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British Islands Bats



Volume Two
2021



Welcome to the second volume of British Islands Bats.

The last 18 months have been challenging for bat work with the restrictions that COVID-19 has placed on the activity of bat workers from the twin perspectives of human and bat health. We are delighted that people have taken the opportunity to write-up their studies for us.

We are sure you'll find much of interest in the various articles that follow. We have, once again, been pleased to get a wide range of submissions in terms of topics and geography (we are especially happy to have our first paper about bats in Northern Ireland). Do let us know what you think of Volume Two 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. We are already pulling together a contents list for Volume Three. 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 on items of interest.

Tina has been the lead editor this year but, as ever, this is a collaborative enterprise and we are grateful to everyone who has contributed content. We are both also grateful to the Bat Conservation Trust for hosting British Island Bats (but please note we are an independent publication).

Best regards,

Handwritten signatures of Tina Wiffen and Lisa Worledge in cursive script.

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Cover image: Whiskered bat *Myotis mystacinus* in flight. © John Kaczanow.

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Bats in Churches: Finding Innovative Solutions to Reduce Conflict

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Abstract

Buildings provide important roosting sites for bats and places of worship are no exception. The architecture of traditional English churches provides roosting opportunities for bats, but their presence can lead to difficulties for those using and caring for these historic buildings. Bat droppings and urine can be unpleasant for congregations, lead to a heavy cleaning burden and cause damage to church heritage. The Bats in Churches project is a five-year project (2019-2023) to help churches without negatively affecting the favourable conservation status of the bats. The approaches include the trial of novel mitigation works to physically separate church communities and heritage from the impacts of bats, as well as engagement activities and training opportunities. The project is trialling these approaches with 108 churches. Here we share the aims of the project and ongoing work with two pilot churches: Tattershall Collegiate Church of Holy Trinity in Lincolnshire and All Saints Church in Braunston-in-Rutland. There have been early positive results in both churches, with the former exemplifying the often-complex nature of the church mitigation works; the need to balance the bats, church community and heritage. The project will continue to work with these churches and monitor the bat roosts over the coming years to understand the effect of the works on the people and the bats. We expect the outcome of the project to inform future works at churches and other historic buildings hosting bats.

Introduction

Churches can be important roosting locations for bats throughout the year, including large, and sometimes internationally significant maternity colonies. In the Bat Conservation Trust's National Bat Monitoring Programme (NBMP) there are currently records of roost counts in churches for nine species of bat, however, a greater number of species have been recorded using these historic buildings (Sargent, 1995).

Churches can provide perfect conditions for roosting bats. Over the years, gaps and holes form, allowing them access. Churches may have lots of small cavities in the supporting timber frame and joints, as well as space in the roof and eave voids and gaps under the roof tiles. Previous studies indicate that the age of the church is likely to affect their suitability for bats, with pre-16th century churches seeming particularly valuable (Sargent, 1995). Importantly, churches can offer varying conditions and temperatures, making them useful roost locations throughout the year.

It is not just the church itself that provides the ideal roosting location, but the features of the surrounding landscape. Churchyards often include hedgerows and mature trees, which can provide bats with good foraging areas as well as linear features, which aid navigation. The best estimates, which are now out of date, indicate that over 60% of pre-16th century churches in England could have bat roosts in the summer months (Sargent, 1995). What is clear from the research is that churches are often used by bats, and these buildings are important for the conservation of many British bat species (Zeale *et al.*, 2016).

Sometimes bats can use a church and go unnoticed, however, the often-open architecture of churches can mean that the bats utilise the same area that is used by people. Bat faeces and urine can damage unprotected artefacts (Hales, 2014). In addition, bats can cause problems for the rural church communities that use and maintain the building. The national and international legislation afforded to bats under the Wildlife and Countryside Act (1981) and Conservation of Habitats and Species Regulation (2017) protects individuals and their roosts and follows substantial declines over the last century (Bat Conservation Trust, 2020). The strict legislation, however, has sometimes led to people caring for churches and church heritage to feel disempowered and not listened to when it comes to issues around sharing the space with these winged mammals.

In some areas, churches are venues for vital services such as health centres, post offices and food banks. Many churches aim to provide facilities and position themselves at the heart of their communities. Upkeep and care of churches often falls to a few volunteers who work hard to maintain their historic fabric, needing project management and fundraising skills as well as time. The cleaning burden presented by the bats can affect the functionality of these churches, having significant knock-on effects for the wider community.

The cultural, historical, and social significance of our churches and the unique fabric that they hold is unequivocal: 12,500 Church of England buildings are listed according to the National Heritage List for England, with the Church of England caring for 45% of England's Grade I listed buildings. Likewise, bats warrant protection for the critical role they play in the natural environment. They account for a third of all mammal species in the UK and are cited as 'indicator species' as their population size is indicative of an area's ecological health. However, when these twin figureheads of the rural landscape occur together, a conflict can result. It is important that we work together to help the church congregations, while protecting both our natural and cultural heritage.

Previous research

There have been past attempts to understand how to discourage bats from roosting in churches without negatively impacting the bats. In 2012–14 the University of Bristol carried out research into Natterer's bat *Myotis nattereri* in historic churches. The bats show high fidelity to their church roosts and to their foraging areas, which suggests that they could be slow to find new roosts. While population modelling indicated that excluding the bats would have a detrimental impact to their welfare and conservation status, the study did have some success in the use of deterrents to humanely move the roosts within a church to prevent accumulations of droppings and urine in sensitive areas (Zeale *et al.*, 2016). The study suggested that these methods are likely to be most effective in the spring, before the young are born and when Natterer's bats are more transient. They also had success with the use of high intensity ultrasound. In most sites, the bats moved away from the noise and found other locations within the church to roost and a majority continued to use the new roost site even after the acoustic deterrent was taken away. In contrast, the use of artificial light as a deterrent was terminated prematurely for welfare concerns as the bats were reluctant to leave the roost at all, raising the potential of entombment and death from starvation. The study showed that the use of deterrents could be a useful tool for licensed ecologists but must be carefully regulated.

Bats in Churches Project Vision

When bats are using a church, the problems facing a parochial church council (PCC) are compounded by the need to navigate the multiplicity of organisations which deal with the regulatory or advisory issues arising from impacts of bats in churches. Organisations such as dioceses, Natural England and Historic England are grounded in different disciplines, with disparate missions and priorities and each with their own distinctive ethos. No single organisation possesses all the knowledge, relationships or resources needed to support church communities in England, protect church heritage and conserve our bat species. This situation has resulted in an increasingly heated debate from voices entrenched on either side. It was from this challenging environment that the Bats in Churches partnership was born. Through a collaboration between Natural England, the Church of England, Bat Conservation Trust, Churches Conservation Trust and Historic England, a shared vision has developed around what needs to be achieved to resolve the conflict of bats and churches. Following a successful development phase that enabled church communities to live alongside their bats in three pilot churches, the project won funding totalling £4.5 million (£3.8 million coming from the National Lottery Heritage Fund and the project partners making up the rest) for five years (2019–23).

The project recognises that practical solutions are the overriding concern of church communities affected by bats. In depth ecological surveys are being funded for project churches where these are necessary. The surveys are carried out by ecologists registered to use the Bats in Churches Class Licence (BiCCL), developed for the project. This new licence, designed by Natural England, enables registered ecologists to take slightly more experimental approaches to separate church communities and bats, whilst preserving the favourable conservation status of the bats. The survey results enable the ecologist to understand the extent of the bat population and how they are using the church and surrounding area. Pairing this knowledge with information from heritage experts on the significance of the church fabric, they can work with the church architect and church community to design appropriate mitigation.

Each church situation is unique, so each proposed solution reflects the behaviour of the bats and the structure of the church. Examples include: making bespoke bat boxes in the roof spaces, selectively blocking entrance holes to prevent bats flying across the church and provision of bat boxes in churchyards.

Cleaning a church inhabited by bats can be an intensive task. The project is able to purchase covers for monuments at risk while churches wait for more permanent solutions or when extensive works are not appropriate. A series of conservation cleaning workshops, in which there is already considerable interest, are being led by conservators from the Churches Conservation Trust.

There is also a significant citizen science element to the project, encouraging existing or new bat surveyors to visit their local churches to look for evidence of bats. With 16,000 churches making up the Church of England estate, this will provide a clearer picture of church perspectives towards bats and of how bats are using churches nationally and regionally.

Finally, the project is keenly aware that the provision of staff and resources will cease at the end of 2023 and is mindful of the need to develop and foster relationships that last beyond the project. Some dioceses, churches and bat groups already have excellent relationships and data sharing arrangements. The project is learning from existing good practice and is working to link county bat groups with churches and dioceses to ensure that the networks of support and knowledge that are made and shared during the project continue to be maintained.

Case Study 1: Holy Trinity, Tattershall, Lincolnshire

The Collegiate Church of Holy Trinity, Tattershall (Figure 1) is an outstanding example of harmonious co-existence with an extremely rich population of up to seven different bat species including two large maternity colonies of soprano pipistrelle *Pipistrellus pygmaeus* and Daubenton's bat *M. daubentonii*, which roost in the timbers of the wooden ceiling. The church is a major building of the late fifteenth century retaining much of its original structure including medieval roofs, the north, west and south doors in the nave and the chancel doors. The fabric is of high archaeological, architectural, historical and artistic significance. It is also an important place for bats with no other site in Lincolnshire known to support as many species.



Figure 1: The Collegiate Church of Holy Trinity, Tattershall in Lincolnshire. © Photo A of the exterior is by David Hitchborne and photo B by the Bats in Churches Project Team.

The church community values its bats and has a long-standing relationship with local bat workers, but struggles with the impacts. The church community has built an excellent partnership with the local bat workers and enthusiasts that make up Lincolnshire Bat Group and they use bats as a unique selling point to engage visitors. The church has been part of the NBMP for many years with bat counts dating back to the 1980s (Figure 2). The

congregation have embraced their bats, organising bat-themed events and merchandise featuring 'Tatty Bat'. However, cleaning is a constant challenge.

