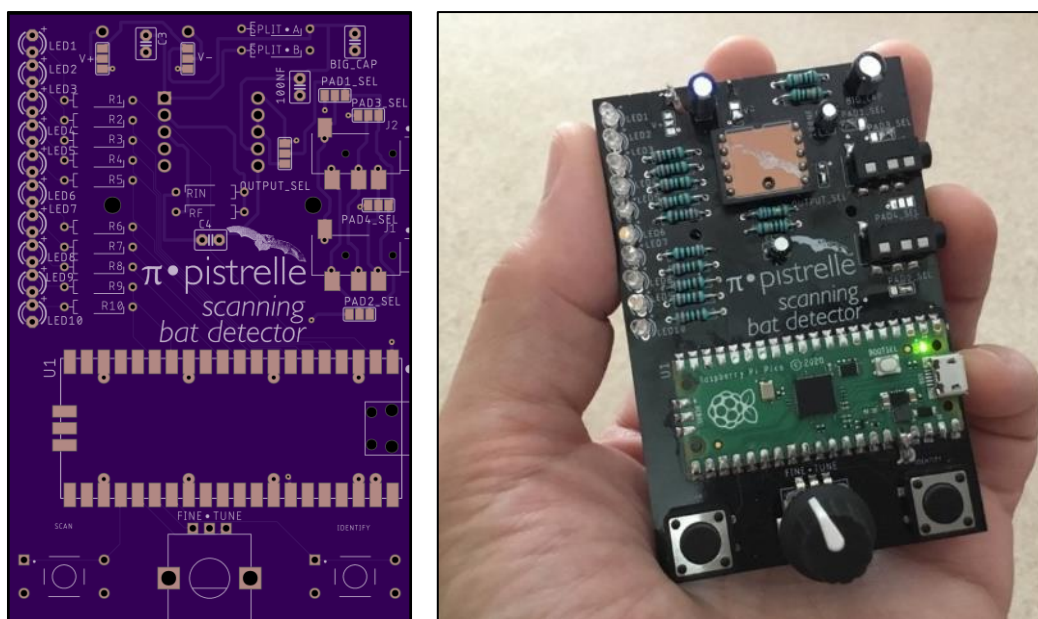


Figure 5: π•pistrelle PCB and assembled device (version 1.2).

The detector becomes a full-spectrum recorder

So, we have reached mid-July 2021. This was, rather alarmingly, half way through the Bats in Churches survey season, and at this point I was politely but firmly informed by my wife Ilene that if I intended to survey any churches for the Bats in Churches project, I had better get up from my desk, put down my soldering iron and get surveying.

So I got surveying. In fact we both got surveying. In actual fact, Ilene did the majority of the survey work - her 'dropping spotting' powers are remarkable, and her efforts were recognised when we jointly won 'Volunteers of the Year' from Bats in Churches at the 2021 Batty awards.

The survey process was a revelation. I used a full-spectrum recorder for the first time - Peersonic, mandated for the Bats in Churches project - and saw first-hand what a full-spectrum recorder could allow a surveyor to do. It was clear that the utility and value of a combined detector/recorder was massively higher than a detector alone.

Additionally, the two shortcomings² of the otherwise excellent Peersonic recorder became clear. Firstly, its battery life was barely up to the job of a 48-hour 'double overnight' session. To get close to the 48 hours run-time required for the Bats in Churches surveys the Peersonic required environmentally unfriendly alkaline batteries, rather than NiMH rechargeables. Secondly, the 8GB of onboard non-volatile memory was not adequate if the church being surveyed was very busy with bat activity. A bat-rich church can generate a huge number of recordings over 48 hours, and you really don't want to miss any in case the endangered one appears on the scene last.

² These comments are based on the model available in early 2019, as used for the Bats in Churches Project, which has been further developed since.

With the lessons of the survey season learned, post survey season my specification for π •pistrelle shifted to include recording, and with that came an increase in the target cost of the system. The goal was now to design a full-spectrum (384kHz/16-bit/mono) recorder that could be deployed 'double overnight' in churches, or indeed anywhere in the field, that could take arbitrarily large microSD cards, and that could be built for as close to £15 as possible. Specifically, I wanted for the 2022 season to be able to acoustically survey many more churches than the Bats in Churches budget could support, by using the mandated Peersonic recorder only for the '1000 Project Churches', and a large number of π •pistrelle units for any other churches that we could opportunistically survey, to add to the Bats in Churches knowledge base.

So a new wave of design iterations began.

Version 1.3 (and 1.4 and 1.5)

The π •pistrelle main PCB was modified to take an AdaFruit 'SD/SPI breakout board', surface-mounted onto the back surface of the PCB, behind the Pico and under the battery compartment. This added an additional £3 to the build cost compared to the previous 'detector-only' designs.

The hardware design effort for version 1.3 was minimal, but the additional software effort turned out to be huge. It proved surprisingly challenging to reliably record a 384kHz/16 bit audio stream to microSD card on a system with such limited buffer memory, and a lot of juggling was required to distribute the software effort over both cores of the Pico to keep things running smoothly and glitch-free.

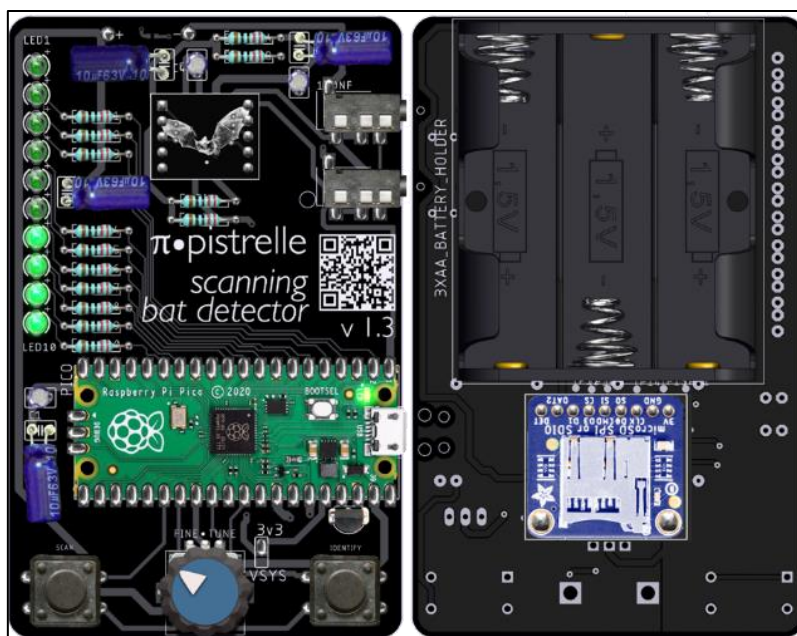


Figure 6: π •pistrelle 1.3 (rendered) front and rear view.

Although version 1.3 was fully functional, the quality of its recordings was poor - unacceptably high levels of electrical noise were breaking through onto the recordings. After a lengthy period of trial and error with multiple hardware revisions (1.3, 1.4 and 1.5), the finger of blame found itself pointing at the microSD card interface.

The electrical noise problem

Here is what I think was causing the problem. The microSD card draws, relatively speaking, a significant amount of current when writing audio files. In an ideal world the entire 5 second/ 4Mbyte audio sample would be captured into RAM then written to microSD, so that the microSD card interface would be idle during capture. This would make the electrical environment much quieter for the op amp, leading to higher quality recordings.

But the Pico has very limited memory, so this approach was not possible. The microSD card simply had to be active during signal capture.

The current surges caused by the microSD interface during signal capture were placing an uncomfortably high demand on the Pico's on-board voltage regulator, causing supply rail glitches. These glitches manifest as electrical noise. This in itself might have been acceptable, but the microphone outputs a very faint electrical signal that requires a lot of amplification before the Pico can sample it in the ADC. The op amp has a gain factor of 250x in order to get the microphone output to a level that the Pico can hear, and the electrical noise was also being amplified 250 times along with the microphone signal.

So the extremely amplified noise, plus the amplified microphone signal, was injected into the Pico ADC, resulting in audible, strong noise in the recordings.

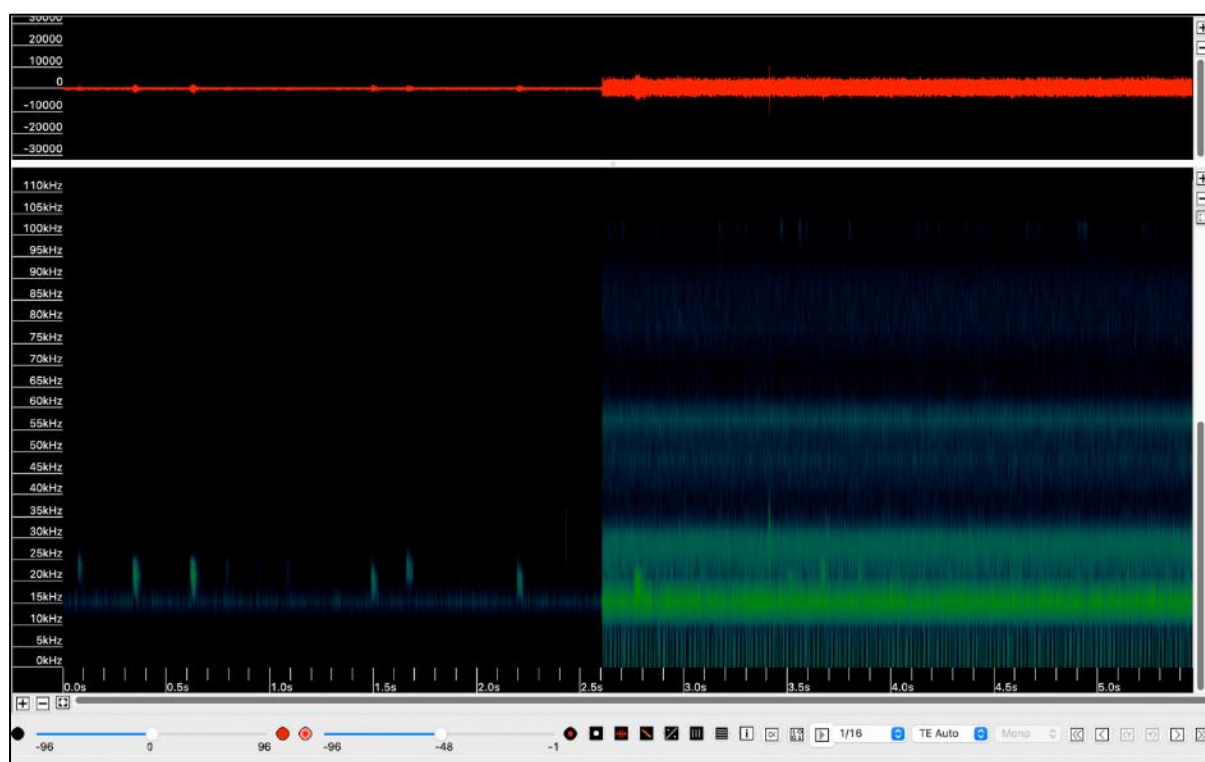


Figure 7: Version 1.5 recording - normal and 16dB boost to reveal noise structure.

Figure 7 is a recording of my 'Virtual Noctule', a looped noctule *Nyctalus noctula* field recording used extensively during device testing and software development. Noctule echolocation is easily reproducible by quality monitor speakers (in my case M-Audio BX5s). The left side shows the recording with no boost. It looks fine apart from a faint interference trace at around 15kHz, but in reality it sounds pretty horrible. Boosting the level by 16dB to

view the underlying noise structure makes it clear why it sounds so bad - there is a LOT of noise in this recording, with a rhythmic, pulsing structure that appears to correlate with microSD card write operations.

The situation wasn't necessarily a disaster. The version 1.3 and 1.5 devices I built were actually quite usable, and bats could be identified using Kaleidoscope to inspect the recordings. Unfortunately, the suite of software tools I had written to help me automatically sift through hours of recordings were largely unusable in the face of the amount of noise in the recordings. This was partly because the 'noise' was far from white. It was quite spectrally 'peaky' and had significant energy in batty regions of the spectrum - a huge broad-spectrum energy band centred at 15kHz can be seen in Figure 7, with more energy down to 0Hz (DC), and up at the harmonics of 15kHz.

Something had to be done to reduce the noise being injected into the op amp.

The solution - a smarter power supply arrangement

The solution for this - recommended in the Raspberry Pi Pico design guide and eventually implemented in version 1.6 - was to add a pair of Low Dropout Voltage Regulators (LDOs) to the design.

Powered by the battery, these LDO devices consume very little power, while dropping the battery voltage from its notional 4.5V down to 3.3V, and are each able to provide as much current as the regulator on the Pico. They provide stable, clean and isolated 3.3V supplies to the microSD card interface and to the BatSignal.

Because the microSD interface and the BatSignal are now powered from different supplies, current surges in the microSD card cause much less disturbance to the BatSignal op amp, and recordings are much cleaner than before.

To enable a comparison of recording quality, I made simultaneous recordings in a budget anechoic chamber - both devices were placed in a sock drawer, buried in cotton. Any non-silence in the recordings can be assumed to be electrical noise generated by the device and printed to the recordings, apart from the single knock against the drawer to ensure the recordings were synchronised.

Figure 8 shows a side-by-side comparison of version 1.5 and version 1.6, both recordings boosted by 16dB to make the noise visible. Clearly, version 1.6 is a massive improvement, but it still exhibits noise, and we will later compare this with a commercially-available device.

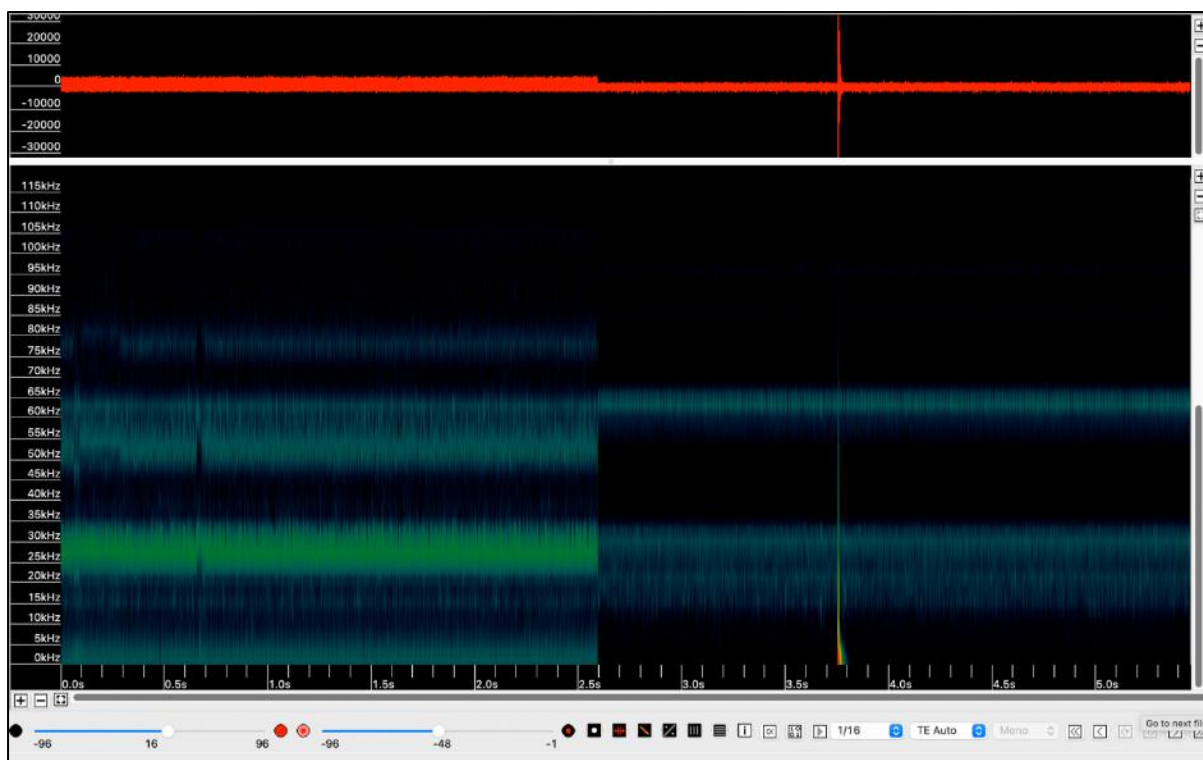


Figure 8: Side-by-side comparison of noise levels, version 1.5 left, version 1.6 right.