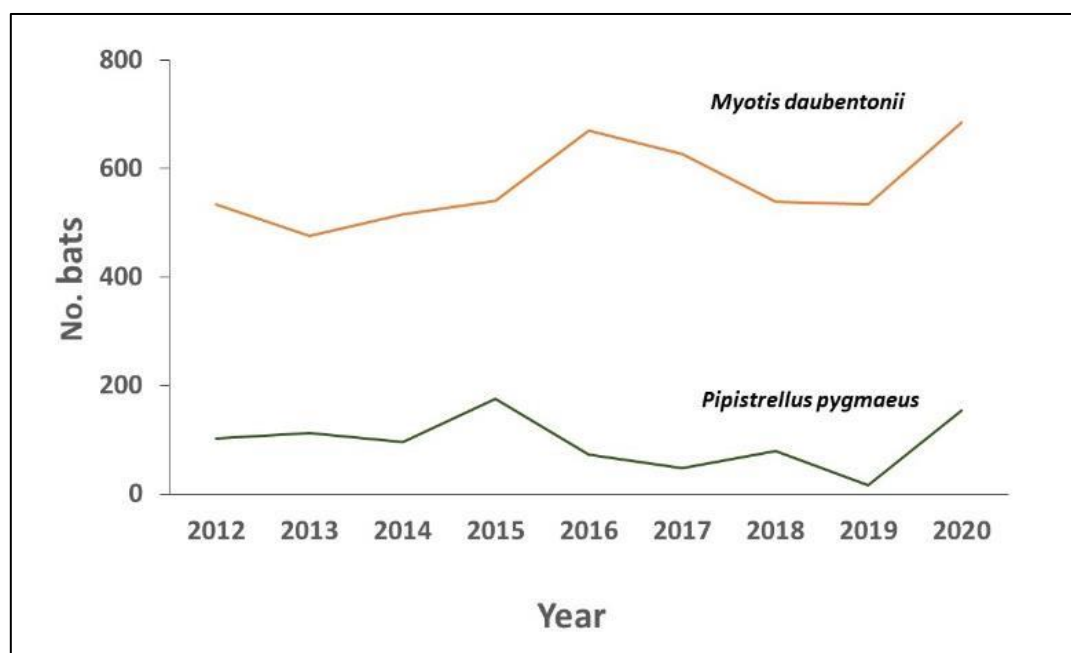


Figure 2: NBMP Roost Count records from Lincolnshire Bat Group for Holy Trinity, Tattershall, showing numbers of bats from two species using the church for their maternity colony.

Supported by the Bats in Churches project and with input from the church community, BJ Collins Ltd consultant ecologists, with the church architect and PCC, created a management plan to alter the way that soprano pipistrelle use the church in order to protect key sensitive areas of the building. There were a number of objectives, primarily to stop bats roosting over the servery and heritage centre (Figure 3). Other plans included access over the south and west nave doors being blocked and replaced by an access point in the south transept window, confining their impact to a less used and more manageable area.

Work to date

The roosting space above the servery was sealed in 2019 (Figure 4) and has led to success in protecting the south aisle, servery and heritage areas of the church, with a substantial reduction in dropping loads. However, an area of the north transept has subsequently started to be used by the bats above an area of historic brasses that are damaged by urine. The bats have also utilised the chancel for roosting in greater numbers in 2020 than previous years.

Continuation of works April 2021

Alternative bat access points were added (Figure 3), but surveys in 2019 and 2020 found that the bats were not using them. Therefore, works to close the west door access point were suspended. Instead, window openings will be created directly above the west and north doors (current bat access into the church). Other works include the sealing off the chancel and the main area of worship where services are held as a bat free area.

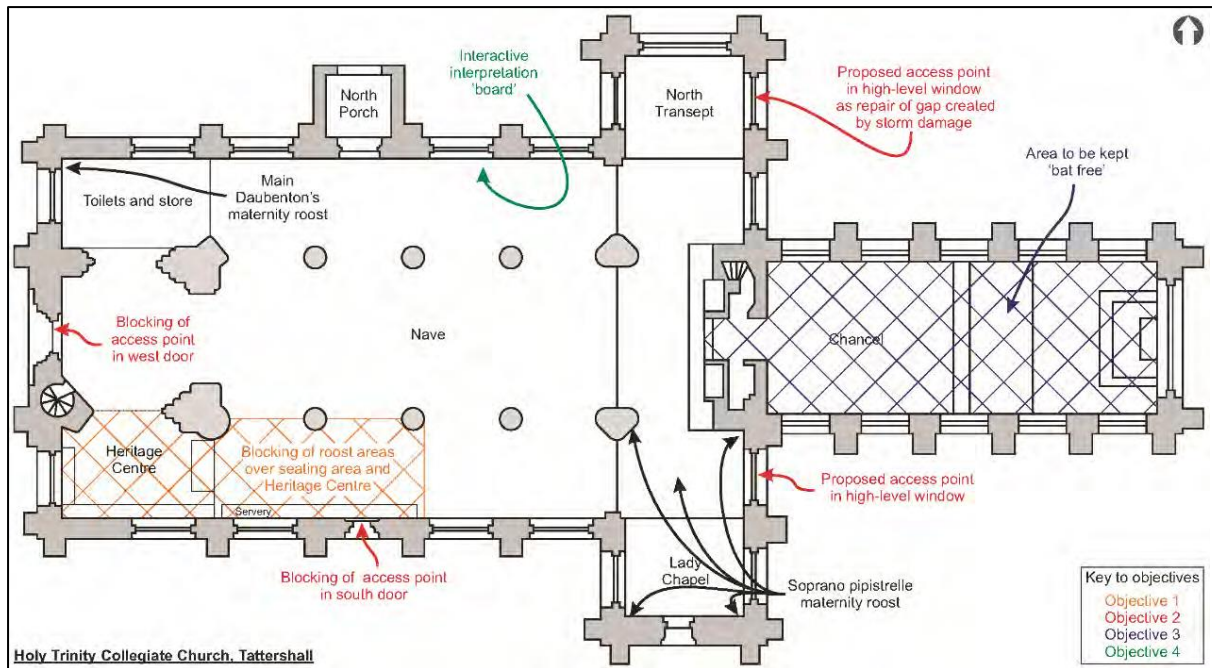


Figure 3: A visual plan for Holy Trinity, Tattershall in 2017 created by BJ Collins Ltd with agreement of the church architect and PCC.



Figure 4: Photo A shows the gaps in the timber above the servery of Holy Trinity, Tattershall, used by soprano pipistrelles to roost. Photo B shows the closing of roosting opportunities above the servery. © BJ Collins Ltd.

The work and response of the bats, as well as the success for the church community and heritage, will continue to be monitored in coming years. The church displays the complexities of finding solutions to help the bats, heritage and church community. The example of Tattershall, however, has given ideas and hope to other church communities who feel overwhelmed by the impacts of bats on church use and fabric. This community

which has not only accommodated its bats, but exploited them to engage visitors, has lessons for similarly affected churches. The project continues to work with the church.

Case Study: All Saints, Braunston-in-Rutland

All Saints church in Braunston-in-Rutland (Figure 5) is a modest Grade II* listed medieval church surrounded by a grassy churchyard set at the highest point in the heart of the village conservation area, enabling the tower and its small spire to be seen from most approaches. Three medieval features are of high significance: the c.1120 font, the c.1400 south wall paintings, which are somewhat fragmentary, and the late medieval bishop's indent at the chancel step.



Figure 5: A bat night event at All Saints Church, Braunston-in-Rutland. © Bats in Churches Project Team.

Bats have been recorded in the church for several decades, but the population increased dramatically about seven years ago when a nearby chimney collapsed, and a maternity colony of soprano pipistrelle moved into the roof void of the south aisle. The bats were able to gain access to the church from the roof void via holes in the south aisle ceiling. Although cleaned regularly, bat droppings could be seen on most floors and walls with a concentration in the south aisle where the most significant items of heritage interest are located. The cleaning burden and the smell became so acute that at one point the PCC thought the church might have to close. Desperate for help, the churchwardens contacted their local MP, Sir Alan Duncan, who helped to publicise their plight, leading to the church becoming one of the three pilot churches in the development stage of the Bats in Churches project.

After carrying out the necessary dawn and dusk bat surveys, ecological consultants Wild Wings Ecology Ltd concluded that there was no need for the bats to enter or fly inside the church. A management plan recommended the temporary blocking of holes in the south aisle ceiling to stop access into the church from the roost, meaning that the only access points to the roost were external and that the bats would not be entering the nave; this work was carried out April 2018. Subsequent monitoring showed that the temporary blocking had not affected the numbers using the roost. Permanent blocking using heritage building materials took place in April 2019 and the soprano pipistrelle colony continues to thrive using the south aisle roof space (Figure 6), but with no mess or nuisance inside the church. Sue Willetts, one of the church wardens who championed the church's involvement in the Bats in Churches project commented "It's been a fantastic outcome for us. The church can now be used as intended."

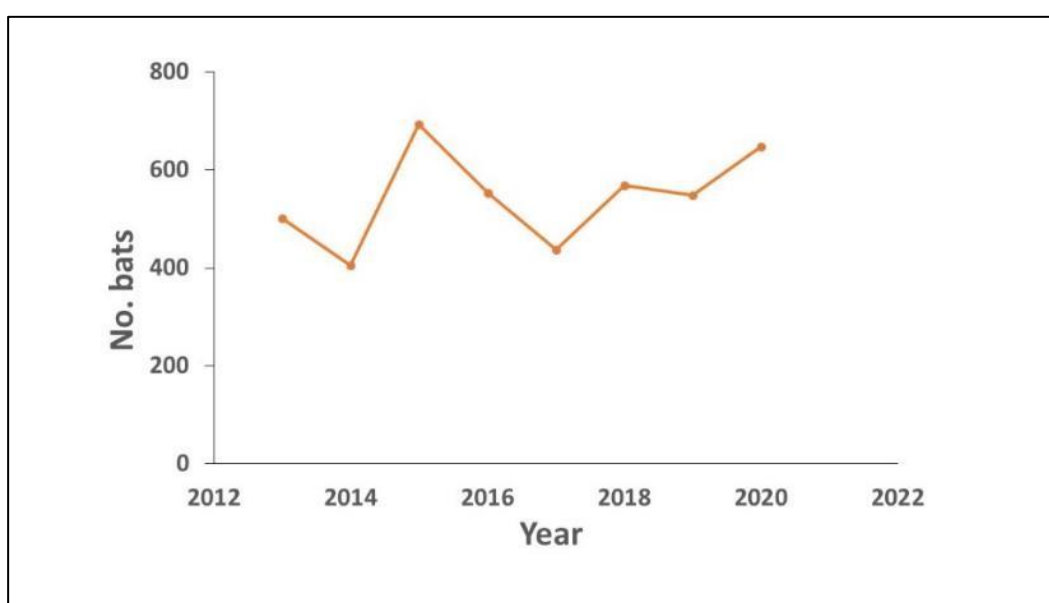


Figure 6: NBMP Roost Count records from Leicestershire and Rutland Bat Group (organised by Jenny Harris) for All Saints Church, Braunston-in-Rutland.

Conclusion

The Bats in Churches project aims to shine a long overdue beacon of hope for many overstretched church communities while protecting the roosting bats, providing practical solutions, and offering learning opportunities about these remarkable animals. Gathering robust research data into the behaviour and impact of bats in church environments is an important first step, which must be followed by bringing separate communities of interest together. The ultimate aims of the project are to create pioneering, multidisciplinary solutions, to enable communities with distinct drivers and passions to respect one another's concerns and to build and maintain support networks of volunteers. The project is committed to safeguarding the bat roosts in these churches to maintain the favourable conservation status, so bats and people can utilise these spaces for years to come.

Many churches with bats embody the fifth of the Five Marks of Mission in their interpretation, striving to safeguard the integrity of creation and sustain and renew the life of the earth, engaging visitors both with their church's history and heritage, and with its

biodiversity, through the resident bats or the churchyard flora. Church communities that live harmoniously alongside their bats and are motivated to protect and understand them often have strong partnerships with bat groups, like the two churches in this paper. When the different communities of interest come together, they can find common ground.

For more information about the project and to find out how you can get involved with the project and our research via our volunteer surveys please see www.batsinchurches.org.uk or follow @BatsinChurches on twitter.

Authors

This article was written by the following officers of the Bats in Churches Project: Rachel Arnold, Heritage Advisor; Ione Fitzpatrick, Communications Officer; Claire Boothby, Training and Surveys Officer (and corresponding author); Honor Gay, Engagement Officer and Rosemary Riddell, Engagement Officer.

Acknowledgements

The project would like to thank all those we have worked with during the project to date. It has been a collaborative effort. We want to give a big thank you to Lincolnshire Bat Group, and to Jenny Harris and the Leicestershire and Rutland Bat Group, who have recorded these church roosts each year for NBMP and have allowed us to use the records. Thanks to BJ Collins Ltd and Wild Wings Ecology Ltd for their work with the project churches mentioned in this article.

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Differences in Forearm Length and Weight in Common Pipistrelle from Cambridgeshire, the Isle of Man, and Jersey

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Summary

During training sessions in advanced survey techniques on the Isle of Man in 2019, common pipistrelles *Pipistrellus pipistrellus* appeared to be smaller but chunkier in the hand than those in Cambridgeshire. Existing morphometric data was collated from Cambridgeshire and the Isle of Man, along with data from Jersey in the Channel Islands, to test for differences in average forearm length and average weight between the three locations.

Results of the statistical analysis revealed that female common pipistrelles from all three locations had a longer average forearm length and heavier average weight than males. Interestingly, male and female common pipistrelles from the Isle of Man were significantly smaller in average forearm length ($p < 0.05$) and significantly heavier in average weight ($p < 0.05$) than individuals in Cambridgeshire and Jersey. Further research is needed to increase the statistical robustness of this study and to explore why common pipistrelles on the Isle of Man are different in body size and shape to those in other locations.

Introduction

In July 2019 a small group of volunteers, including myself, travelled to the Isle of Man to provide training in advanced survey techniques to members of the Manx Bat Group. Over the course of six nights we carried out mist netting and harp trapping surveys, and radio-tracked several *Myotis* bats back to new roost locations. As well as additional training in the handling and processing of bats, the survey work contributed to existing knowledge on the distribution of species across the island.

During the trapping surveys it was noted that common pipistrelles appeared to be chunkier in comparison to their mainland counterparts in Cambridgeshire, simply based on visual observations. Several individuals also had an unusual colouration, being a beautiful golden-blond (Figure 1), which was confirmed by Manx bat carers as a common colouration variation on the island.

Over winter 2019 I looked at morphometric data (e.g. forearm length and weight) in more detail by carrying out descriptive statistics (e.g. averages) and compared data to those from Cambridgeshire bats. But it wasn't until autumn 2020 when I completed a Masters degree that I had the skills to carry out statistical analysis to see if there was in fact any significant differences between the two locations. Data from Jersey in the Channel Islands was also included in the analysis, to enable a more robust comparison.

This short report details the methodologies used to carry out the descriptive and statistical analysis and presents the results – considered to be a pilot study into size differences in common pipistrelles between different locations.



Figure 1: Common pipistrelle with unusual colouration, Isle of Man. © Rachel Bates.

Methods

Existing morphometric data from Cambridgeshire Bat Group (collected 2016-2019), the Isle of Man (collected 2019) and Jersey in the Channel islands (collected 2017-2018) was collated into a single dataset, comprising Location, Sex, Forearm Length and Weight. All measurements were taken from adult common pipistrelles.

Forearm length is considered to be a good indicator of overall body size (Ralls, 1976) and while weight varies greatly between the seasons, reproductive status and even between periods of foraging (Ulian and Rossi, 2016), this measurement was also included to test the assumption that Isle of Man bats appeared to be chunkier. Published ranges for forearm length and weights for common pipistrelle were identified using Dietz and Kiefer (2016) and any forearm measurements greater than 0.3mm at either end of the range and weights greater than 0.5g at either end of the range, were discarded to account for human error during processing.

Descriptive and statistical analysis were carried out using R for Windows, version 4.0.0, in RStudio (R Development Core Team, 2019). Average forearm length and weight between the three locations were compared using one-way ANOVA and then the post-hoc Tukey test was used to carry out multiple comparisons to discover if any averages were significantly different from one another. Student's T-test was used to compare size differences between the sexes in each of the three locations.

Results

A total of 211 records formed the final dataset. The results show that common pipistrelles from all three locations exhibit female-biased size dimorphism in both forearm length and weight (Table 1), whereby females are larger than males. All results except forearm length for Isle of Man ($p = 0.15$) were significant ($p < 0.001$).

Table 1: Locations and sample sizes for male and female common pipistrelles, with descriptive and test statistics using forearm length and weight.

Location	Sample M : F	Forearm Length (mm) (Mean $\pm$ SD ^a)		p ^b	Weight (g) (Mean $\pm$ SD ^a)		p ^b
		Male	Female		Male	Female	
Cambridgeshire	14 : 19	31.54 $\pm$ 0.60	32.39 $\pm$ 0.59	*	4.68 $\pm$ 0.30	5.65 $\pm$ 0.78	*
Isle of Man	24 : 30	31.30 $\pm$ 0.83	31.67 $\pm$ 1.01	0.15	5.15 $\pm$ 0.37	5.85 $\pm$ 0.53	*
Jersey	69 : 55	31.72 $\pm$ 0.74	32.43 $\pm$ 0.92	*	4.70 $\pm$ 0.39	5.23 $\pm$ 0.55	*

^a Standard Deviation ^b * $P < 0.001$

Both sexes of common pipistrelle from the Isle of Man had a smaller average forearm length compared with males and females from Cambridgeshire or Jersey (Figure 2). They also had a greater average weight compared with males and females from Cambridgeshire or Jersey (Figure 3).

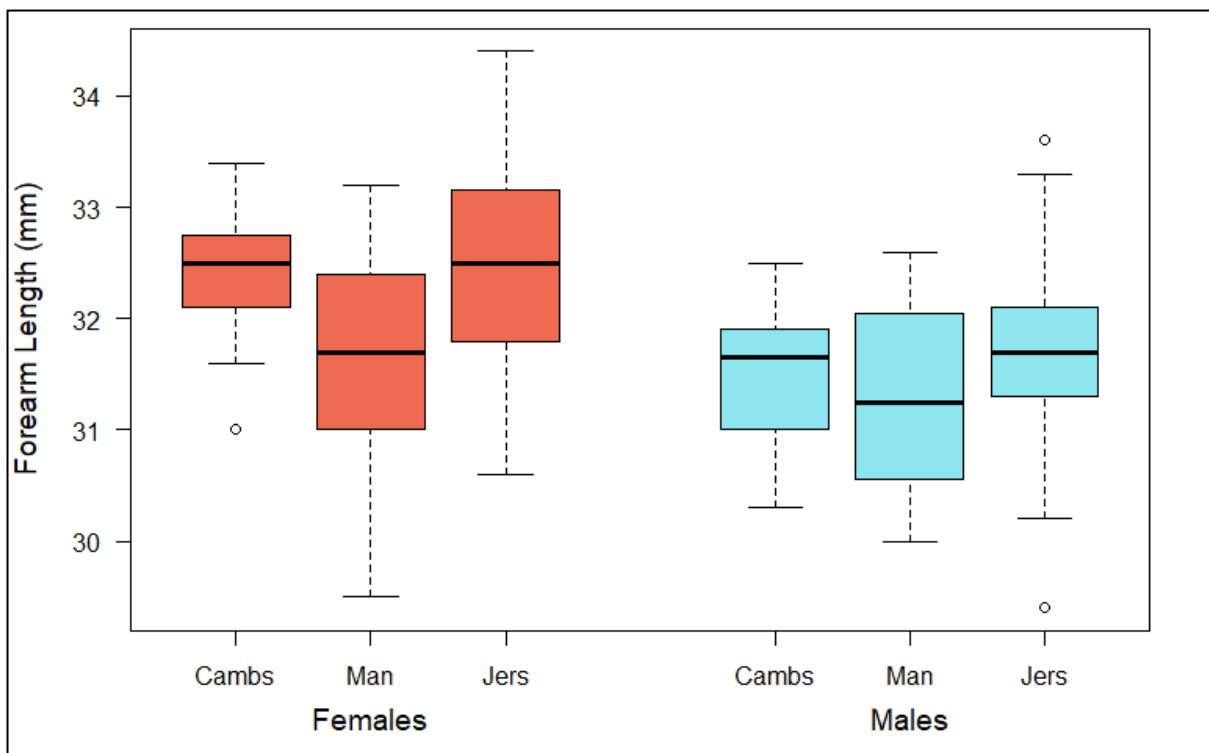


Figure 2: Average forearm length and standard deviation of male and female common pipistrelle from Cambridgeshire, Isle of Man, and Jersey.