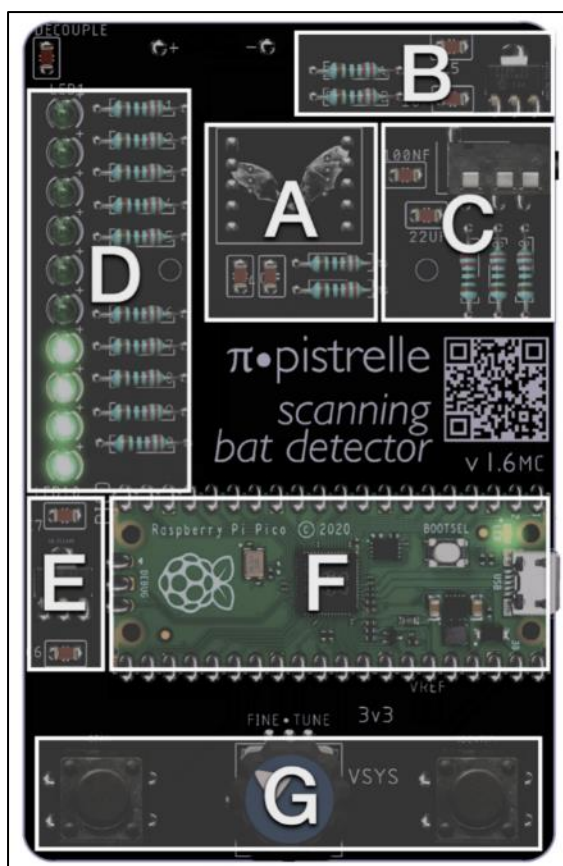
These LDOs and their decoupling capacitors add almost £2.00 to the build cost, but a rationalisation of other capacitors, a removal of one of the headphone jacks and a move to inexpensive surface-mount Multi-Layer Ceramic Capacitors (MLCCs) has allowed the build cost to remain under £20 per unit (when built in quantities of 10 or more).

Version 1.6 - status late May 2022

At the time of writing this article, version 1.6 is the most recent revision of the π •pistrelle. The hardware components of version 1.6 and their functions are shown in Figure 9.

Assembly of a π •pistrelle 1.6 takes less than half an hour for someone with soldering experience. A local bat group, with two volunteers adept with a soldering iron, can turn 10 blank PCBs into 10 functioning detectors / field recorders in just two and a half hours, for a total outlay of £190. Because volunteer time is free.

To put this cost into perspective, it is less 2/3 the price of a single Peersonic RPA3, which is listed at £300 inc. VAT in the Q4 2021 price list.



A: Analog input - BatSignal and high-pass filter

B: LDO supply for BatSignal

C: Analog output - 3.5mm jack, low-pass filter and AC coupling

D: LED spectrum display and current limiting resistors

E: LDO supply for microSD card writer (mounted on back)

F: Raspberry Pi Pico microcontroller

G: User input hardware - buttons and rotary controller

ON BACK SURFACE: 3 x AA battery compartment, AdaFruit microSD interface

Figure 9: π•pistrelle 1.6 hardware.

Software Structure

The software structure of the system is illustrated in Figure 10. Conceptually the system consists of a number of concurrently-executing processes, communicating by mailbox messages. In reality only two processes are able to execute concurrently, one on each core, so processes must switch themselves in and out rapidly enough to present the appearance of true concurrency.

The cyan arrows show the flow of 384kHz samples through the system, and the red arrows show the messages that are passed between processes.

Notably, unless the system is recording to microSD, every single sample that enters the ADC is FFTd to allow spectral energy to be tracked for both auto-scanning heterodyning and for 'wake on bat' functionality when operating as an overnight recorder. This is quite remarkable computational throughput for £3.50 - the Pico is a very powerful microcontroller platform.

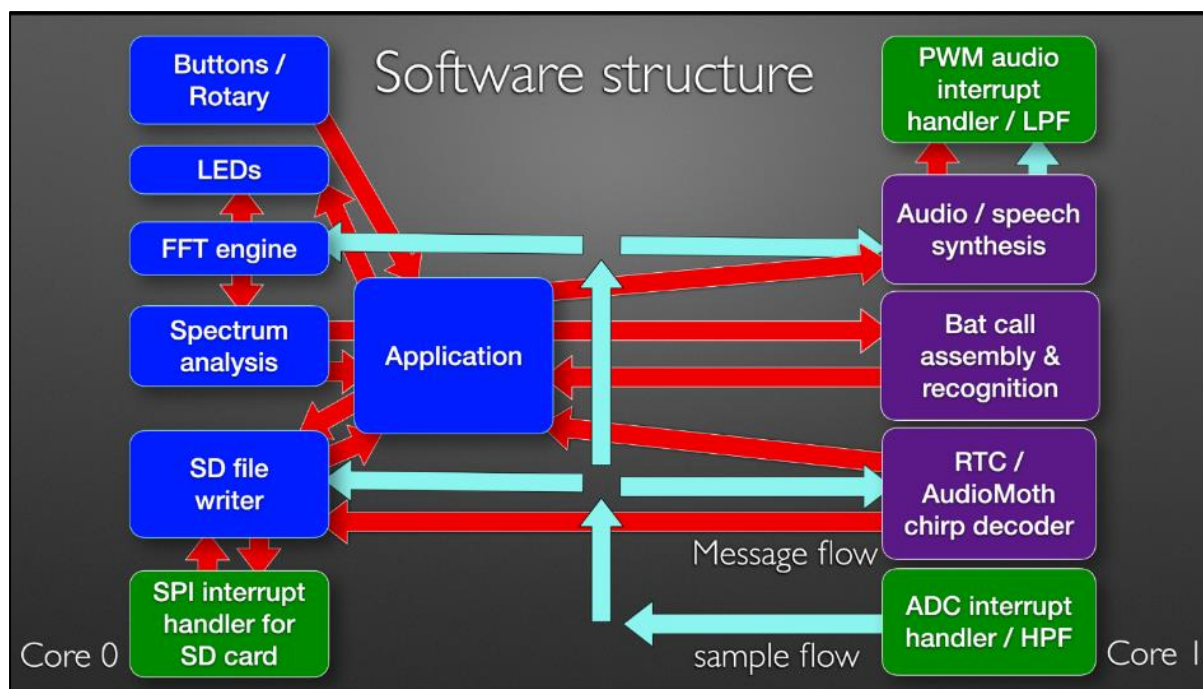


Figure 10: π•pistrelle software structure.

AudioMoth app to set Real-Time Clock

Note the AudioMoth³ process running on Core 1. The Pico has an internal Real-Time Clock (RTC), but in the absence of a persistent power supply the RTC needs to be set every time power is applied, otherwise recordings cannot be timestamped.

With only a rotary and two buttons, and no display as such, programming a date and time would be extremely cumbersome, to say the least. Fortunately for this project the AudioMoth team have open-sourced their iOS/Android app, so I was able to look at their source code and reverse-engineer a mechanism for decoding an AudioMoth 'chime' and was able to retrieve the encoded date and time.

So the AudioMoth smartphone app for iOS and Android is used to set the RTC clock, a painless and simple operation. The RTC can only be set if there is a valid, formatted microSD card in the slot.

Once the RTC has been set the flash pattern of the Pico LED changes to a 'heartbeat' flash, so you know that the setting has been successful.

Species recognition

The 'Bat call assembly and recognition' process is not yet fleshed out (as of May 2022), so there is at present no automatic species recognition. This is planned to come soon, but it will be at best a rudimentary piece of assistance for novice users.

³ <https://www.openacousticdevices.info/audiomoth>

Speech synthesis is used to give status feedback, and to give a precise indication of the currently selected heterodyne frequency when in manual mode, or the most recently tracked ultrasonic energy activity when in automatic scanning mode.

Real-time Time Expansion (RTTX)

The most recently added feature is Real-time Time Expansion (RTTX). In RTTX mode the incoming audio stream from the microphone is continuously analysed by a combination of the FFT engine and the Spectrum Analysis process. When a sound is detected that is suspected to be a bat call, a complete internal buffer (64k samples, 170ms) is captured, then played back over the audio output port at 1/16 real-time. Warning - here is where I abandon any pretense to 'science' and get massively subjective. I understand that 1/10 is more typically used when time expanding bat calls for acoustic analysis, but 1/16 is not only more musical - the bat has been dropped exactly 4 octaves - but is also easier to listen to. Soprano pipistrelles *Pipistrellus pygmaeus* at 1/10 speed are at around 6kHz, which is mighty squeaky. At 1/16 speed they are at more like 3.5 kHz, a much more pleasant experience, and soprano pipistrelles deserve to be experienced with a smile rather than a wince. And don't get me started on 1/10 time expanded lesser horseshoe bats *Rhinolophus hipposideros*. Those things could drive the family dog insane. Also - briefly back to actual, verifiable maths here - 1/16 stretched out the 170ms to 2.7s rather than 1.7s, so the individual calls (back to subjective) sound less hurried.

I can't understate this - RTTX is a VERY cool feature in the field. On a recent field trip to Portugal (with extreme bat novices) we took an Echo Meter Touch and two π •pistrelles, one for recording and one for RTTX. The combination of Echo Meter Touch heterodyning and providing on-the-spot species hints with the π •pistrelle RTTX made for a brilliantly entertaining evening. Heterodyned clicks are all well and good, but proper, ghostly, sweeping bat calls at 1/16x real-time are amazing to experience as the bats fly overhead.

Using π •pistrelle

There is a lot of documentation on the [\$\pi\$ •pistrelle](#) website, so I will only provide a brief summary here. Please read the site in more detail - just point a smartphone at the QR code on the first page of this paper.

Detector Functionality

When detecting, the LED array shows a real-time spectrum. The bottom LED corresponds to 15kHz-25kHz, the top LED 110-125kHz. So a single pulsing LED near the top indicates a greater *R. ferrumequinum* or lesser horseshoe, the bottom LED is noctule/serotine *Eptesicus serotinus* territory, and *Pipistrellus* will light up the third/fourth LED from the bottom.

The left button and the rotary encoder are used in detector mode, along with 'long click' (press - wait - release) on the right button. The available functions are:

LEFT SINGLE CLICK - enter heterodyne mode and start auto-scanning, locking onto the strongest ultrasonic band if it exceeds the 'minimum significant energy' limit. The detector is only allowed to change frequencies every four seconds.

LEFT DOUBLE CLICK - enter heterodyne mode and speak the most recent heterodyne frequency. This may be an frequency detected by auto-scanning, or a frequency selected by the rotary encoder.

LEFT DOUBLE CLICK - enter heterodyne mode and speak the most recently recognised bat species (functionality currently not implemented).

LEFT LONG CLICK - no action mapped at present.

ROTARY ENCODER - enter heterodyne mode and set the heterodyne frequency according to the rotary. The rotary is an 'endless' controller which allows the frequency to be set from 10kHz to 120kHz in 0.5kHz increments.

RIGHT LONG CLICK - enter RTTX mode and scan for bat activity. On candidate bat detection the most recent 170ms of samples from the ADC are replayed at 1/16 real-time (optionally 1/10 or 1/20).

Recorder Functionality

The right button is used mostly for recorder functions, along with the microphone which is listening for AudioMoth chimes to set the RTC and enable recording to microSD card. The available functions are:

ON AUDIOMOTH CHIME DETECTION - if RTC is not yet running, and if microSD card is detected, set the RTC to the date/time embedded in the AudioMoth chime and start the RTC.

RIGHT SINGLE CLICK - if RTC is running immediately record 4Mbytes/5.2 seconds to microSD card.

RIGHT DOUBLE CLICK - if RTC is running wait a few seconds accompanied by flashing, then record 12 files each 4Mbytes/5.2 seconds to microSD card - roughly 1 minute of recording.

RIGHT TRIPLE CLICK - if RTC is running, enter 'overnight mode'. In overnight mode the device sleeps between 7.00 am and 8.00 pm, flashing the LED occasionally. Between 8.00 pm and 7.00 am the device listens for bat activity, if detected it records 4Mbytes/5.2 seconds of audio data to microSD card.

Bat Synthesizer functionality

The 'Bat Synthesizer' function is intended as a classroom aid for educational outreach, or as a training aid for detection/surveying. Having a virtual bat in a classroom or presentation room is hoped to make demonstrating a detector or recorder much easier, but this proposition has not yet been tested.

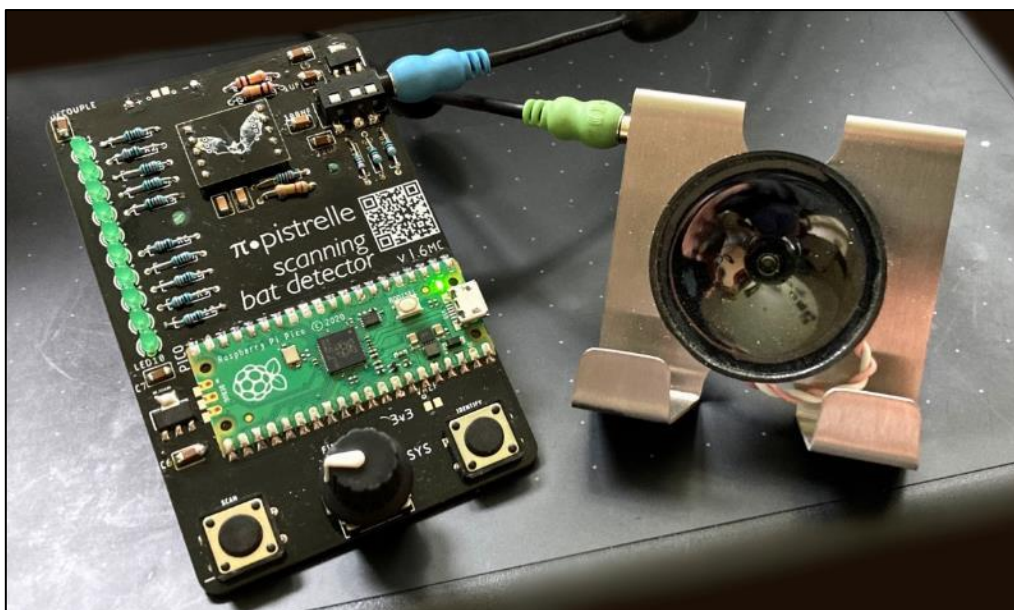


Figure 11: π•pistrelle configured as a Bat Synthesizer with L010 speaker.

A π•pistrelle Bat Synthesizer requires an external ultrasonic speaker, a slight modification to the audio output filter to stop the ultrasonic energy being suppressed and a completely different firmware image in the device. The firmware can be downloaded from the π•pistrelle website (the QR code on the first page of this paper takes you there).

The audio circuit modification is just a single capacitor change, replacing a 100nF with a 2.2nF, moving the corner frequency of the low-pass filter up from 7.3kHz to 329kHz. A π•pistrelle configured as a synthesizer can still be used as a detector/recorder albeit with somewhat 'fizzier' audio output, but one configured as a detector/recorder cannot be used as a synthesizer.

The affordable ultrasonic speaker I have found online is the L010 (typically available on eBay) which allows bats up to soprano pipistrelle frequency to be synthesized effectively. The speaker has poor response above 60kHz, so greater horseshoe bats are possible but very attenuated and lesser horseshoe bats are barely detectable. I am sure that more much expensive ultrasonic amplifier/speaker combinations are available but this has not been investigated.

When configured as a synthesizer the π•pistrelle has ten possible programs it can cycle through, eight are currently in place:

1. Common pipistrelle, echolocation with occasional social calls
2. Soprano pipistrelle, echolocation with occasional social calls
3. Noctule
4. Brown long-eared bat *Plecotus auritus*
5. Daubenton's bat *Myotis daubentonii*
6. Natterer's bat *Myotis nattereri*
7. Greater horseshoe bat

8. Five bats at once from the above - simulates a crowded bat environment to let people get to grips with a detector in the presence of multiple signals

All the programs attempt to simulate bats flying around the environment, so call intensities vary according to simulated distance to the bat, and simulated direction of the bat's flight (i.e. vocalisation direction). Tiny pitch shifts, simulating doppler effects, are included so that *Rhinolophus* species will heterodyne convincingly.

Figure 12 shows three bat calls synthesized by π •pistrelle - a greater horseshoe bat, a brown long-eared bat (with detail view showing fundamental, second and third harmonics) and finally a soprano pipistrelle. These are direct outputs captured from the synthesizer software, these do not represent a signal that has been passed through a speaker and captured by a microphone.

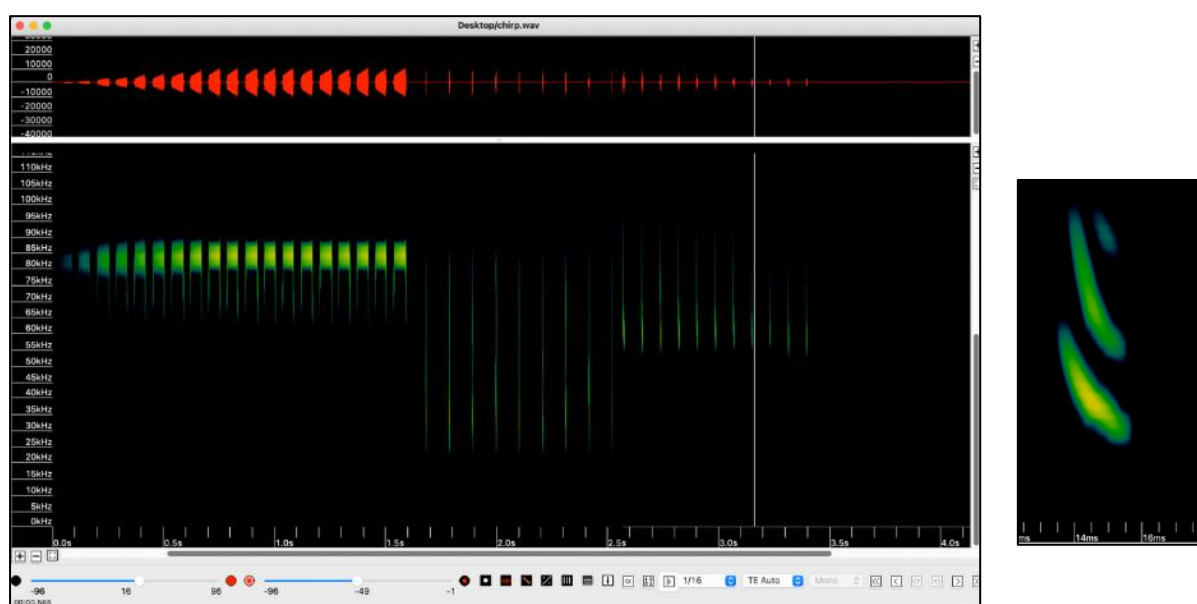


Figure 12: Three bat echolocation calls synthesized by π •pistrelle.

Recording quality comparison with Echo Meter Touch 2 for iOS

With version 1.6 the recordings from π •pistrelle are as good as I can get them, but are still not as clean as those produced by professionally-designed/commercially-manufactured devices. I will compare recordings with those from a Wildlife Acoustics Echo Meter Touch 2 connected to an iPhone SE.

Figure 13 shows two recordings made at the same time, with the microphone ports as coincident as I could get them, pointed at monitor speakers replaying a noctule field recording, while I generated some environmental noise.

It was clear that the π •pistrelle has much more gain than the Echo Meter. My recording is much louder, so these images are presented in a way that normalizes recording levels - I have turned the π •pistrelle gain down by 10dB within Kaleidoscope.

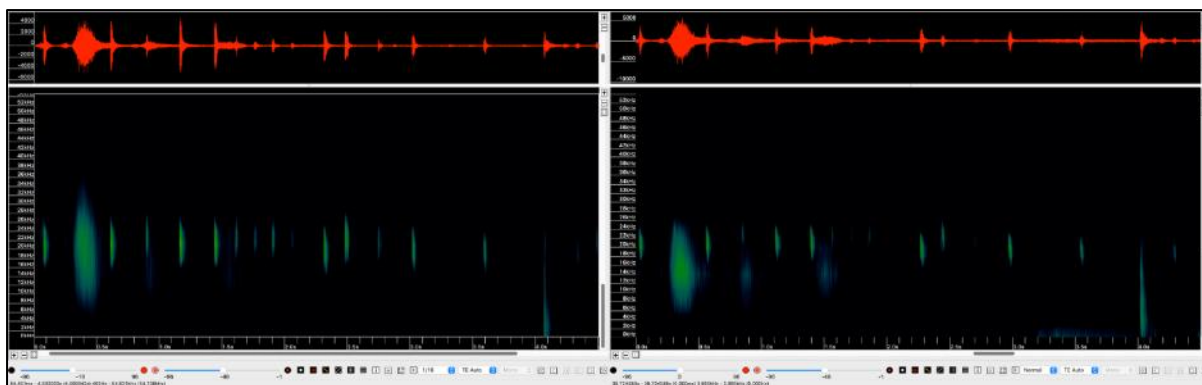


Figure 13: Left π •pistrelle (-10dB), right Echo Meter Touch 2.

It looks (and sounds) like the Echo Meter has no high-pass filter to suppress non-ultrasonic sounds. Speech and lower-frequency environmental noise comes through very clearly, whereas π •pistrelle was designed with a hardware high-pass filter (corner frequency 7.5kHz) to both suppress speech and maximise the number of ADC bits available for ultrasonic frequencies. The π •pistrelle firmware also includes a software high-pass filter with an adjustable corner frequency, currently set to 1.9kHz. Together these filters do a very good job of suppressing environmental sound and speech, but they do firmly position π •pistrelle as a 'bats only' device, rather than a more general field recorder.

There is no noise apparent in these recordings by visual inspection, so let's boost both by 20dB relative to this image (Figure 14). The Echo Meter Touch will go to +20dB, π •pistrelle to +10dB, to leave the signals at the same peak-to-peak level. Additionally the vertical scale will be reduced so we can see what is happening at the higher frequencies.

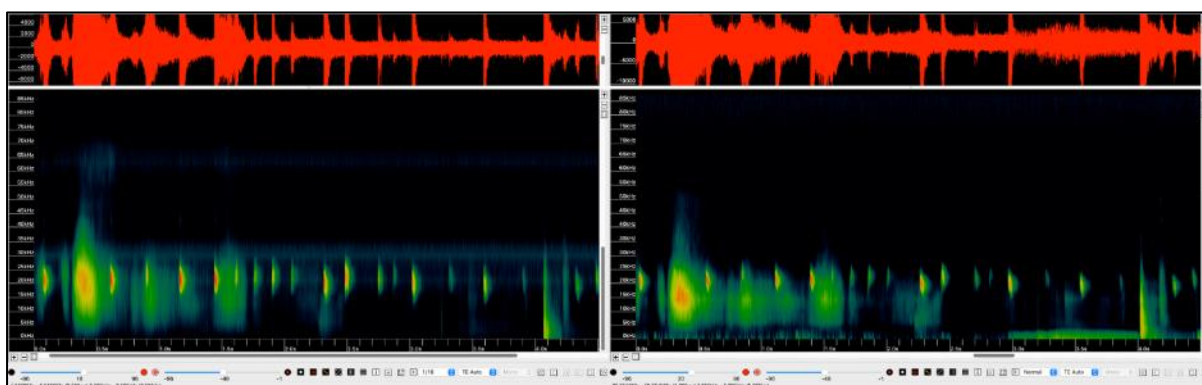


Figure 14: Boosted captures: π •pistrelle (+10dB), Echo Meter Touch 2 (+20dB).

Now with 20dB of boost compared to the previous image, the noise structure in the π •pistrelle recording can be seen - energy bands are clearly centred at 30kHz and at a reduced level at 60kHz. The low frequency energy in the Echo Meter recording is also clearly visible in the final third of the recording, but nothing at all is visible in the π •pistrelle recording thanks to its high-pass filters.

Clearly, even after adjusting for gain, the Echo Meter has much lower intrinsic noise levels than π •pistrelle. Some of this could be the inherent lower quality of the Pico ADC, which has according to its datasheet an 'Effective Number of Bits' of just nine. This indicates that there

will be significant quantization noise on the π •pistrelle recordings that I cannot do anything about, in addition to any noise associated with the design and electrically noisy environment of the π •pistrelle PCB.

So, given all that, are π •pistrelle's field recordings fit for purpose?

Field recordings

Take a look at Figures 15a and b. These show a π •pistrelle recording of a common pipistrelle and a lesser horseshoe bat, recorded outside on a still night at the Côa Valley prehistoric rock art site in Portugal, 20th May 2022. To better view the faint lesser horseshoe bat trace, the images have been slightly boosted in Kaleidoscope - the right slider is at -53 vs. the usual -48. There is still no visual evidence of noise in the recording.

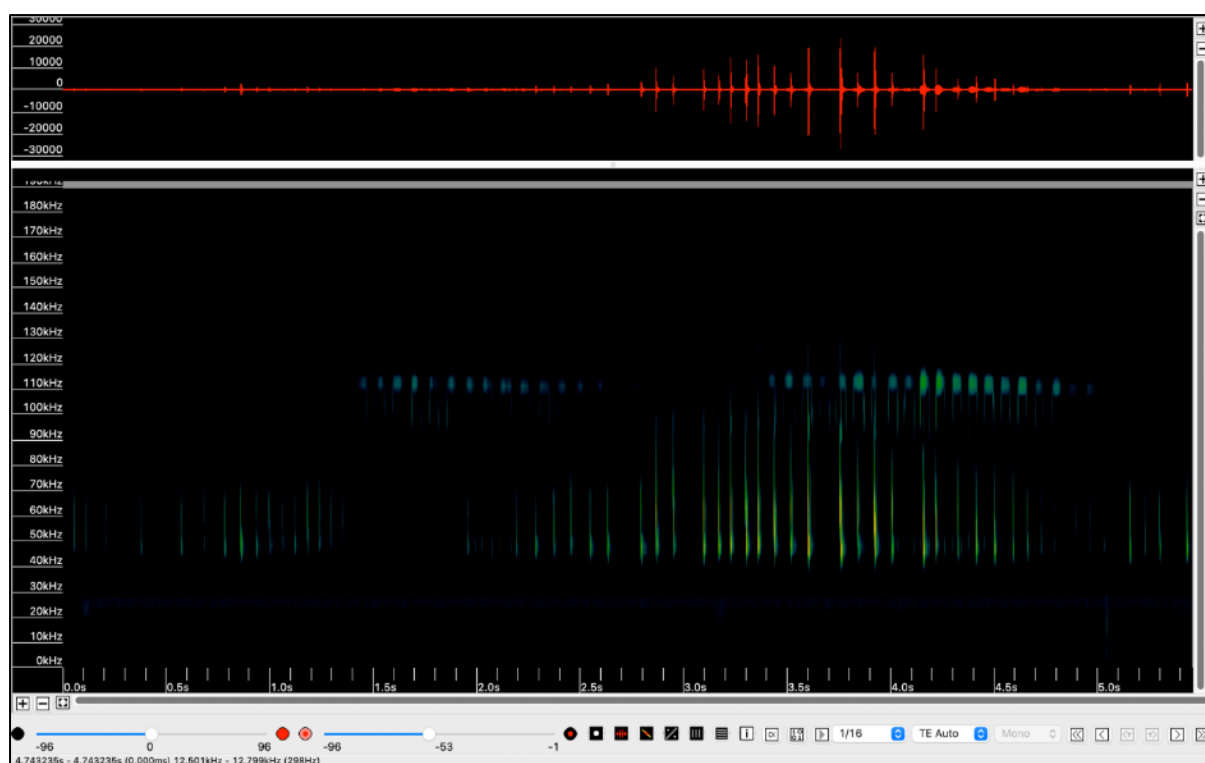


Figure 15a: Recording of common pipistrelle and lesser horseshoe bat.

There is a lot of echo as the detector was placed quite close to the 'rock art wall', a vertical feature where the prehistoric engravings are located, so a strong initial reflection is present. This is pretty much a best case recording, as the signal amplitude is approaching the pre-distortion maximum. This is a really nice recording, and is the first time a π •pistrelle captured a *Rhinolophus* species. I honestly did not know whether the ultrasonic microphone on the BatSignal would stretch as far as 113kHz, I was absolutely delighted to capture this recording.

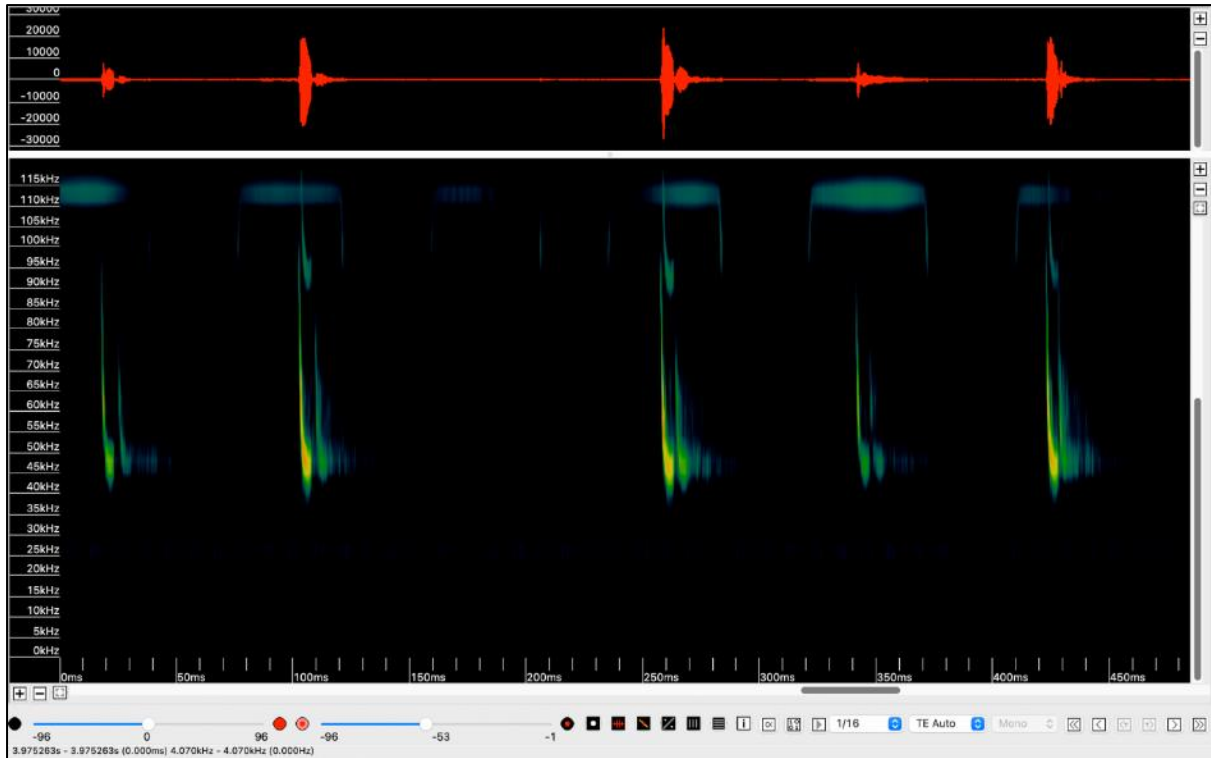


Figure 15b: Recording of common pipistrelle and lesser horseshoe bat (zoomed).