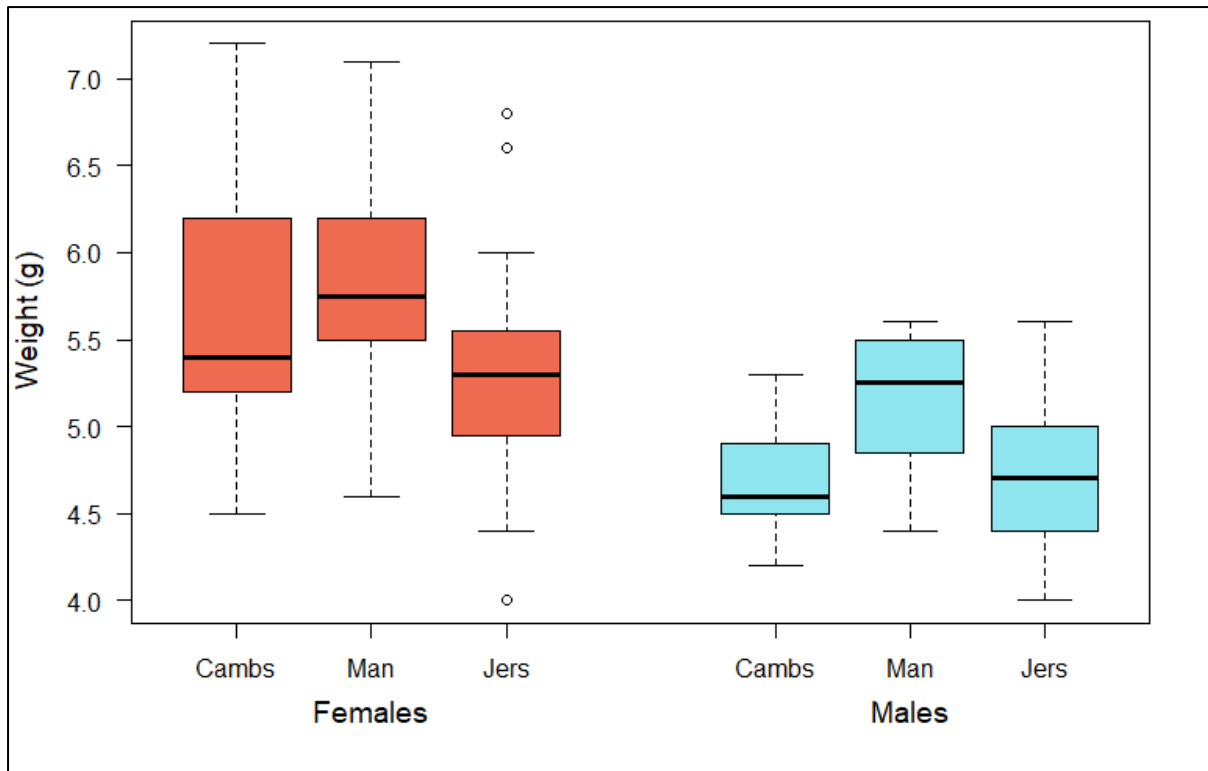


Figure 3: Average weight and standard deviation of male and female common pipistrelle from Cambridgeshire, Isle of Man, and Jersey.

The results of the one-way ANOVA revealed a significant difference in both average forearm length ($p < 0.001$) and average weight ($p < 0.001$) between Cambridgeshire, Isle of Man and Jersey data. Tukey's post-hoc test for average forearm length (Figure 4) and average weight (Figure 5) using the 95% confidence intervals revealed:

- No significant difference in average forearm length between individuals from Jersey and Cambridgeshire ($p = 0.96$).
- A significant difference in average forearm length between individuals from the Isle of Man and Cambridgeshire ($p = 0.02$).
- A significant difference in average forearm length between individuals from the Isle of Man and Jersey ($p < 0.001$).
- A significant difference in average weight between individuals from Jersey and Cambridgeshire ($p = 0.02$).
- A significant difference in average weight between individuals from the Isle of Man and Cambridgeshire ($p = 0.02$).
- A significant difference in average weight between individuals from the Isle of Man and Jersey ($p < 0.001$).

For the Tukey's post-hoc test graphics below, significant differences are represented by locations which are on opposite sides of the dotted line, but do not overlap the dotted line, and correlate to the bullet points above.

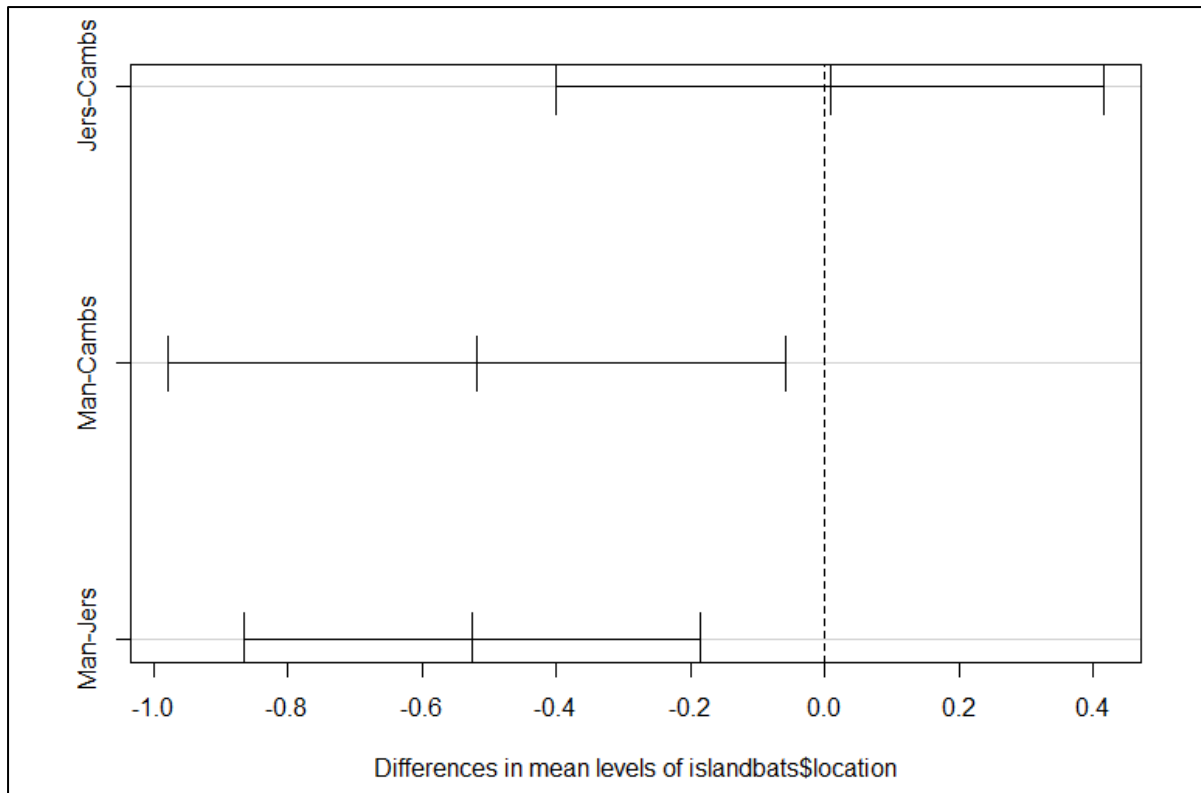


Figure 4: Results of Tukey's post-hoc comparison test for forearm length in Cambridgeshire, the Isle of Man, and Jersey.

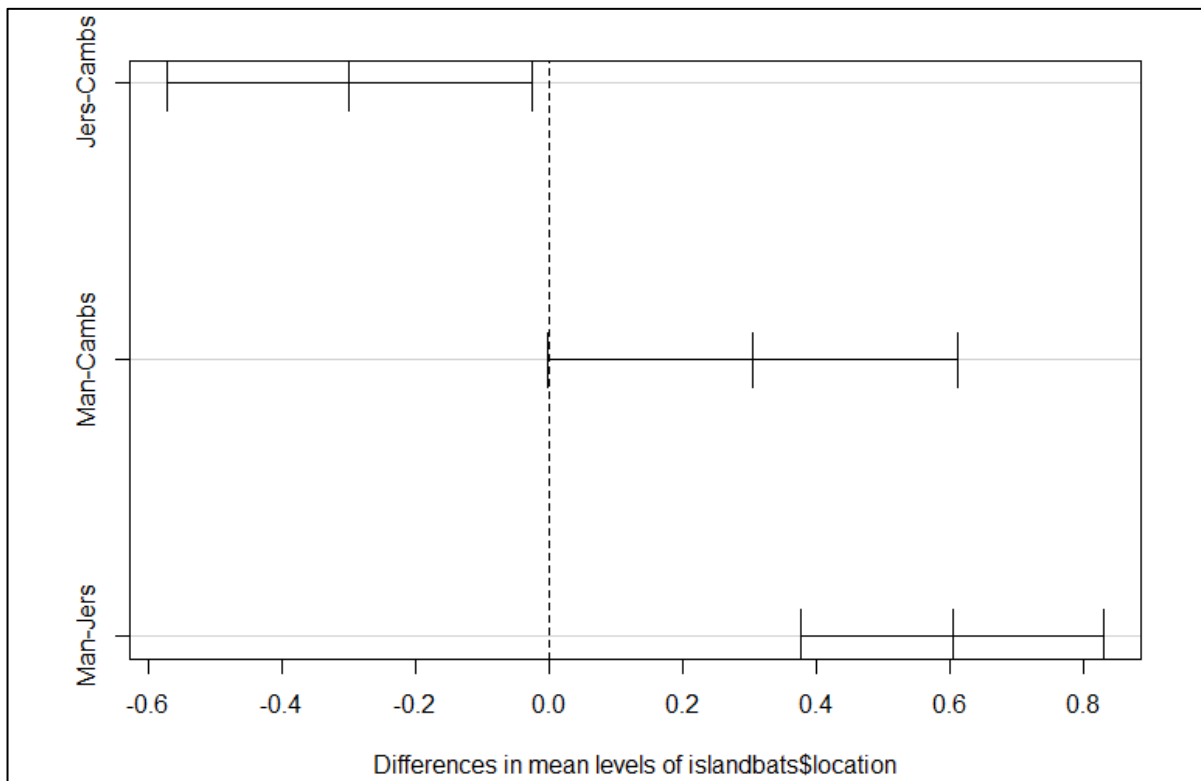


Figure 5: Results of Tukey's post-hoc comparison test for weight in Cambridgeshire, the Isle of Man, and Jersey.

Discussion

The results of statistical analysis conclude that common pipistrelles in Cambridgeshire, the Isle of Man and Jersey all exhibit female-biased size dimorphism, where females are larger than males. This result supports the findings of my Masters project whereby females from all 16 species in south-west England were larger than males, with females from 14 species significantly larger than males. Comparisons between the three locations revealed that male and female common pipistrelles from the Isle of Man have a significantly smaller average forearm length but a significantly greater average weight than those from Cambridgeshire and Jersey, supporting the observations from 2019 that individuals on the Isle of Man seemed to be chunkier.

As with all small datasets these results will not be statistically robust and therefore may be the result of falsely identifying trends between the data. To support the findings of this study, future research should aim to achieve a larger sample size to increase the statistical robustness of all tests.

However, this present study does indicate differences in common pipistrelles between the three locations, raising some interesting questions. The key question is why are common pipistrelles on the Isle of Man smaller and chunkier than bats in either Cambridgeshire or Jersey? Could differences in latitude be responsible? Latitudinal differences in body sizes are described by Bergmann's rule, but this rule states that body size increases with increasing latitude in response to colder climates (Blackburn *et al.*, 1999), which is not the case here.

A possible scenario is that a smaller average forearm length and heavier average weight in common pipistrelles on the Isle of Man are the result of evolution on an island, with little or no genetic mixing between mainland populations. Flemming and Racey (2009) state that ecological features of island bat species can include a smaller or larger body size. Perhaps common pipistrelles on the Isle of Man have adapted to an island environment? This is certainly an area for future research!

Acknowledgements

I would like to thank Jonathan Durward, Bob Cornes, Jude Hirstwood and Adrian Bayley for joining me on the Isle of Man and for their help in providing training. Thanks also go to the Manx Bat Group members, for being so enthusiastic and allowing me to use the data we collected. Finally, thanks go to Anni Binet for giving me permission to use Jersey Bat Group and Annyctalus Ecology records.

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Cambridgeshire Bat Atlas: 2010-2019

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Introduction

From 2010 onwards the Cambridgeshire Bat Group became more active in carrying out bat trapping surveys using mist nets and harp traps, with the help of enthusiastic members and neighbouring bat groups. Trapping surveys meant that individual bats could be identified in the hand to species level and an increasing number of species records were added to the group database alongside bat care and commercial records.

The Cambridgeshire Mammal Group released the Cambridgeshire Mammal Atlas in spring 2016, which included distribution maps for 11 species of bat confirmed as being present within the county. The Mammal Atlas can be viewed using the following link:

<https://issuu.com/markhows/docs/atlas>.

Winter 2020 seemed like an appropriate time to create updated distribution maps from bat records over the last decade. Records from Cambridgeshire Bat Group and Cambridgeshire and Peterborough Environmental Records Centre (CPERC) from 2010-2019 were collated in a single spreadsheet before being 'tidied'. Cambridgeshire was split into 1km x 1km grid squares and a black circle in the centre of a square indicates presence of any given species in that 1km square. In addition to species distribution maps, a second map for each species was created for the distribution of known roosts.

In total, there are species and roost distribution maps for 11 species – common pipistrelle *Pipistrellus pipistrellus*, soprano pipistrelle *P. pygmaeus*, Nathusius' pipistrelle *P. nathusii*, brown long-eared bat *Plecotus auritus*, noctule *Nyctalus noctula*, Leisler's bat *N. leisleri*, serotine *Eptesicus serotinus*, whiskered bat *Myotis mystacinus*, Natterer's bat *M. nattereri*, Daubenton's bat *M. daubentonii* and barbastelle *Barbastella barbastellus*. One combined distribution map was created for a twelfth species, Brandt's bat *M. brandti*, as this is from a single confirmed roost record. Finally, a map was created for all bat records across the county, including those unidentified to species level. Distribution maps for each species are provided over the following pages.

These distribution maps will be used by the group to identify areas that would benefit from further survey in the future to increase coverage of Cambridgeshire, north Cambridgeshire in particular, and to hopefully bring known roost sites into the National Bat Monitoring Programme run by the Bat Conservation Trust by allocating sites to members and volunteers who live nearby.

Acknowledgements

Thanks go to all volunteers and professionals who have shared their records with the bat group and to CPERC for sharing their bat records to cross-reference with bat group records. Particular thanks go to Jonathan Webb for creating the distribution maps and to Val Perrin, the Records Officer for Cambridgeshire Bat Group, for pulling together group records and for his encouragement during the project.

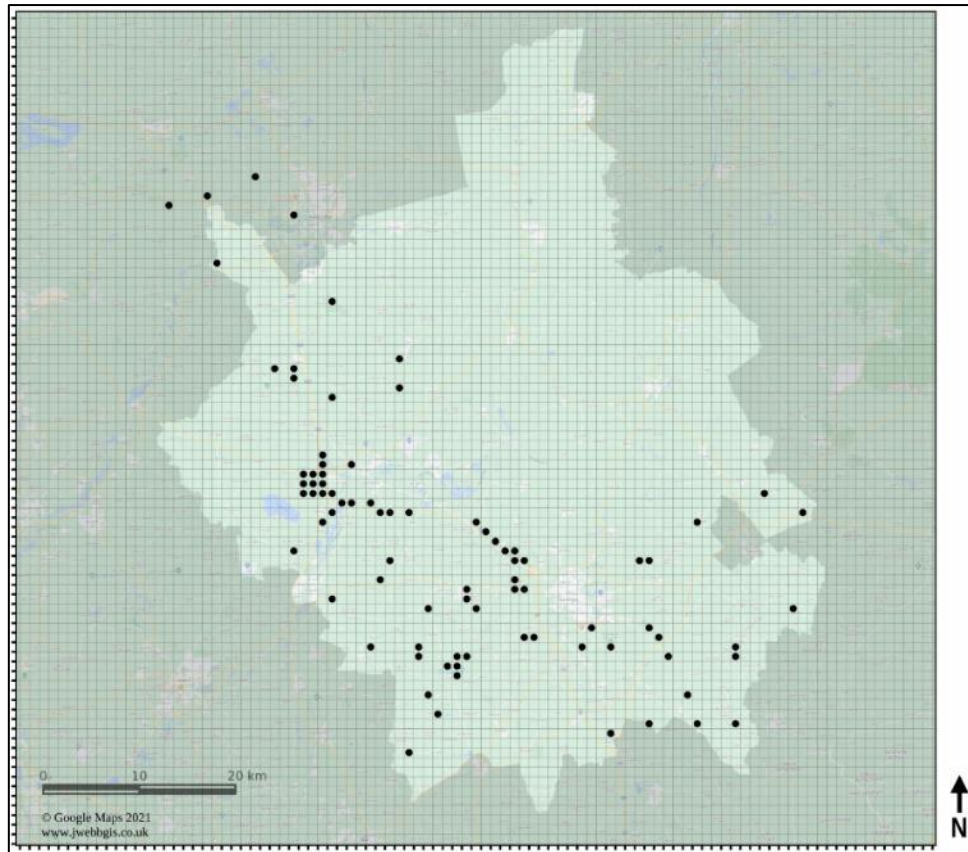


Figure 1: Distribution map, barbastelle.

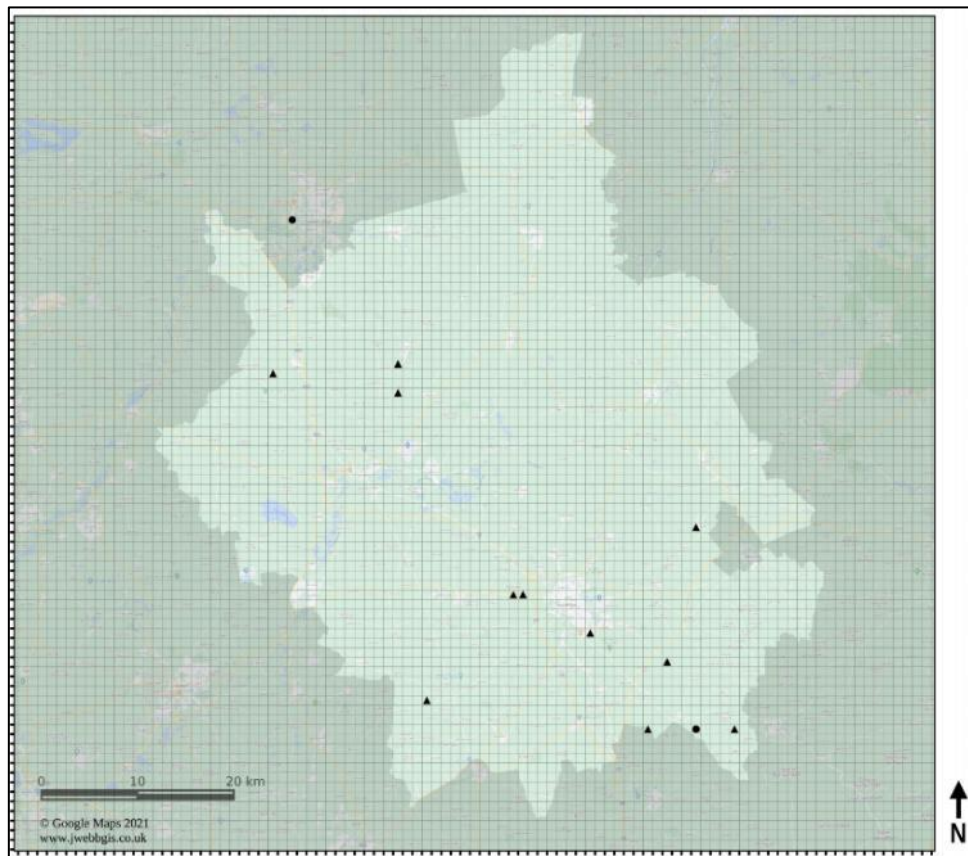


Figure 2: Roost distribution map, barbastelle.