Next, Figure 16 shows a more typical recording - a soprano pipistrelle recorded in my garden on the 24th May 2022. I need to explain the way this looks. There is no automatic gain control or dynamics management in the π •pipistrelle signal chain, so overly-loud signals will clip, and with 10dB more gain the Echo Meter Touch, clipping is quite likely in the presence of strong bat signals.

This recording has visibly clipped, the red sample display at the top is up against the 32767 endstops, so the recording has generated the characteristic 'full spectrum overload' vertical line in the spectrogram. But again, there is no visible noise on the signal to obscure or distort the bat calls, this recording is more than adequate to identify the bat.

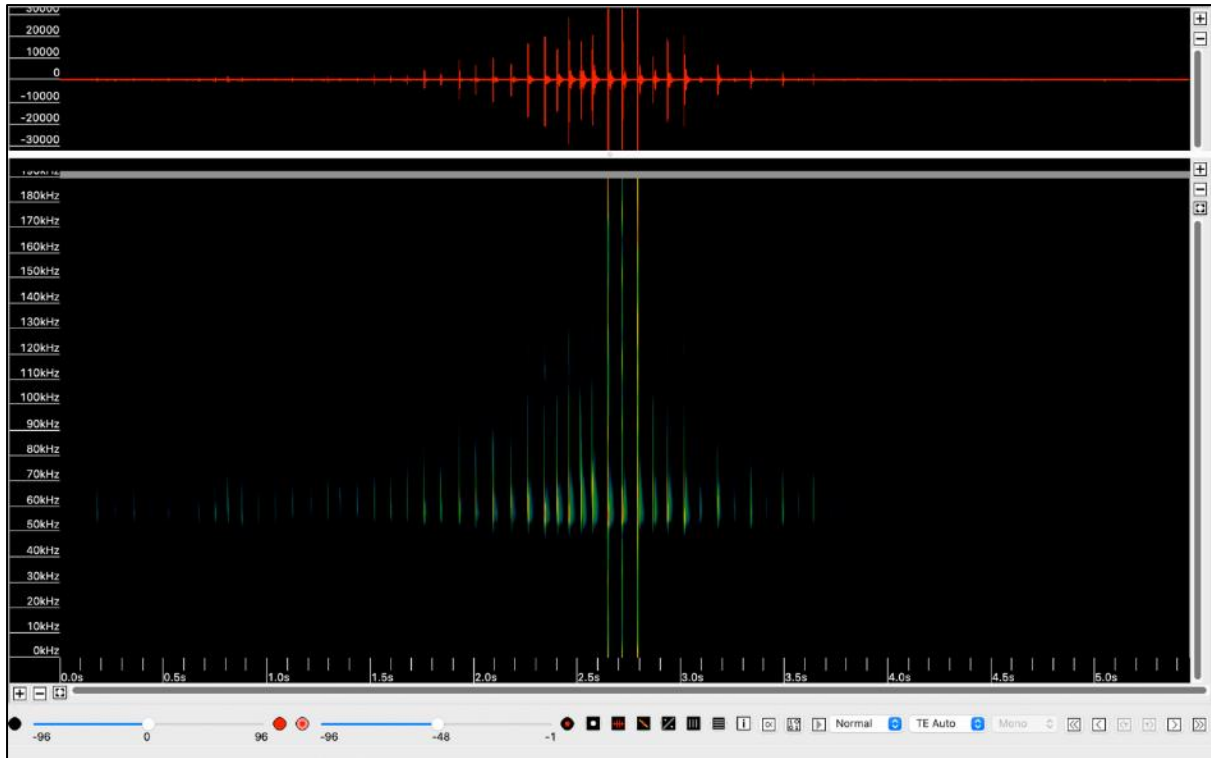


Figure 16: Recording of soprano pistrelle showing signal clipping artifacts.

Figure 17 shows another soprano pipistrelle on the same evening, at a much lower signal level, but still clearly identifiable.

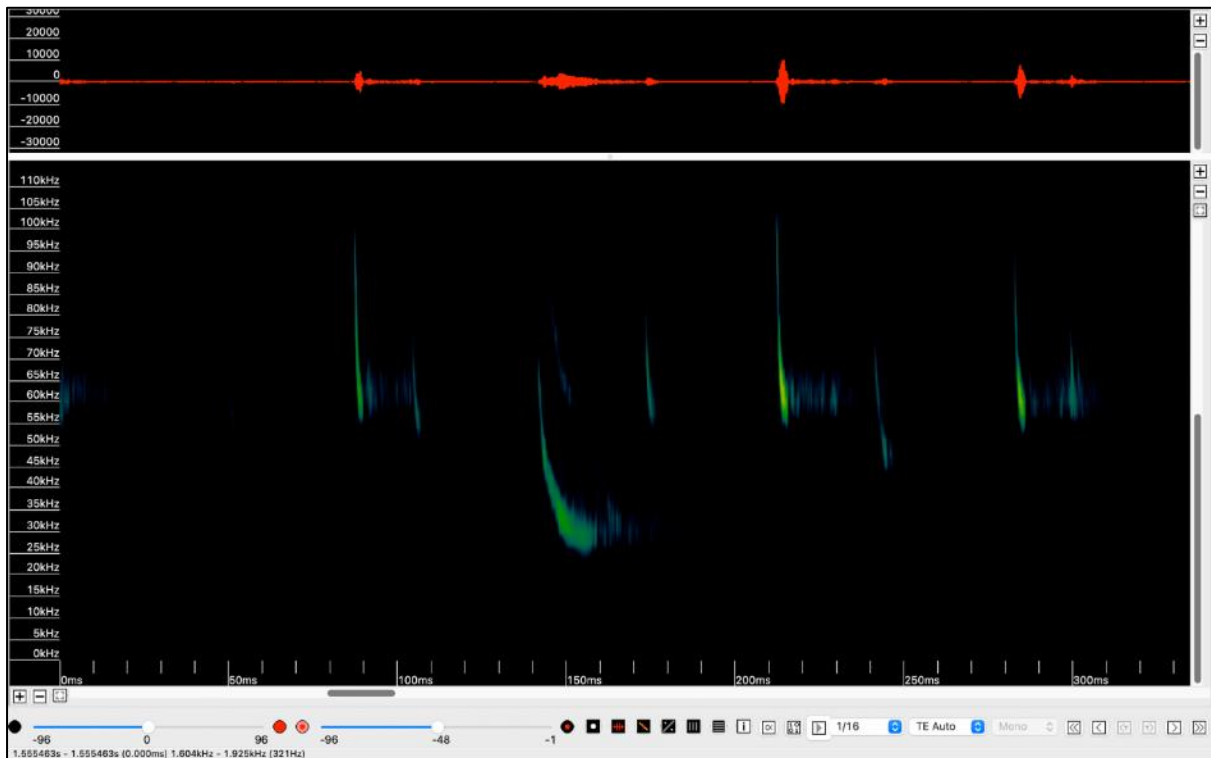


Figure 17: Another soprano pipistrelle and single-note social call.

Finally, Figure 18 shows π •pistrelle at the absolute limit of its usability. I have a gain of 16dB applied just to see what is happening. Barely breaking through the noise, this spectrogram is (to my eyes) impossible to read, with noise, call and echoes all at the same energy level, but clearly something is happening in the 20kHz region. A quick listen in Time Expansion mode makes it clear that this is a four-note common pipistrelle social call.

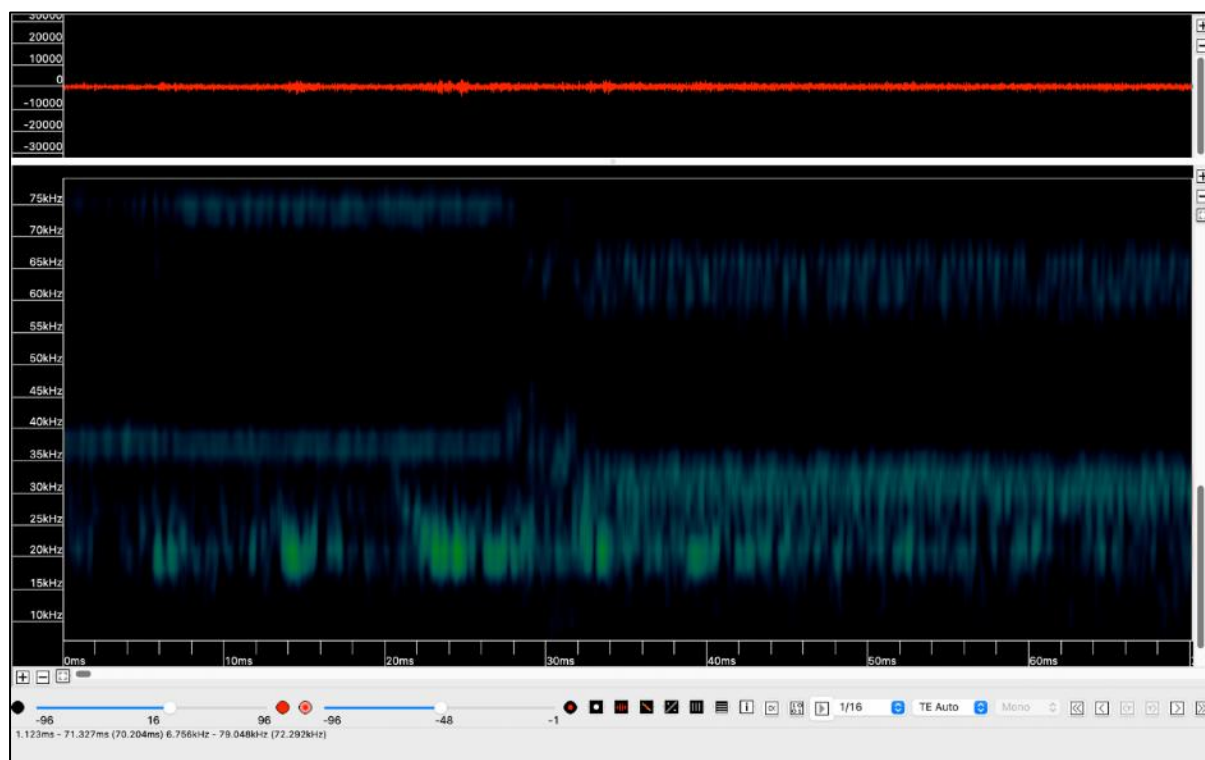


Figure 18: Only by listening to this recording can it be identified as a common pipistrelle social call.

So even at the very limits of its ability to capture an ultrasonic signal, the π •pistrelle makes recordings that can allow users to identify bats with confidence.

Summary

π •pistrelle - an ultra-affordable, battery-powered handheld bat detector and full-spectrum recorder - has been developed over six hardware revisions and is available to anyone with a soldering iron and half an hour of free time.

PCBs for the main board may be ordered from PCBWay.com and cost only \$5 for 10 PCBs⁴. Since PCBWay typically ship 11 working PCBs whenever an order for 10 is submitted, this equates to around 40p per PCB. Shipping costs dominate (typically \$16 for a \$5 order), but PCBWay allow a buyer to merge shipping costs on multiple orders, so if a bat group or a research project wanted say 50 units, the circuit boards would cost well under £1 each.

Unit cost when assembled in volumes of 10 or more is between £15 and £20 per unit (Appendix A), the actual cost depends on the US dollar exchange rate, and on component

⁴ Of this \$5, 10% goes to me, so please feel free to order several million PCBs.

availability at the lower-cost suppliers. Costs can be further reduced if devices are to be used as field recorders only, as the audio output and LED array components may be omitted. If a detector with no recording function is needed, for example to accompany bat walks, the recorder LDO and capacitors and the AdaFruit breakout board can be omitted, saving around £4.

Recording quality is not on par with (for example) a Peersonic or an Echo Meter Touch. This is partly due to limitations with the Raspberry Pi Pico ADC (it has a well-documented bug and somewhat limited precision), but also due to limitations with the analog input circuitry and power supply arrangement on the π •pistrelle. Despite these limitations, π •pistrelle is perfectly suited for Bats in Churches surveys, where environmental noise is very low, and is likely to be extremely effective for other field survey work where multiple recorders need to be deployed over multiple nights as its battery life is very good.

PCBs for the BatSignal module must be bought either from PCBWay in huge quantities - it is a 'panelised' PCB, meaning that each PCB contains a large number of modules that can be broken off as needed. The minimum order is for an eye-watering 150 units - 5 PCBs panelised with 30 modules on each - so if I have them in stock I am happy to sell them on within the UK at as near cost as I can manage - £5 plus shipping for 10 BatSignal PCBs. I intend keeping a few hundred in stock at all times, but these are for UK shipping only. I can also supply very small numbers of assembled BatSignal modules, but I encourage people to build their own as I have no intention of becoming a one-person electronics factory.

Future Work

Hardware-wise, two more revisions of the design have been prepared but not yet manufactured (manufacturing is happening as I write, 3rd June 2022).