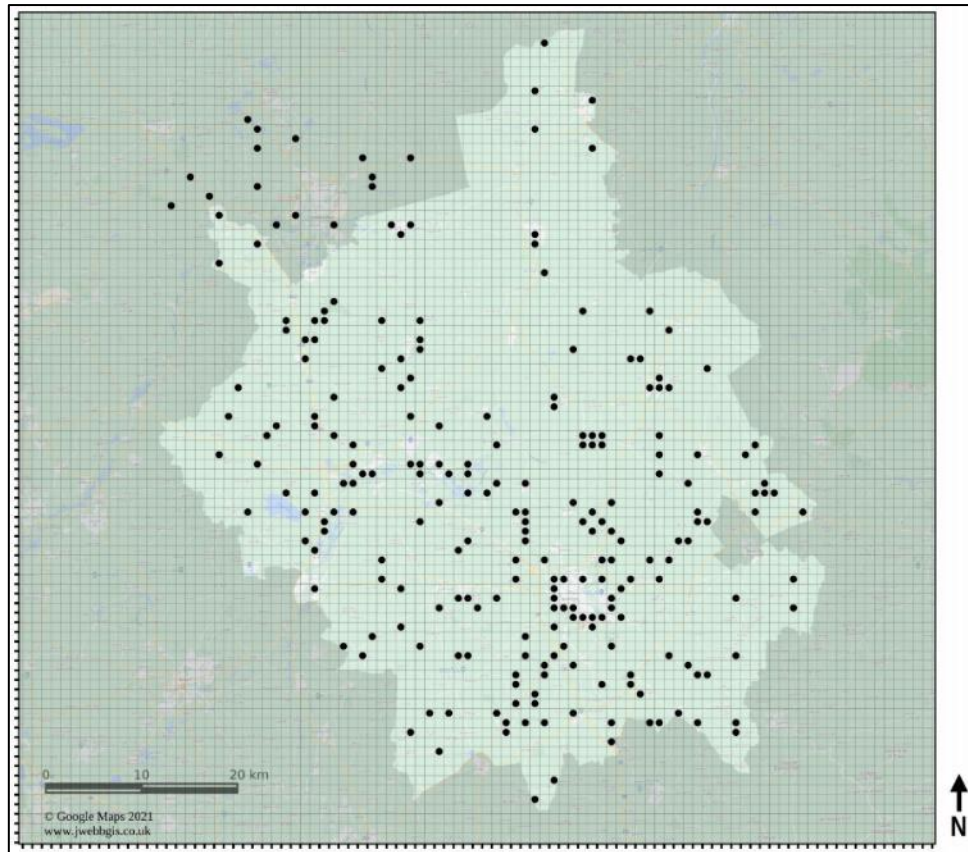


Figure 3: Distribution map, brown long-eared bat.

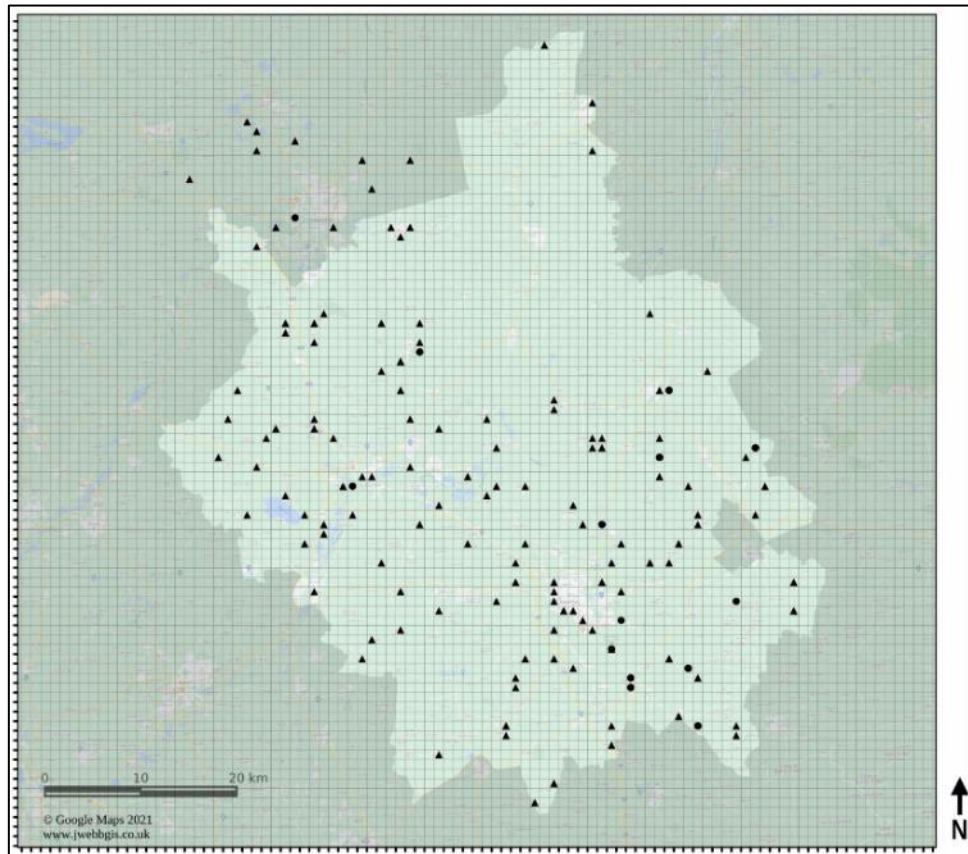


Figure 4: Roost distribution map, brown long-eared bat.

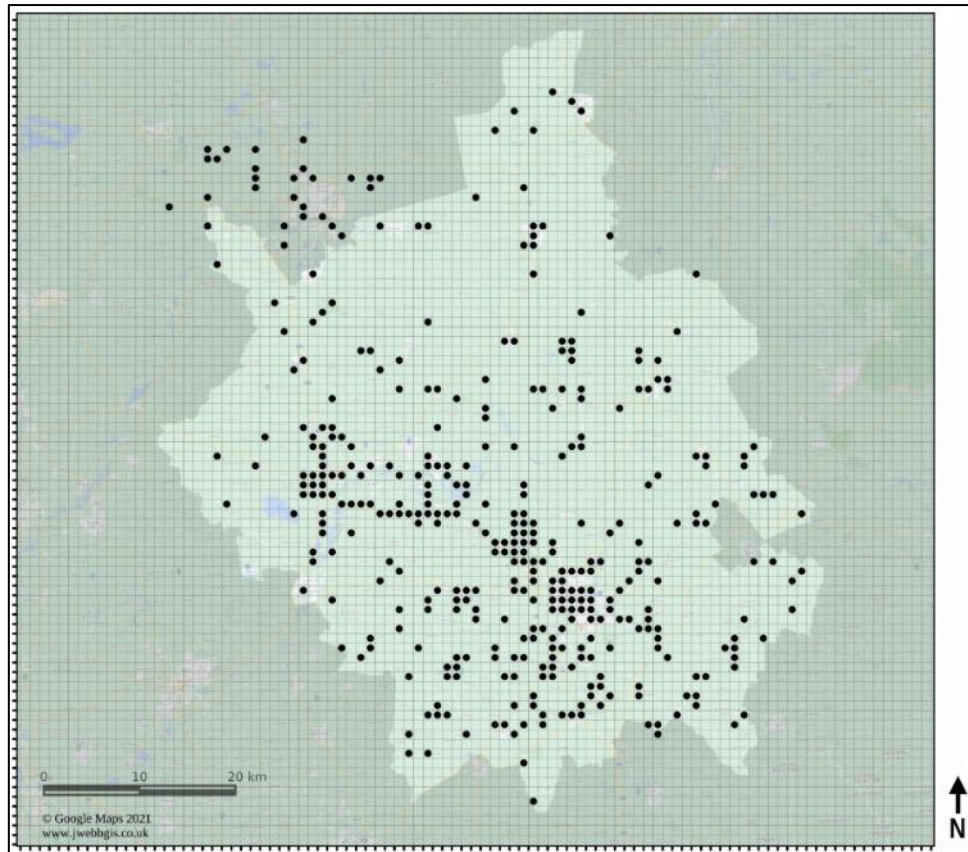


Figure 5: Distribution map, common pipistrelle.

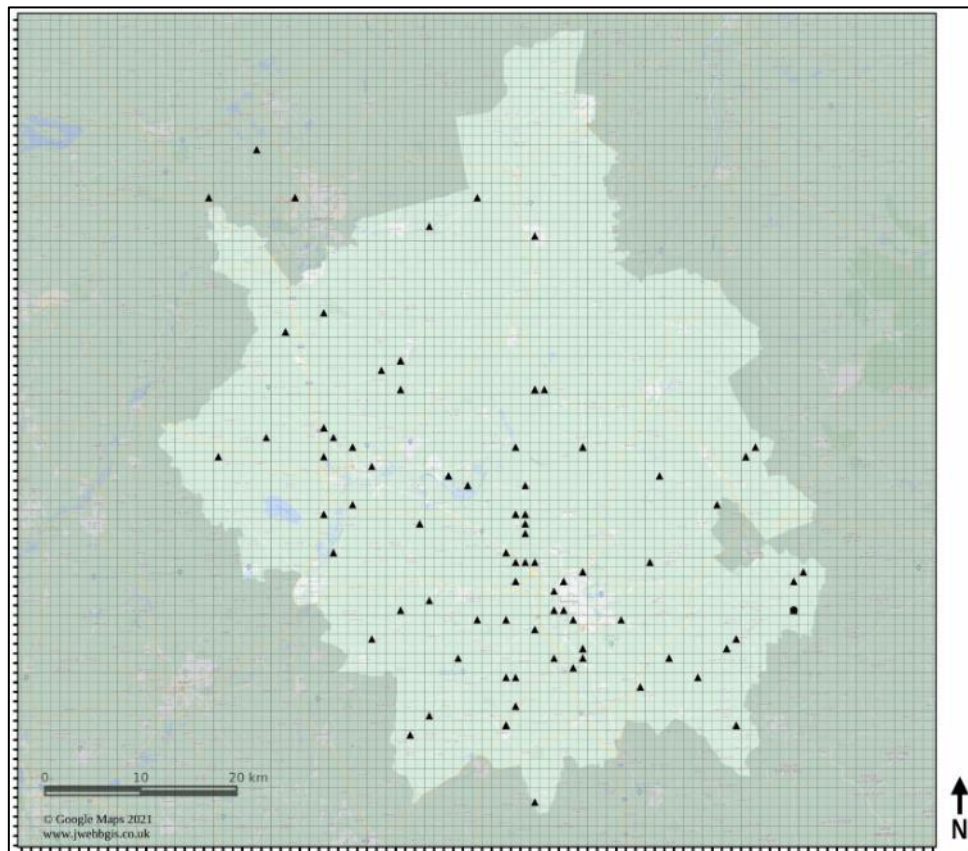


Figure 6: Roost distribution map, common pipistrelle.

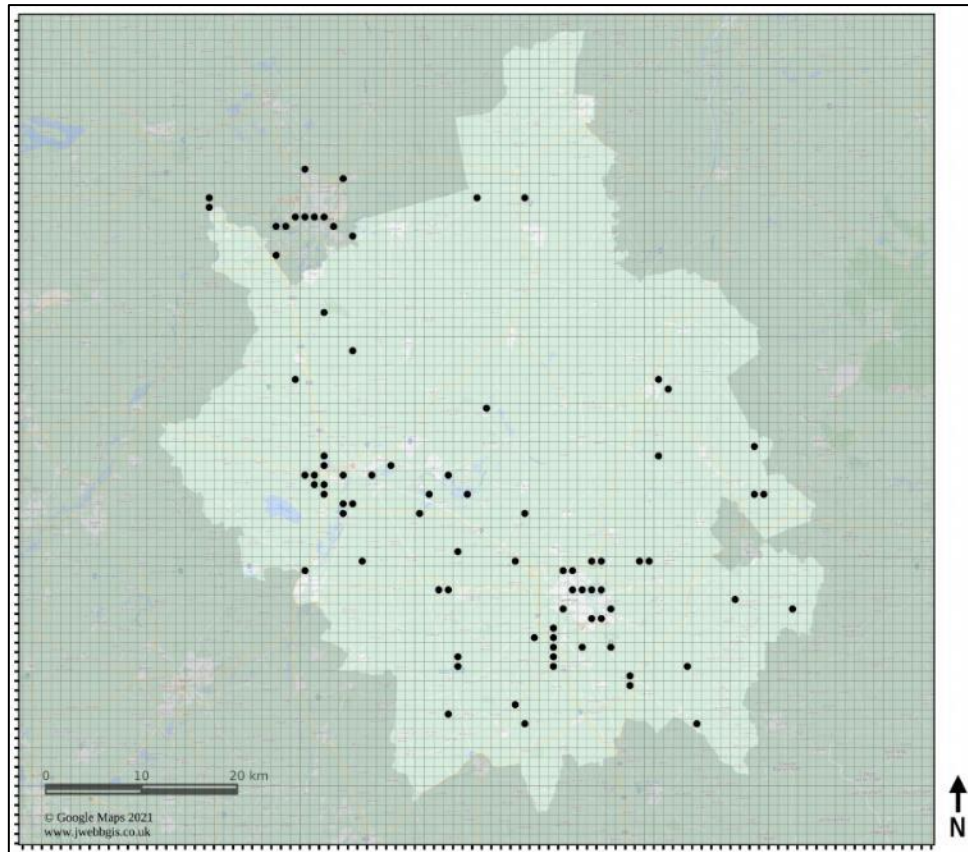


Figure 7: Distribution map, Daubenton's bat.

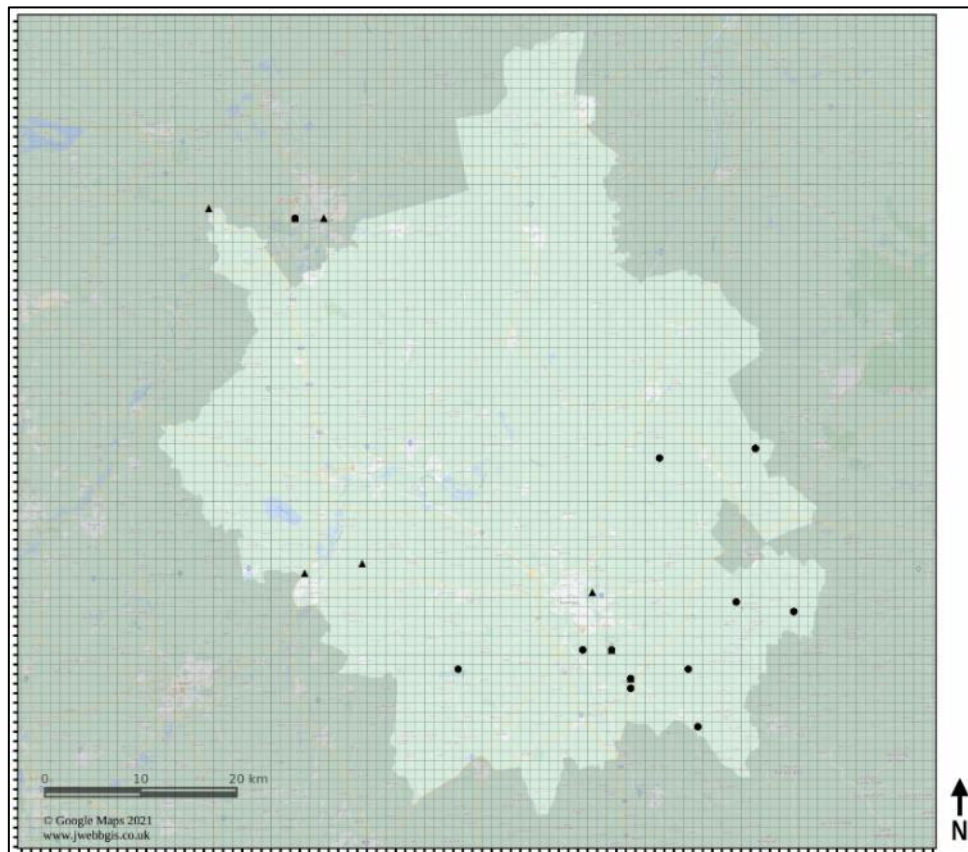


Figure 8: Roost distribution map, Daubenton's bat.

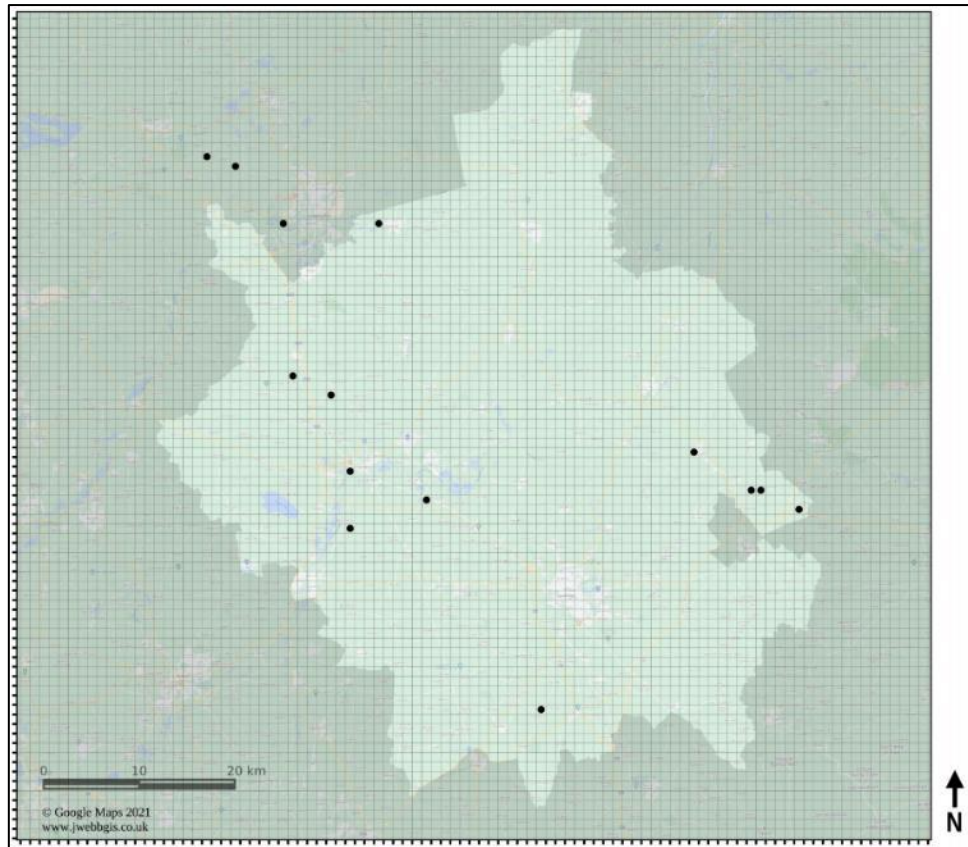


Figure 9: Distribution map, Leisler's bat.

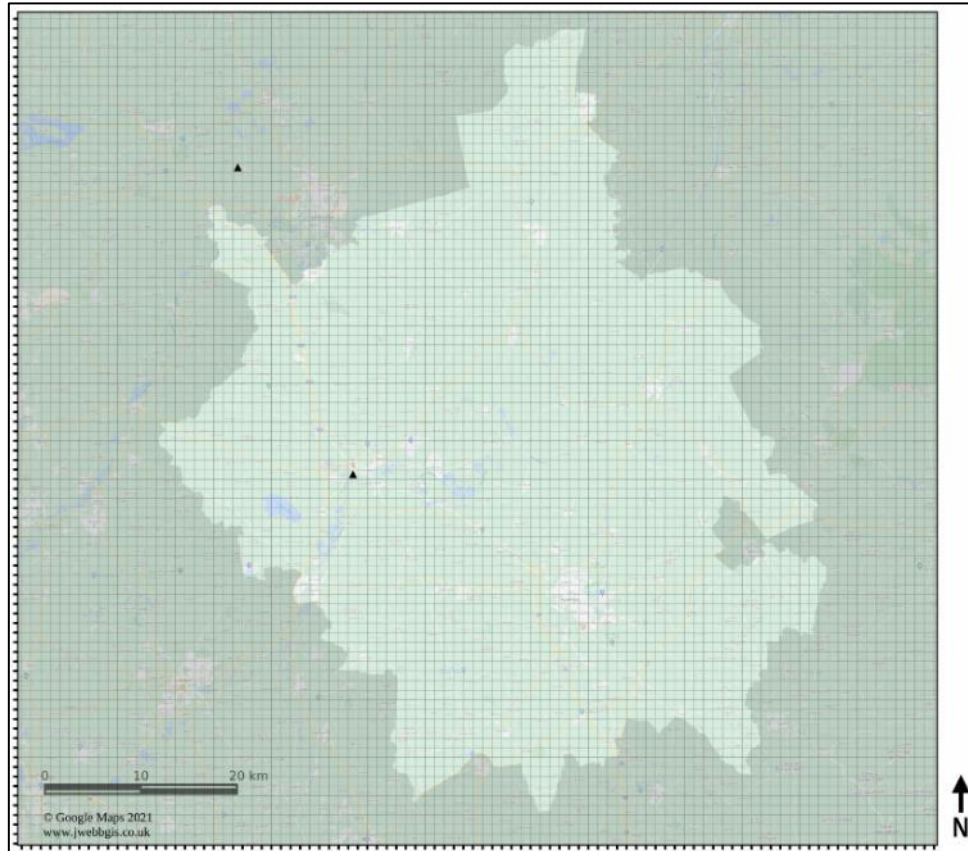


Figure 10: Roost distribution map, Leisler's bat.