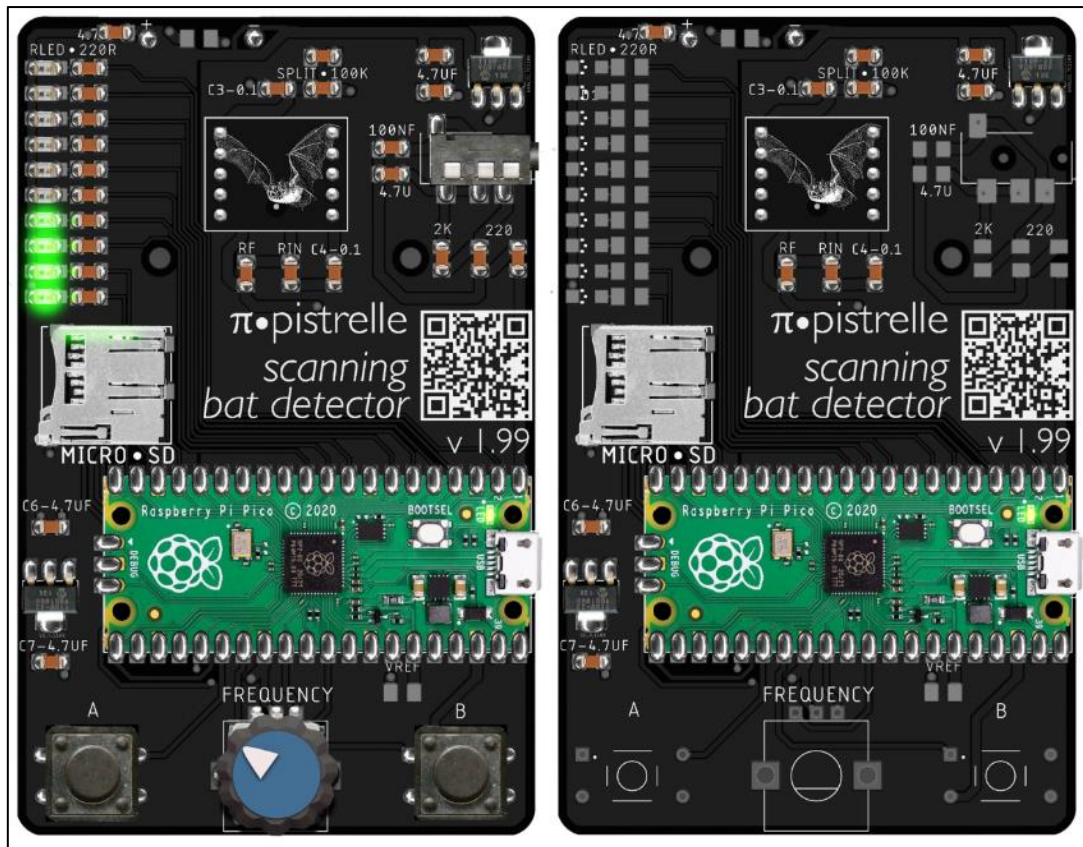


Figure 19: Version 1.99 assembled as a detector/recorder (left) and recorder-only (right). Version 1.99 replaces all the discrete components - resistors, capacitors, LEDs - with surface-mount devices (SMDs), specified to be large enough that they can be either hand-soldered with an iron or with a hot plate. SMD parts are less expensive than through-hole parts, so a couple of pounds is saved here. The AdaFruit interface card on the back side of the PCB has been replaced with a surface-mounted microSD interface on the top surface of the PCB, this alone saves around £2 of component cost.

This version, when configured 'recorder-only' (i.e. omitting the LED array, the audio output components and the buttons and rotary encoder) should drop the self-build cost to around £12 per unit, and also, by placing all the SMD components on the top surface, paves the way for mechanised assembly and higher volume production, should anyone ever be interested in pursuing that. By using a solder paste stencil and a larger hotplate, assembly time for a version 1.99 should be down to between 5 and 10 minutes per device.

Version 2.0 will be a smaller form factor recorder-only device, only slightly larger than the battery case. It is functionally identical to the recorder-only configuration of 1.99, but importantly it removes the BatSignal, placing all components on the bottom side of the board, with a view to automated assembly. This is intended to be manufacturable in medium volume (say 100 units) for around £15 per device, **including** assembly. Version 2.0 may never see the light of day if the 'recorder-only' version of 1.99 does the job - I will wait for a lot more feedback before committing to another hardware revision.

On the software side, the 'auto species ID' needs to be improved and reintegrated into the firmware, and in general the sensitivity of the device to false positives needs to be improved to minimize blank recordings during overnight surveys.

The Bat Synthesizer functionality needs to be revisited and finalized.

So after all this, if you need an insanely cheap full-spectrum ultrasonic recorder with heterodyning, real-time time expansion and bat synthesis, do get in touch.

Acknowledgements and thanks

Thanks to Rachel Morley at [Friends of Friendless Churches](#), without whom I would have never been aware of the Bats in Churches project.

I owe a huge debt of gratitude to Claire Boothby and Giada Giacomini at BCT/Bats in Churches for their insight, support, experience and endless patience throughout this development process.

Technology giants upon whose shoulders I stood:

- The Raspberry Pi Foundation whose [Pico](#) microcontroller, its toolchain and documentation made this project possible.
- Wildlife Acoustics, whose excellent '[Kaleidoscope](#)' software let me get to grips with bat calls, and whose Echo Meter Touch still sets the bar for usability in a handheld detector/recorder.
- [CircuitLab](#), an online circuit simulation tool which allowed the analog circuits to be debugged before committing to hardware.
- Analog Devices, specifically their application note AN-851 '*Biasing and Decoupling Op Amps in Single Supply Application*' authored by Charles Kitchin. Before I digested this document my microphone amplification stage sounded like Jimi Hendrix crashing a bus. Now it records beautiful, clean bat calls.

And biggest thanks of all to my wife Ilene who accompanied me on every Bats in Churches survey in 2021 (and will again in 2022) and whose enthusiasm for the Wildlife Acoustics Echo Meter was instrumental in convincing me to add recording to the π •pistrelle feature set.

Appendix A: bill of materials for a single device, more details on [\$\pi\$ •pistrelle website](#)

Component	Quantity	Approx. unit cost GBP	Possible supplier - but shop around for best price
Raspberry Pi Pico	1	3.50	Pimoroni
π •pistrelle blank PCB	1	1.75	PCBWay - assumes order of 10
BatSignal blank PCB	1	0.50	Direct from me - email me for details
Knowles microphone	1	0.50	Digi-Key
Microchip MCP622 op amp	1	1.20	Digi-Key

Component	Quantity	Approx. unit cost GBP	Possible supplier - but shop around for best price
3.5mm 2.2V green LED	10	0.17	RS
220Ω resistor	13	0.08	RS
100kΩ resistor	2	0.08	RS
56kΩ resistor	1	0.08	RS
2kΩ resistor	1	0.08	RS
Microchip 3.3V LDO 300mA	2	0.83	Farnell
3.5mm jack	1	0.5	eBay
100nF MLCC capacitor 3.2mm	3	0.15	RS
4.7μF MLCC capacitor 3.2mm	6	0.15	RS
Rotary encoder	1	1.20	RS
12mm push button	2	0.1	Pi supply
3x AA battery holder, PCB mount	1	0.7	eBay
6mm knob 'D' shape	1	0.4	eBay
AdaFruit microSD / SPI breakout	1	2.7	Pimoroni
TOTAL ESTIMATED BUILD COST		£19.16	

Not costed here are the rechargeable AA batteries and a microSD card. Typically these can be found sitting unused in a modern household.

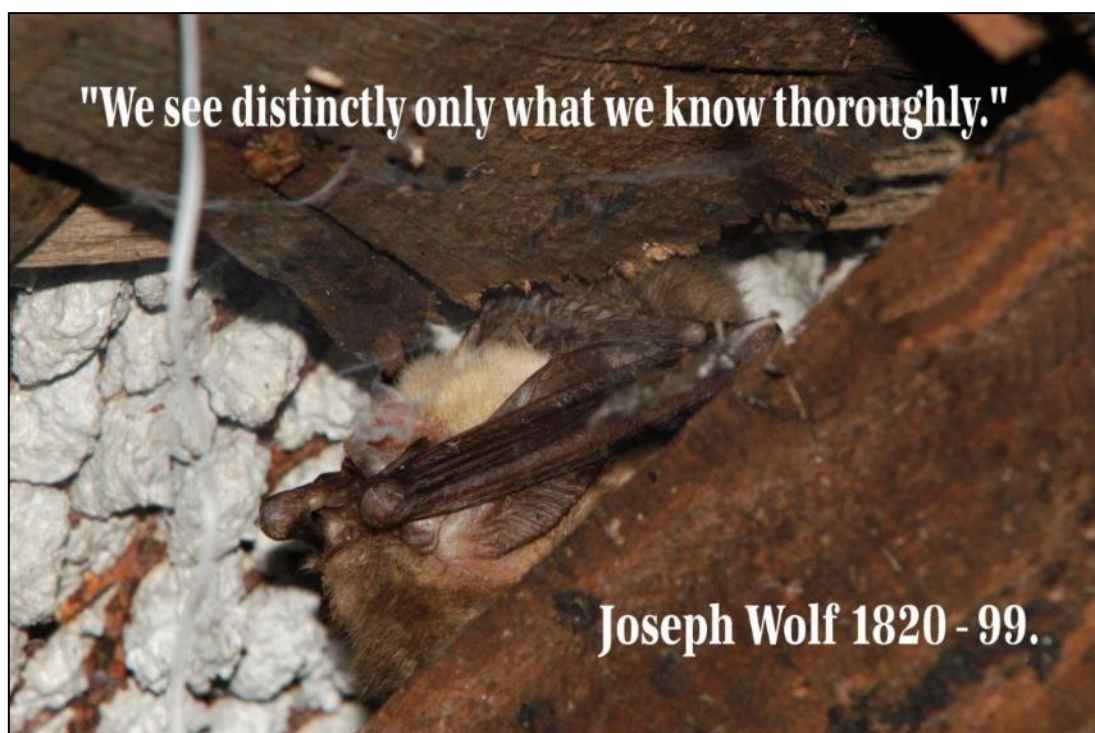
Many of the components listed above can be found more cheaply if you shop around on eBay or Amazon, and higher volume at the component suppliers will come with a price drop, so if you have a need for 20 units, be bold.

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A steep learning curve! A triple compilation of monographs

John J Kaczanow

John.kaczanow@gmail.com



A bat detector becomes a bat roost!

Last summer I was called out to assist in the repatriation of three common pipistrelle *Pipistrellus pipistrellus* pups. These pups were found in the offices of a mineral products company on Dartmoor. They obviously came from above and the first task - find the roost.

After extensive internal and external surveys a target area was decided and I made my way into a loft section. Just inside the loft hatch there was a small ring of planking acting as a box without a lid. Hanging from this box was another pup which was bagged to keep it secure. I found a roosting area at the gable end internal loft section. This was quite extensive and I thought that if I released the bats here they may well make their way away from the main part of the roost. After inspecting the outer part of the wall I found several small entrances behind some metal cladding; under which were spotted with a few droppings. This spot was to be the repatriation site.

I went inside to the office to collect the pups which had just been fed by the plant manager; a lady that had grown attached to the bats and proved to be a very efficient carer. I removed the new pup from the bag and was handing it over to be fed before release when it became really active and managed to escape; it dropped a foot onto an office table where it immediately disappeared.

We could not believe where it had gone. When I returned into the office I put my search equipment onto the table; included in such was my trusty old Tranquility 11 bat detector. Imagine our surprise when we found the pup hiding inside the small cavity (30mm x 10mm)

at the front-end of the detector that contains the microphone! (Figure 1). For such a young animal (10-14 days) to be able to react so very quickly was amazing. Truly, it recognized a quality instrument!



Figure 1: Tranquility II bat detector - spot the pup. © Julie Cunningham.

Have we found the Alcatthoe bat *Myotis alcathoe*?

During an autumn evening's harp trapping at a favoured Devon site, locally known as a SAS (Social Assemblage Site). One can always rely on catching many whiskered bats *Myotis mystacinus*. 30 individuals in a good session would not be outstanding.

Identification of whiskered bats was relatively easy; that was up until 1970 when Brandt's bat *M. brandtii* came along. The Brandt's bat has proven, to me at least, to be an extremely rare species in the region; perhaps our rarest? In rare cases when one was captured along with a whiskered bat, I considered that its identification proved to a certain extent, rather easy!

Moving on through the decades and many hundreds of whiskered bat captures later the Alcatthoe bat *M. alcathoe* showed up here in the UK (2010) to add confusion. At this time DNA sequencing was a bonus and if we wanted to claim this new species, we just had to send a sample to the lab and pay for the fame it would generate!

In the first place, deciding on the likeness of a whiskered bat specimen to be a probable candidate for testing seemed straightforward, going by the positive descriptions by others in the know. There were many candidates over the years and many months pocket money down the drain. I therefore decided that I would no longer desire to be the first to find Alcatthoe bat in the region. Low and behold up to the time of writing, this species for whatever reason has stayed hidden.

Recently, due to a renewed interest in the elusive bat, I decided on a new path to fame. After updating my identification pamphlets for attending bat workers, I chose a new method for deciding on the criteria for choosing a likely specimen for DNA sampling. That method is wing venation patterns. *Pipistrellus* species enthusiasts will be quite aware that a lot of work has been done on the wing venations of many *Pipistrellus* species. Published patterns have been used for many years to single out types.

Due to the COVID-19 situation very little capturing was done in 2020 and 2021. However, during last autumn we managed to visit the favoured site and captured a number of whiskered bats. Bulk bat biological data acquisition was curtailed due to COVID-19 limitations and the only measurements taken were from likely species.

Two samples were obtained and both bats were weighed and right forearms measured. Also, photographs were taken of the right wing venations (Figures 2 and 3). Surprisingly, there were numerous differences in the two patterns. This led us to believe we had a difference in bat species; leading to getting both samples tested. Well, what a disappointment, both samples came back as whiskered bat.

The results were certainly surprising; especially considering the slightest difference between the venation in the common pipistrelle *Pipistrellus pipistrellus* and Nathusius' pipistrelle *P. nathusii* confirms different species. Yes, there are other features to go by, as have our two *Myotis* species in question.



Figure 2: Sample: SEL4998-1, captured 25/09/2021, *Myotis* species, male, right-hand forearm 33.9mm, weight 4.6g. © Emma Scotney.

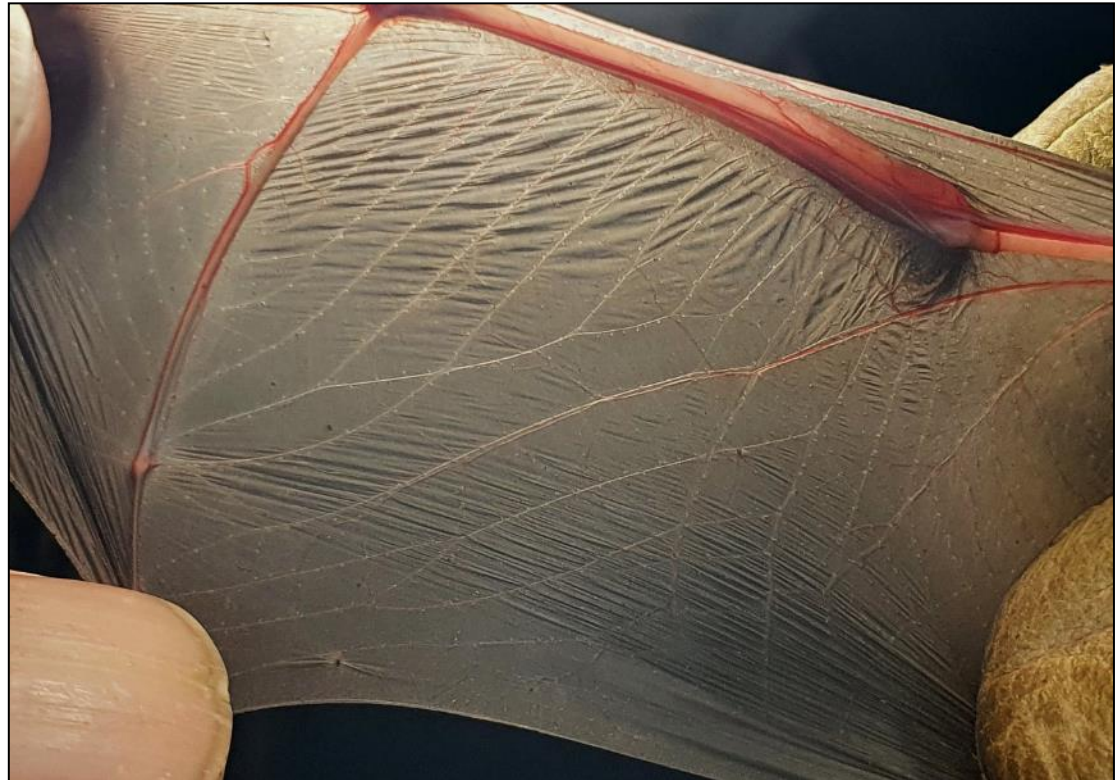


Figure 3: Sample: SEL4998-2, captured 25/09/2021, *Myotis* species, male, right-hand forearm 34.5mm, weight 4.9g. © Emma Scotney.

This leads me to contemplate whether to even consider believing that identification of a species can be determined by the methods used. As you all will probably say; how can I suggest such a thing, when incredible results have been achieved in the use of DNA sequencing throughout numerous industries (criminal and medical etc). So yes it does work, so why have I got the results that were truly unexpected? We still have a lot to learn.

A photographic marvel

Batting and photography: there can't be many hobbies that gel as well as mine. I have the opportunity to alleviate the stresses of everyday life by reliving my fascination of photography and getting close to Chiroptera species through trapping/close observation etc.

I am going through a period of developing my own camera remote triggering devices to allow me to photograph bats (and other animals) in flight using high speed flash. Although, I have had some satisfactory results, I feel more is out there to achieve!

Stephen Dalton (a hero of mine, as is Eric Hosking) is a world leader of in-flight photography of most animal types and I have all of his 15 books. Many of these books depict bats in flight. The ones of our European species capturing their prey are the most amazing, even though as a rule they are taken under controlled conditions, but even then it is not that straightforward!

Whilst visiting a favoured trapping site last autumn many *Myotis* species were captured, and on their release I decided to try photographing them in flight. This did not involve a preset auto triggering setup. My method of release did emulate Dalton's when photographing greater horseshoe bats *Rhinolophus ferrumequinum* in Germany. However, I did not have a supply of moths to work with.

Due to COVID-19 limitations, bats were not held long before release. To gain some data we identified species and determined the sex prior to liberation. My two helpers that evening during the release period recorded data and triggered the camera when instructed.

The camera setup was facing an old building wall which guided the flight of each bat along a predetermine path. As the flash and camera shutter achieves 13 frames per second three to four shots can be taken before the bat changes direction or leaves the preset frame. Thus, allowing a greater chance of obtaining a suitable result.

About a dozen or so bats had been released and a few photos were reasonable i.e. the head was not covered by a wing, adequately exposed, in focus and acceptably positioned in the frame. These shots were quickly appraised and the procedure continued.

The next release was a Natterer's bat *M. nattereri* which went well, sensing something different we reviewed the sequence. Three frames were collected which are shown in Figures 4 to 6. On review the first frame (Figure 4) was quite good and showed the bat leaving my hand.

The second (Figure 5) was centrally positioned in a good pose, what was surprising was a moth was positioned directly in front and in line of its mouth. In the third shot (Figure 6) the bat was at the edge of the frame and with the wings in line with the body and the head was covered.

My two helpers said that a moth had been seen in flight as the flash illuminated the scene. Due to my position and being more in line with the flash, I had not noticed it. On further inspection the moth is shown in flight above the release point on the first frame.

The identity of the moth species I will leave for others; I do however believe it is 'tympanic' that is, it has tympanal organs which enables it to pick up the bats ultrasonic call, once informed it can then take evasive action. Thus, did the bat capture the moth? We cannot determine this as its mouth is hidden in the third shot (Figure 6). There are no wing scales in the picture, as perhaps there would be if the moth was captured?

The moth is in full flight in the first picture and probably not in the bats flight line; so why is the moth on a downward spiral in the second shot (Figure 5)? Evidently it is in an evasive dive. Was it successful? Whatever; it was certainly our very lucky evening!



Figure 4: Natterer's bat leaving the author's hand.



Figure 5: Natterer's bat in flight closing in on a moth.



Figure 6: Natterer's bat in flight.

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Pipistrelle distribution on the Isle of Man – an exception that could help prove a rule?

Nick Pinder; Manx Bat Group

nickpinder@manx.net

Introduction

From recent records of bat distribution and activity in the Isle of Man, the distribution of soprano pipistrelle *Pipistrellus pygmaeus* appears anomalous in terms of occupied habitat compared to its published habitat preference. Recent records of bats feeding over beaches in the north of the island indicate a possible mechanism by which soprano pipistrelle numbers there may be maintained while common pipistrelle *P. pipistrellus* appears to exclude them from favourable habitat in the south of the island.

Records

The Manx Bat Group has been collecting records since 1990, for the first 25 years mainly with heterodyne detectors, plus in-hand specimens. Included with those records were several observations of bats apparently feeding over beaches and in bays around the coast of the Isle of Man. With the acquisition of static recording detectors in 2016, record collecting began to be more focused, targeting not only development sites but also sites with statutory or de facto protection for nature conservation, including sites owned or managed by the Department of Environment, Fisheries and Agriculture, Manx National Heritage, the Manx Wildlife Trust and Manx Birdlife. The number of records collected also increased dramatically, from an average of 70 per year to 670.

In addition, static detecting gives some insight into the level of activity on any one site-night, since the number of recordings of each species can be counted and compared to other sites. They can also be mapped for visual interpretation, in this case using QGIS. Viewing the results for the period 2016 to 2020 (inclusive) revealed an unexpected pattern in the distribution of the two pipistrelle species, common pipistrelle and soprano pipistrelle (Figure 1).

Both species are recorded all around the island but large numbers of recordings of soprano pipistrelles, indicating high activity levels, are largely restricted to the northern plain, the triangle north of the TT course. This is an area of low elevation, largely agricultural, dominated by grazed grassland and arable fields (Figure 2), the complete opposite of the received wisdom of soprano pipistrelle habitat preference which is said to be riverine woodland (Davidson-Watts *et al.*, 2006; Nicholls and Racey, 2006), a habitat much more prevalent in the centre and south of the island. Indeed, soprano pipistrelles seem to be almost excluded from those habitats by the higher activity levels of common pipistrelles.

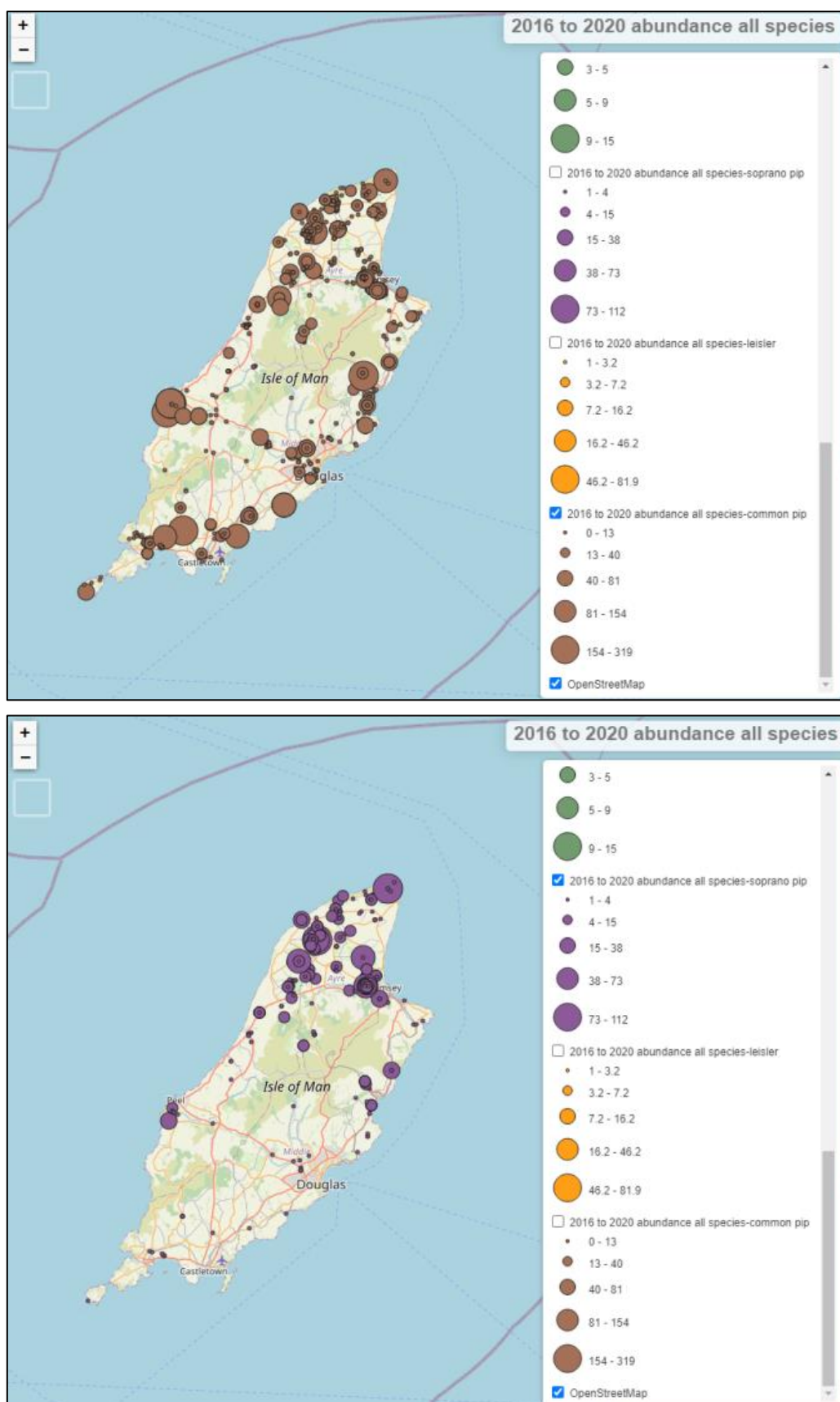


Figure 1: *Pipistrellus* records, 2016-2020, showing location and estimated abundance, common pipistrelle above, soprano pipistrelle below. Please note that the size of the circles represents different numerical intervals for the two species.



Figure 2: The Enhanced Thematic Mapper on the Landsat 7 satellite captured this natural-colour image of the Isle of Man on 1st May 2001. This image shows the northern end of the island, and the image has been rotated so north is to the right. Croplands cover the relatively flat terrain of the northern coastal plain, which forms a rough triangle.

It therefore seems pertinent to ask what has caused this apparent reversal in habitat preference for soprano pipistrelles? Several reasons could be put forward, ranging from the implausible to the credible. It could be an artefact of the survey methodology or timing, it might reflect the national north-south cline in soprano pipistrelle abundance or recent colonisation from Scotland, perhaps there are climatological differences across the island or ecological factors at play such as resource partitioning.

Survey methodology

A variable number of Anabat Express units have been deployed at a large number of sites across the island in recent years to collect records. During 2020 alone there were 57 surveys, at 22 locations, during which both species of *Pipistrellus* were recorded, varying in duration from one to 11 nights and in timing from January to October. Sites were not selected on any stratified sampling basis but rather to further biological recording of various nature reserves or to inform planning decisions. There is, however, a tendency for selected sites to be located in the north of the island since these are closer to the author's home.

The results can be seen in the chart below (Figure 3). The average ratio of common to soprano pipistrelle recordings over the 57 surveys in 2020 was close to 2:1 but the median ratio was 15:1. There were only six surveys where soprano pipistrelle recordings outnumbered those of common pipistrelle, but all those were in the north of the island.

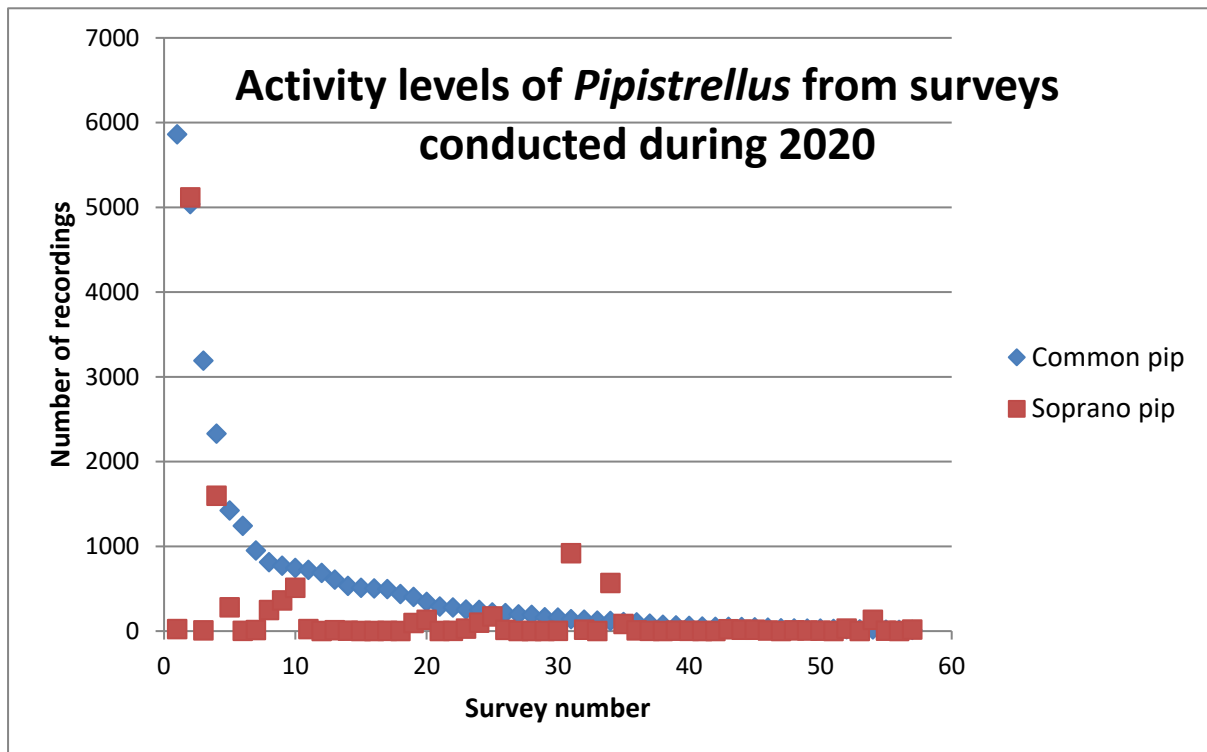


Figure 3: Number of recordings of the two species of *Pipistrellus* from 57 surveys where both species were present during 2020.

Despite the non-standardised survey methodology, however, the results of the surveys do still point to major differences in activity levels of both species of *Pipistrellus* across the island. It is only the soprano pipistrelle which shows a geographic trend in its activity levels as the common pipistrelle has high activity levels in both the north and the south.

This can be seen in outline in Figure 1 and in Figure 4. Figure 4 shows the locations of a selected number of surveys in the years prior to 2020 which had interesting results, either where the activity of soprano pipistrelles was higher than expected on habitat grounds (sites 1, 2 and 7) or much lower. Sites 3 and 6, in particular, were situated in wooded valleys which might be expected to have higher activity levels of soprano pipistrelle.

Some confirmation of the assessment of high activity levels of soprano pipistrelles on northern sites has been provided by Ecobat (2017), a web-based tool offering a standardised method of interpreting bat activity data. Over 18 survey-nights at seven northern locations in 2018 and 2019, soprano pipistrelles were reported to exhibit high or moderate-to-high activity levels on 14 nights.



	Habitat	Duration	Month	Common pipistrelle	Soprano pipistrelle
1	Beach, backed by marram	1 night	September	772	362
2	Grassland + tall hedges	7 nights	June	141	920
3	Mill pond in wooded valley	1 night	September	3192	8
4	Mill pond in wooded valley	5 nights	August	54	1
5	Beach in small bay	5 nights	September	5862	24
6	Wooded gorge	7 nights	July	1485	0
7	Small meadow + willow carr	3 nights	August	120	567

Figure 4: Selected survey sites (map) and number of recordings of common and soprano pipistrelles (table) across the island. Note the trend of the hills from north of Port Erin in the south to Ramsey in the north. Map from OpenStreetMap.

Biogeography

It is difficult to conceive that a small island, 45km from north to south, could reflect the pattern seen across the United Kingdom, with soprano pipistrelle being the commonest bat in Scotland (Bat Conservation Trust, 2022). Nor does it seem plausible that the soprano pipistrelle has only recently colonised the Isle of Man, putatively from Scotland, and that the hill land, rising to 2000ft at Snaefell, has formed a barrier to any spread further south.

The hills are actually taken as the dividing line between north and south in the Isle of Man and they had an impact on human activities in the past. There were, in fact, different dialects of Manx Gaelic in the two areas and, until relatively recently, it was possible to meet people from either end who had never visited the other side of the island.

However, soprano pipistrelle has been recorded south of the hills, albeit in small numbers. It is more likely that climatic factors vary across the island. The north of the island, particularly the Point of Ayre is locally reputed to be the sunniest place in the British Isles but that perhaps reflects that it also one of the windiest. Regrettably, until recently the island had only one weather recording station and so detailed examination of isoclines or rainfall patterns is not possible.

Resource partitioning

There have been many articles on resource partitioning in sympatric species of bats, particularly *Pipistrellus*, although the exact operating mechanism doesn't seem to have yet been defined. Rachwald *et al.* (2016) provided probably the best summary of current understanding and felt that further studies of habitat preferences of common pipistrelle living in allopatry (without influence of sibling species) are needed for conclusion, whether the observed distribution of common pipistrelle between habitats is the result of preferences of this species, or mostly interspecific competition. They also discussed the apparent ability of common pipistrelles to consume larger prey, and the published differences in prey composition (Barlow, 1997), but felt that these studies were inconclusive without supporting data from dietary studies.

Diet

Diet would seem to be one mechanism whereby soprano pipistrelle abundance could be influenced in the Isle of Man. The one major geographic difference between north and south in the Isle of Man is the prevalence of beaches, with one continual beach running north from Kirk Michael (Figure 2) round the point of Ayre and south to Ramsey. The common pipistrelle is known to feed on seaweed flies and Hawkes-Southern and Lintott (2020) found a significant relationship between the number of common pipistrelle passes and beach presence (as the tide receded). Irwin (2021) has also recorded common pipistrelle over a beach on the Sefton coast, including forays over the open seaward sands to approximately 30m away from the frontal dunes.

Such findings have been replicated in the Isle of Man, with several surveys conducted in 2018 and 2020 although, again, they were principally designed to add species records for localities (Table 1). All the sites detailed below had active dunes of variable width with marram grass at the inland edge of the beach and the detectors were placed at the seaward edge of the dunes.

Table 1: Number of *Pipistrellus* recordings from selected beach surveys on the Isle of Man - records of Leisler's bat *Nyctalus leisleri*, Daubenton's bat *Myotis daubentonii* and whiskered bat *M. mystacinus* omitted for clarity.

Location	Grid Ref	Start date	Duration	Soprano pipistrelle	Common pipistrelle	Nathusius' pipistrelle
Cronk y Bing (nature reserve)	NX 37793 01512	31/07/2018	2	3	30	0
Ayres NNR	NX 41507 03421	07/09/2018	2	32	76	0
Ayres NNR	NX 41326 03391	07/09/2018	2	9	54	0
Ayres NNR	NX 43515 03866	28/08/2018	3	1	9	0
Lhen beach	NX 37431 01288	28/09/2020	2	362	770	2
Lhen beach	NX 37336 01219	27/09/2020	3	6	19	0

The survey at Lhen beach (Figure 5) was conducted as a direct result of noting extensive signs of small waders feeding at the top of the beach, utilising two Anabat Express facing out over the beach approximately 100m apart. The numbers are remarkable and in fact are largely attributable to one night. Despite the date it is not thought that the high activity levels are attributable to swarming behaviour given the lack of any landmarks but are, like the waders, attributable to bats feeding on seaweed flies. Further dedicated surveys are required to confirm this conjecture but tidal conditions during 2021 were unfavourable.

The northern beaches extend for some 30km and although changes in beach composition, from sandy to stony, exposed to covered, are continuous there must always be patches where seaweed flies are abundant. Any one patch is well within the foraging range of soprano pipistrelles from any roost in the north of the island. It would seem therefore that an abundance of prey is supporting the co-existence of the two species of *Pipistrellus* in the north of the Isle of Man and it would be interesting to test this conjecture. Dietary studies would be required in addition to distribution and abundance surveys but recent advances in DNA bar-coding mean that prey species can be identified from bat droppings (Razgour *et al.*, 2011; Allaby Research Group, 2022).

The Isle of Man may offer a pertinent site to study niche separation in the two sibling species of *Pipistrellus* bat. The relative absence of soprano pipistrelles in the south may provide a study site to answer whether the observed distribution of common pipistrelle between habitats is the result of preferences of this species, or mostly interspecific competition (Rachwald *et al.*, 2016).

The Manx Bat Group would be happy to host any researcher(s) wishing to investigate this apparently anomalous pattern of *Pipistrellus* distribution.



Figure 5: Location of survey site on north-west coast of Isle of Man-Lhen beach. The detectors were placed on the outer edge of the marram overlooking the beach. Photo from <https://coastradar.com/places/isle-of-man/ayre/ramsey/jurby-beach/> [Accessed 3rd January 2022].

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The automatic identification of bat calls

Dean Waters; Department of Environment and Geography, University of York, YO10 5NG
Dean.Waters@york.ac.uk

Background

Ever since the discovery of bat echolocation (Pierce and Griffin, 1938) and the realisation that it may be possible to identify bats from the structure of their echolocation calls (Galambos and Griffin, 1942), scientists have striven to create rules by which bats can be identified by their vocalisations. While it was possible early on to create simple time-frequency representations using oscilloscopes e.g., Novick (1958), it was the advent of digital sampling, enabling time-expanded recordings that encouraged the process of identifying bats through their echolocation calls. Once cheap and portable digital storage media arrived, it meant that for the first time that it was possible to automate both the detection and the classification of calls, by which a series of files could be searched, and the calls identified without having to manually locate and process them.

Initial methods for identifying bats relied simply on examining the call spectrographically and comparing it with a list of parameters extracted from known species (Fenton and Bell, 1981). However, more rigorous techniques were soon explored, using a range of standard statistical techniques to group calls together and discriminate between them (Jones *et al.*, 2000). Studies often paired the well-known multivariate analysis (Vaughan *et al.*, 1997) with discriminant function analysis (Parsons, 1997). More recent workflows have used machine learning techniques which 'learn' what the differences are between species to create a template or filter for classification, and these are now applied in commercial automatic identification products.

The principles of classification

Classification workflow

Automatic species identification consists of a number of separate processes. Firstly, there is the detection of a bat call in a recording sequence. Humans can be very good at identifying a call from a spectrographic display in the presence of noise, while automatic systems tend to only lock on to the stronger calls. This may mean that quiet bats may be under-represented in automatic systems as the signal searching algorithms simply may not see them (Mac Aodha *et al.*, 2018).

The second process, once the call has been found, is parameter extraction. This is where the measurements of the call which will be passed to the classifier are extracted. There can be a range of parameters, from simple maximum and minimum frequency to slope rate, measurements of slope shape or even if subsequent calls alternate - Batscope for example, a free bat classifier, uses 59 different parameters extracted from the calls (Obrist and Boesch, 2018). Once the parameters are extracted, these are passed to the classifier which will match the extracted parameters to those from known species and provide either a best match or a suggested range of matches, sometimes with an estimate of the certainty of correct assignment.

Statistical processes

To allocate a call from an unknown species to a known one, a general set of principles is applied to create a classifier. Firstly, a set of reference calls must be collected with which the model can be created, and the unknown call can be compared. This presents an initial difficulty as the reference calls should be unambiguously assigned to a particular species. For some easy to distinguish species such as greater horseshoe bat *Rhinolophus ferrumequinum* or lesser horseshoe bat *R. hipposideros* in the UK, simple field recordings may suffice to collect the reference calls, but for other hard to distinguish species such as *Myotis*, the call library may have to be obtained from bats exiting known roosts, released from the hand following identification or recorded where no other species occur (e.g. Rydell *et al.*, 2018) - situations which not only lead to relatively small sample sizes but which also result in bats producing only a limited set of call types or even atypical calls. The reference calls should ideally be representative of that species in a range of different foraging situations to capture all the natural variation that the species will exhibit (Russo *et al.*, 2018), but this may not always be possible to obtain. The second stage is the creation of a model in which the extracted parameters are assessed in terms of their likelihood to be able to distinguish between species and then combined in a form to which an unknown call can be compared.

While the basic principles of classification are the same, each statistical process will have its own methodology. Consider two species of bats which differ in the duration of the call and the minimum frequency (Figure 1).

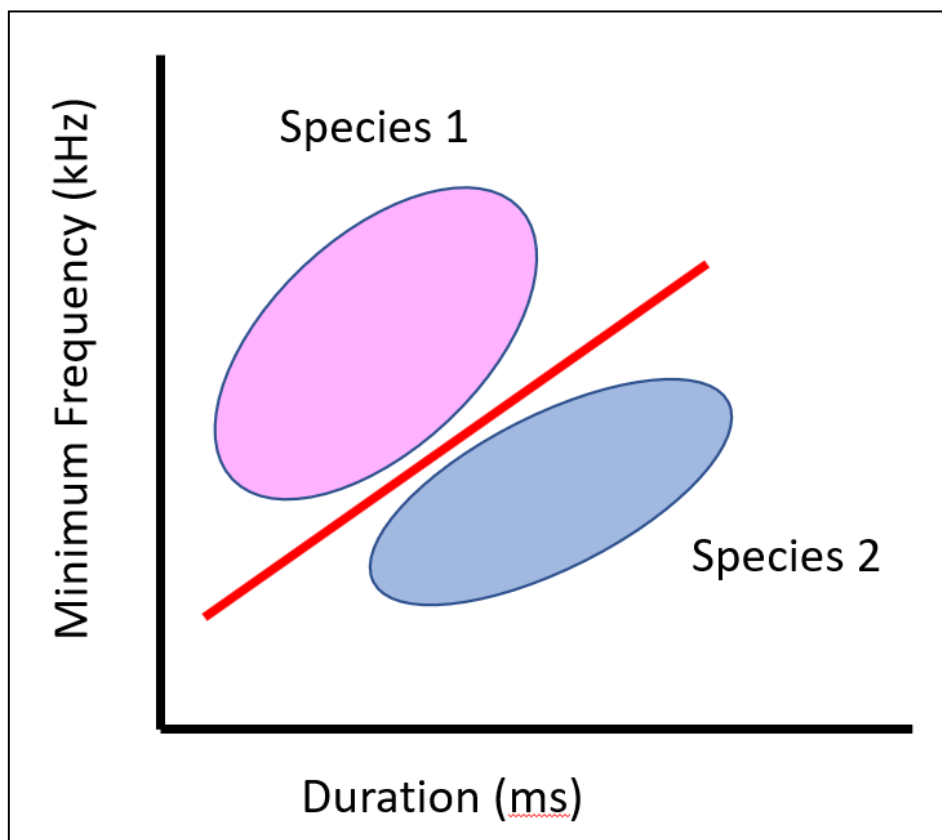


Figure 1: Calls from two species of bats are plotted with duration vs minimum frequency. While there is overlap in both duration and minimum frequency, the combination of the two allows separation (the red line).

While there is overlap between the species in duration on the x axis and minimum frequency on the y axis, the combination of duration and minimum frequency can be used to assign bats to either species as a line can be drawn between the two groups - they are linearly separable. However, if there is overlap between the combination of duration and minimum frequency (Figure 2) it is not possible to unambiguously assign bats to either species. Bat A can be assigned to Species 1 and Bat B can be assigned to species 2, but Bat C could be assigned to either. The closer Bat C is to the centroid of each of the different species' clusters can give an idea of how likely it is to belong to each species, but it cannot be unambiguously assigned to either. If a third parameter could be added, such as bandwidth, it may be possible to assign bats once again unambiguously by creating a third dimension and having a plane that separates the two species. Such a process can extend to high dimensions with species being separated by a hyperplane. This is the basic idea behind most types of classifications though this process is closest to that of a Support Vector Machine (see below).

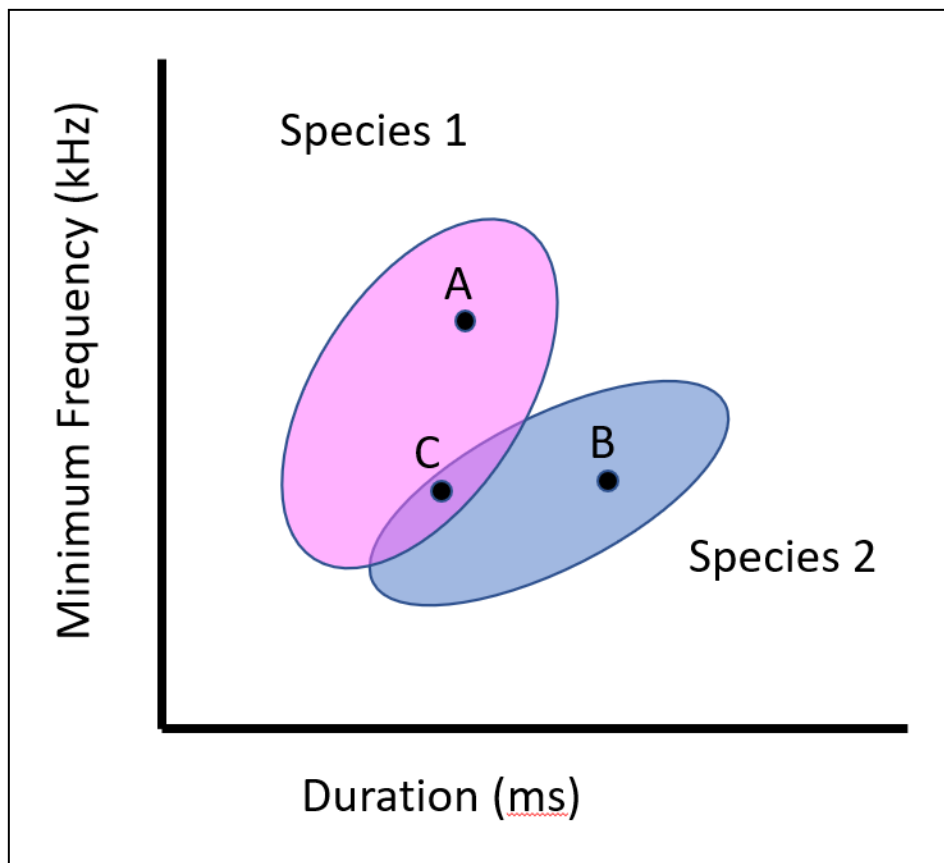


Figure 2: In this example, there is overlap in duration, minimum frequency and the combination of duration and minimum frequency. While calls A and B can be assigned unambiguously to species, call C cannot.

In Discriminant Function Analysis (DFA), a set of independent variables (the call parameters) are used to predict a dependent variable (the species of bat). Firstly, the DFA is calculated and a set of two or more discriminant functions created from the variables most likely to separate bat species. Using these, it is possible to take the parameters from an unknown species, feed these into the DFA equation and extract a set of probabilities that the unknown call belongs to each group. Such an approach is quite common and used in many

studies such as that by Preatoni *et al.* (2005) for bats in Italy. The default metric for assessing the ability of the classifier to do this is correct classification rate (CCR). A CCR of 90% means that 90% of the calls from that sample are assigned correctly to species. As calls from known species are hard to obtain, the testing is sometimes done using the calls from which the model was created. This can create a falsely high CCR since the model is tested using the data used to create it. A more realistic way of testing is to keep some data back from creating the model and then use that data to validate the model. A study by Clement *et al.* (2014) on North American bats found that using a different library to test a classifier rather than the training library resulted in a significant reduction in CCR depending on species. While some species were unaffected, others had a CCR decrease from close to 100% down to 35%.

While DFAs are relatively simple to create and use, they suffer from a number of problems in that they are sensitive to outliers (measurements that are unusual and do not conform to the rest of the data for that species), data should be independent (in other words, ideally only one call per bat used to train them), not co-vary, so parameters such as maximum frequency and bandwidth can't both be used as they are linked, and rely on the data being statistically normally distributed. However, they can show which of the call parameters are most important at making the discrimination, something that other classifiers may keep hidden.

Artificial neural networks (ANNs) can give similar (Preatoni *et al.*, 2005) or slightly better results than DFA (Parsons and Jones, 2000) but are based on a process much more like an animal's central nervous system using connected neurones. In this case the network is trained on which calls are from which species through supervised learning, which is where the classifier is told which species the training call belongs to. This is opposed to unsupervised learning where the machine forms its own categories based on the information it is fed. The ANN has a series of input nodes into which are put the measured parameters of the calls - one node per parameter (a simplified example is given in Figure 3). There are a series of nodes in one or more hidden layers and then a series of output nodes corresponding with the different species, one node per species. The call parameters are entered into the input node, and the highest value on an output node corresponds with the species the call is assigned to. If this is incorrect, the ANN adjusts the internal weights of the connections between nodes until the correct output is achieved. This continues for all of the training data, the weights of the connections continually adjusting until the best classification of the training data is achieved. ANNs can be combined into groups, called ensemble ANNs (or ENNs) where different networks do different roles, one to assign calls to bat or non-bat, then next to get to genus and then next to get to species. Such ENNs can improve the overall classification performance (Redgwell *et al.*, 2009).

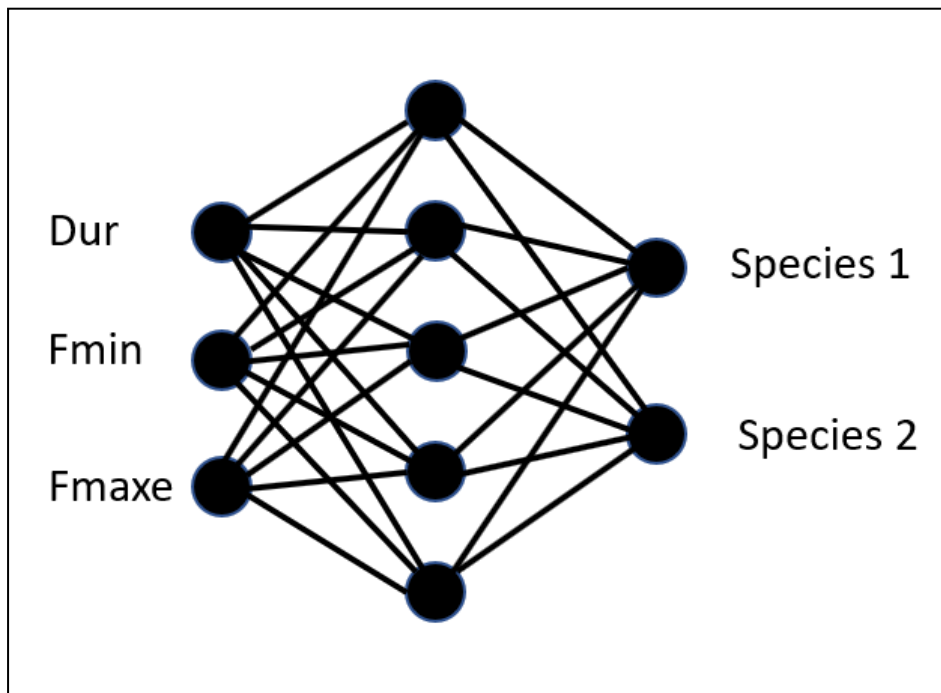


Figure 3: A representation of a simple artificial neural network. There are three input nodes corresponding to duration (Dur), minimum frequency (Fmin) and frequency of maximum energy (Fmaxe), a hidden layer with five nodes and an output layer of two nodes corresponding to Species 1 and Species 2. The strengths or ‘weights’ of the connections between each node can be varied when the network is trained.

Random forest algorithms (Breiman, 2001) are another popular machine learning algorithm. In this case, several decision trees are created much like traditional taxonomic keys. At each stage the data are split into groups that maximise the differences between groups but minimise the differences within groups based on differences in call parameters, then the next split happens and so on, sorting the data between branches and eventually out into the individual species - the leaves on the tree. However, unlike in a taxonomic key where each stage must create an unambiguous split between characters and results in a single key, this is not the case with random forest. Multiple trees are created all based on slightly different splits between the data, in effect creating several different taxonomic keys. The trees then must reach a consensus on what species of bat the unknown call comes from by voting. The species that receives the most votes is the one that the call is assigned to. In a study on Mexican bats, Random Forest could correctly identify species 81% of the time compared with an ANN (69%) and DFA (62%) (Ayala-Berdon *et al.*, 2021).

There are many other types of machine learning which can be applied to classifying unknown calls to species. Support vector machines (SVMs) work on the principle illustrated in Figure 1 by creating a multidimensional hyperplane that will separate species based on combinations of call parameters (Suthaharan, 2016). Where a linear separation in multidimensional space is not possible, other kernels can be used to create the separation (Cristianini and Shawe-Taylor, 2000). Armitage and Ober (2010) found that SVMs were comparable in performance at classifying bats to species as DFAs and ANNs.

Most classification techniques rely on parameters from the frequency or joint time-frequency domain, such as maximum and minimum frequency, bandwidth, slope rate, slope shape and so on. However, the popular Kaleidoscope software (Wildlife Acoustics) uses a different approach taking time domain information fed into Hidden Markov Models (HMMs), often used in speech recognition (Rabiner, 1989). Here, the data are taken from the separations between the 'dots' in a zero-crossing representation of the call from either natively collected zero-crossing data or full spectrum recordings converted to zero-crossings (Agranat, 2012). Such an approach has the advantage that both full spectrum and zero-crossing data can use the same classifier but may suffer from the need to have relatively good signal to noise ratio calls to extract the zero crossings and therefore miss weaker signals.

The nature of variation

Generally, there is very little intraspecific variation in bat echolocation calls *given the same environmental situation*. Each individual, or different individuals of the same species, will produce echolocation calls with a similar structure for the same task and in the same location. While variation due to age (Jones *et al.*, 1992), gender (Jones and Kokurewicz, 1994) or geographical location does exist (Veselka *et al.*, 2013), it is generally small (Murray *et al.*, 2001). There are however a number of other sources of variation that can spread the measured call parameters over a great range and hence increase the overlap between species. The first of these is call plasticity; bats will alter their emitted call structure depending on their foraging location due to height (Jensen and Miller, 1999), habitat (usually open or closed) (Obrist, 1995; Kalko and Schnitzler, 1993) and phase of the prey capture cycle (Kalko, 1995). Bats in the open tend to produce calls which are longer in duration and more narrowband, while those in clutter are shorter in duration and more broadband (Russo *et al.*, 2018). Secondly, there is variation in the received call structure due to the distance and angle to the bat due to sound attenuation and the effects of directionality (Pye, 1993). Finally, there may be a small amount of additional variation caused by the bat detector or sampling device itself due to the microphone frequency response, sampling rate or filtering (Kaiser and O'Keefe, 2015).

The variation in call structure by the bat due to different foraging situations will blur the boundaries between the calls of different species but is an important part of that species' intraspecific variation. An especially challenging source of variation is in those bats which alternate call types, such as noctule *Nyctalus noctula*, Leisler's bat *N. leisleri* and barbastelle *Barbastella barbastellus*. The fact that they alternate call types is a useful identification clue but is challenging for an automatic identification system as they have to associate multiple calls in a sequence to a single bat rather than rely on a single call's parameters. Indeed, training a statistical classifier where bats have two distinct call types is problematic since the input of two very different calls must produce the same species as an output.

The extra variation due to distance and angle to the bat and recording differences further blurs the boundaries between each bat species. This reduces the value of parameters such as maximum frequency, and duration which derives from it in FM bats, as both decrease markedly with change in angle and distance to the bat. If there is any overlap between species in the multivariate combination of measured parameters, then that species can never be assigned with 100% accuracy no matter how sophisticated the classifier.

The performance of automatic ID systems in practice

The use of automatic ID systems is essential in many consultancies and for large scale projects where the manual processing of huge numbers of recordings would be otherwise impossible. In the Norfolk bats project for example over 600,000 recordings were collected (Newson *et al.*, 2015). In these scenarios, there is a benefit to gathering large spatial samples at the possible expense of accuracy. However, for smaller scale studies where the detection of calls for presence/absence studies are required, or for the detection of rare or out of range species, then the limitations of automatic identification must be acknowledged.

The ability of software systems to find and extract calls from noise was studied by Paumen *et al.* (2021) who found that 99.7% of recorded sequences in their study were correctly classified as containing bat calls. However, Mac Aodha *et al.* (2018) compared a range of commercial software products and found the precision (number of true calls and false calls of noise reported as calls) and the recall rate (the number of calls correctly found in a sequence with a 5% false positive rate) varied considerably, with sometimes less than 20% of calls from real field recordings being found. This is of concern, particularly if those calls are from quiet species such as *Plecotus* where the presence/absence around potential roosts is an objective of the study. The choice of filter to detect calls can also affect the subsequent classification accuracy. Clement *et al.* (2014) found that in Analook, not only did filter choice affect the number of calls found, but that calls extracted using different filters significantly affected the classification rates in a subsequent DFA.

Quantifying the accuracy of automatic identification systems is problematic since an identification in the field can never be confirmed unless the bat is caught and checked in the hand afterwards. Correct Classification Rates (CCR) derived from training sets can be artificially high and there are no real data on their actual performance in the field. The best that can be achieved is the manual verification of suspect records in conjunction with the CCR of the classifier. Even with manual verification, species are not always assigned correctly. Jennings *et al.* (2008) compared the performance of an ANN with experienced human analysts. Humans correctly classified 86% of recordings to genus and 56% to species while an ANN correctly classified 86% to genus and 62% to species, with the ANN performing better than 75% of humans. The circular nature of manually checking 'dubious' identifications is highlighted by Russo and Voigt (2016), where human checking is wrongly assumed to be the gold standard to which automatic ID can be compared. In fact, given that human abilities are often no better than the artificial systems (and vice versa), it will only be obvious misclassifications which will be spotted.

A comparison of commercially available systems for European bats found that overall CCR varied from 77% to 31% though this was based on a small dataset with a limited selection of species (Brabant *et al.*, 2018). Rydell *et al.* (2017) found that for a range of commercial systems, easy to identify species with structurally distinct calls such as common pipistrelle *Pipistrellus pipistrellus* or barbastelle could be classified with 83-100% accuracy with others with less characteristic calls such as *Myotis* and brown long-eared bat *Plecotus auritus* could be identified with between 0-93% accuracy depending on the software and species concerned.

As shown above, the CCR is highly dependent on species. Some species are easy to classify, while others are much more problematic. Walters *et al.* (2012) used an ensemble ANN to classify 34 European bats from their echolocation calls. The CCR ranged from 100% for greater horseshoe *Rhinolophus ferrumequinum* where there is no overlap with other European species and 97% for common pipistrelle where the peak frequency is usually diagnostic, to 50% for Bechstein's bat *Myotis bechstenii*, Brandt's bat *M. brandti*, whiskered bat *M. mystacinus* and Daubenton's bat *M. daubentonii*. Paumen *et al.* (2021) using a convolutional neural network (CNN) found an overall 96% CCR but based on a mix of species and species classes, grouping *Myotis* together and a group of Nyctaloid bats which included serotine *Eptesicus serotinus* and parti-coloured bat *Vespertillio murinus* as the network could not distinguish species within those groups. Parsons and Jones (2000) found that an ANN was marginally better than a DFA with an overall CCR of 87% compared with 79%, though CCR depended on species with common pipistrelle and soprano pipistrelle *P. pygmaeus* having over 90% CCR while whiskered bat and Brandt's bat were between 45% and 65% depending on which call parameters are used. A comparison of DFA, Ensemble ANNs and Support Vector Machines (SVMs) by Redgwell *et al.* (2009) found that ANNs had the best overall performance. DFA classified 73% of calls to species, SVMs classified 87% and ANNs 98%, though this was from a small number of high-quality calls.

CCR is a blunt instrument for assessing the overall performance of classifiers on real field data as it depends on a number of often hidden parameters. As the quality of the call goes up, and arguably the ease of identification, then the CCR will improve. Setting a threshold on the quality of the calls to be classified will increase the CCR but reduce the number of calls that are classified. Barré *et al.* (2019) found that decreasing the false positive rate (the rate at which extracted calls are misclassified, effectively being more rigorous in the assignment to species) increased the CCR but this was also species-dependent. Changing the false positive rate made no difference to the CCR for common pipistrelle, while for many other species it had a significant effect - for Natterer's bat *M. nattereri* for example, decreasing the false positive rate led to a 38% reduction in calls classified to any species. In general, a more rigorous classification criteria led to fewer calls classified but an increase in CCR.

A different approach is rather than looking at CCR in isolation is to compare the performance of different software classifiers. If the classifiers agree, then it either means that they are all correct or all wrong, but at least they provide a consistent output. Lemen *et al.* (2015) found that for North American bats, commonly used classifiers only agreed with each other about 40% of the time, while Nocera *et al.* (2019) found that in North American bats on a night by night basis, different classifiers would agree on the call between 20% and 90% of the time, depending on the species. Overall, despite a large amount of research into the development and testing of statistical techniques, there is no clear winner in terms of the best process for classifying bats. Many systems seem no better or no worse than human observers who are themselves not that accurate for some species.

Conclusions

Evaluating automatic identification software is a challenging process. The simple question of 'is it correct?' masks a series of other questions and processes such as how many calls that are present are actually found by the software? How many calls are missed and how many noise events are assigned to calls? How many detected calls are assigned to any genus or

group or species and how many of those are correct? The higher the tolerance for detection and identification then the higher the proportion that are correctly classified but the fewer the number of calls that are detected and assigned. As such, the degree of certainty can be dictated to some extent by the user where the software will allow it. The traditional validation techniques of manually checking a random selection or suspect calls may be of no benefit as humans are often no better than the machines themselves. We are left with the uncomfortable truth that in some cases it may simply not be possible to classify some species due to the variation in the calls themselves or by the imposed variation due to the environment. There is an implicit view that given time, software will develop and improve to one day identify everything, but this takes no account of the fact that if Species A and Species B make calls which are sometimes identical, then no matter how good the classifier, it will never be possible to separate them.

In the UK we are fortunate that the majority of calls recorded are from common pipistrelle and soprano pipistrelle which have a high CCR. In the Norfolk bat project these made up 97% of all recordings (Newson *et al.*, 2015). Looking at a local or national population level scale, automatic classifiers are an appropriate tool given the large number of recordings that must be processed as the majority of calls will be from readily identifiable species. However, relying on automatic or manual classification for rarer species is problematic. At the smaller scale where uncommon species may be of interest and where species identification is more ambiguous, not only are automatic identification systems less reliable, but they are no better or worse than humans at manual verification. Accepting that some species simply cannot be reliably identified is not a failure of software or human ability, it simply represents the fact that in many cases calls overlap too much to be assigned to any species.

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