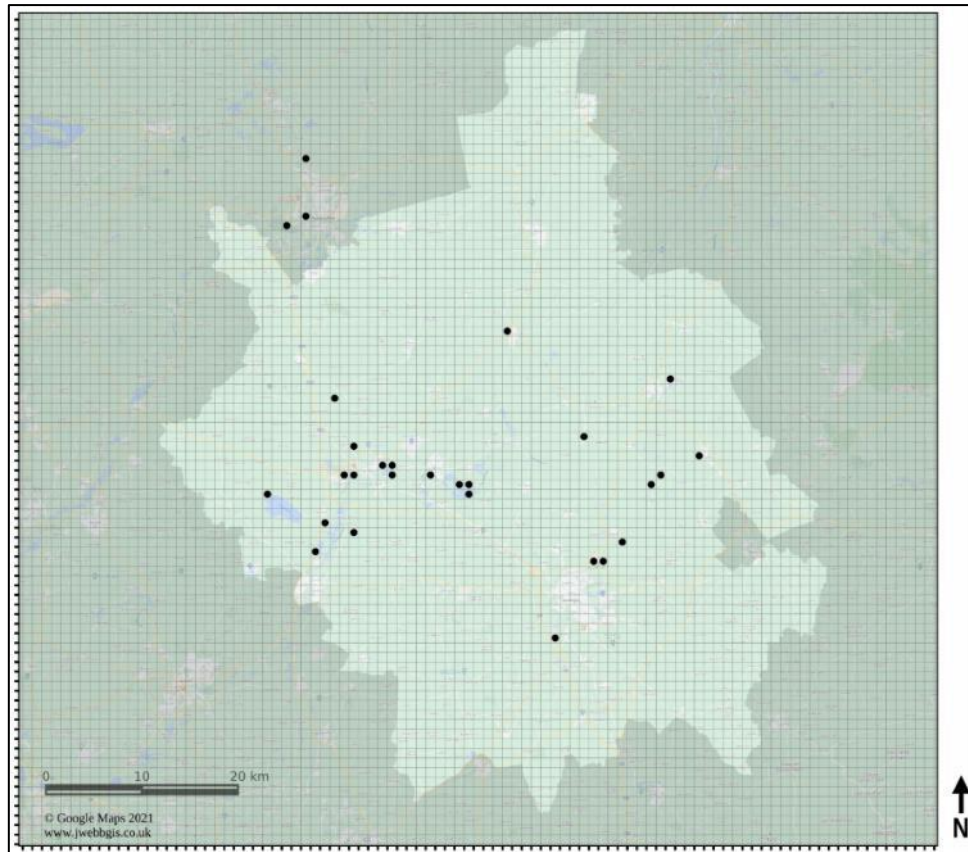


Figure 11: Distribution map, Nathusius' pipistrelle.

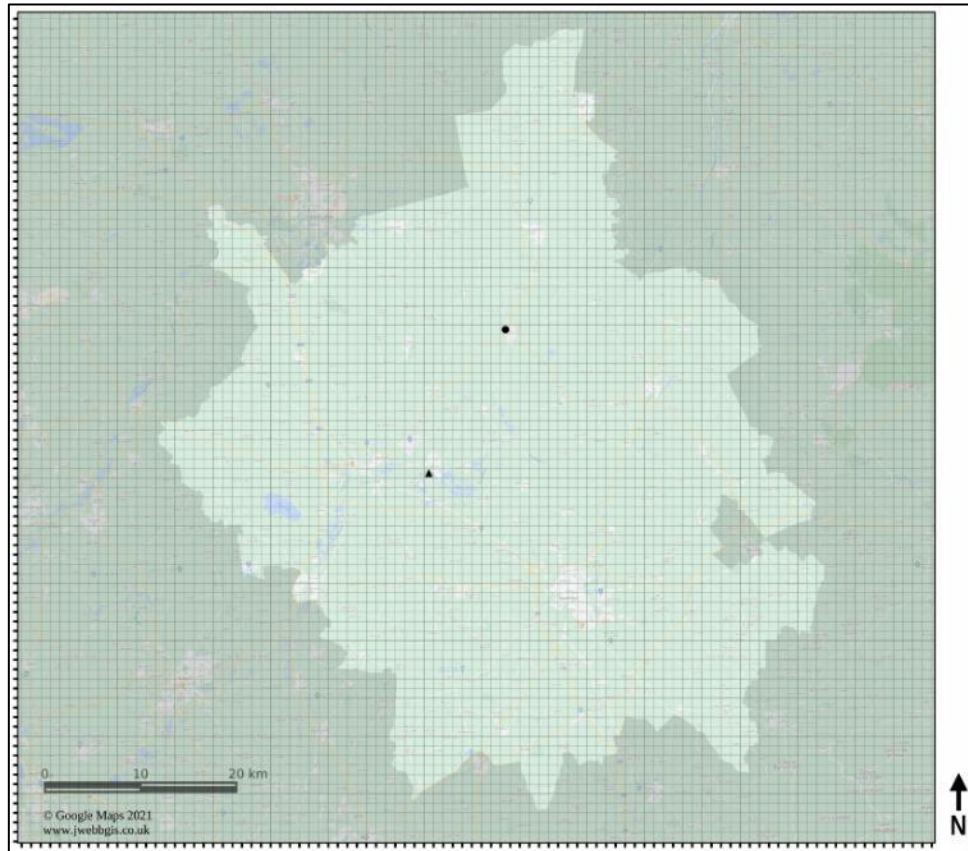


Figure 12: Roost distribution map, Nathusius' pipistrelle.

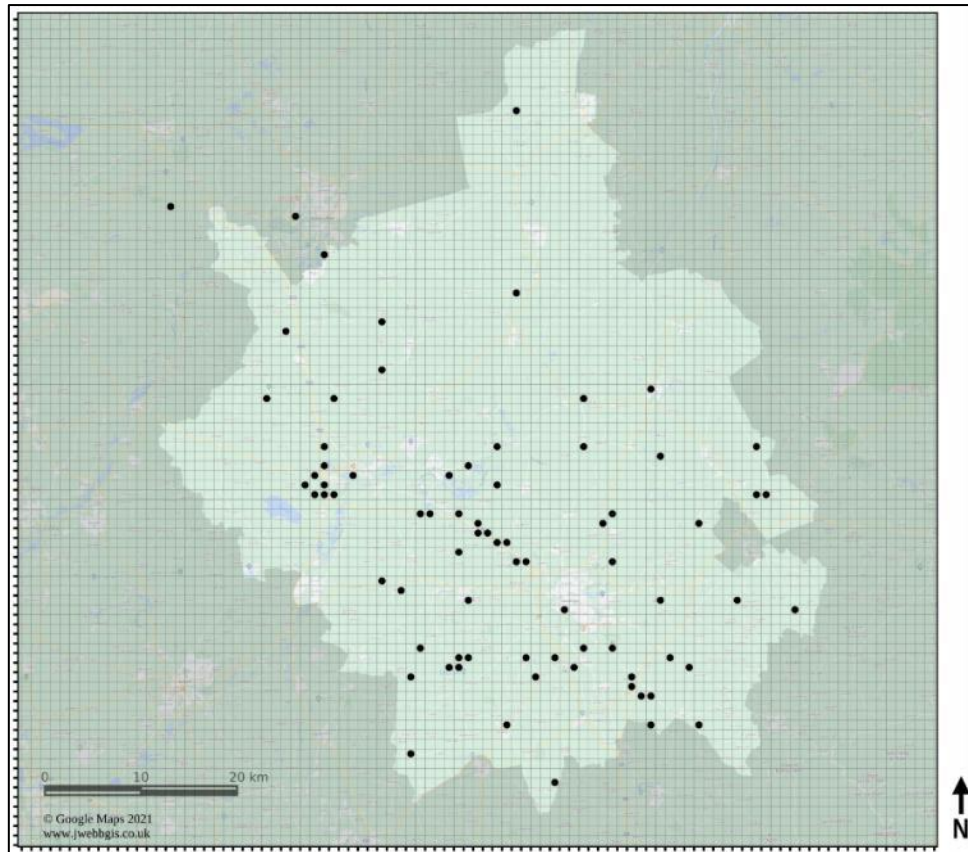


Figure 13: Distribution map, Natterer's bat.

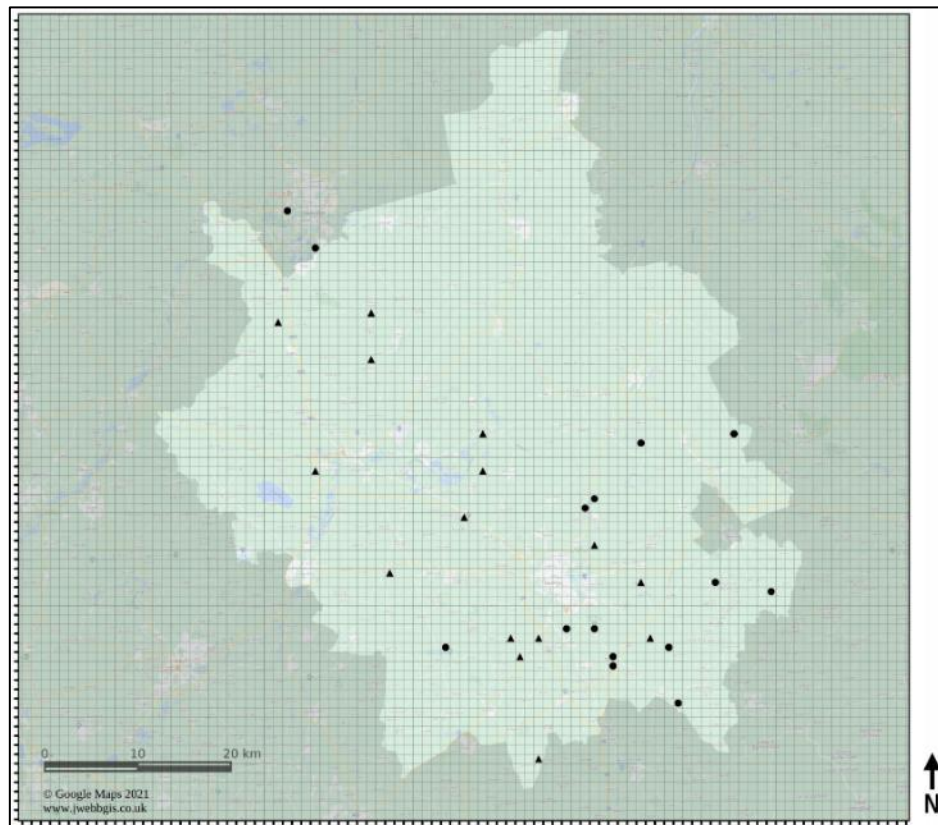


Figure 14: Roost distribution map, Natterer's bat.

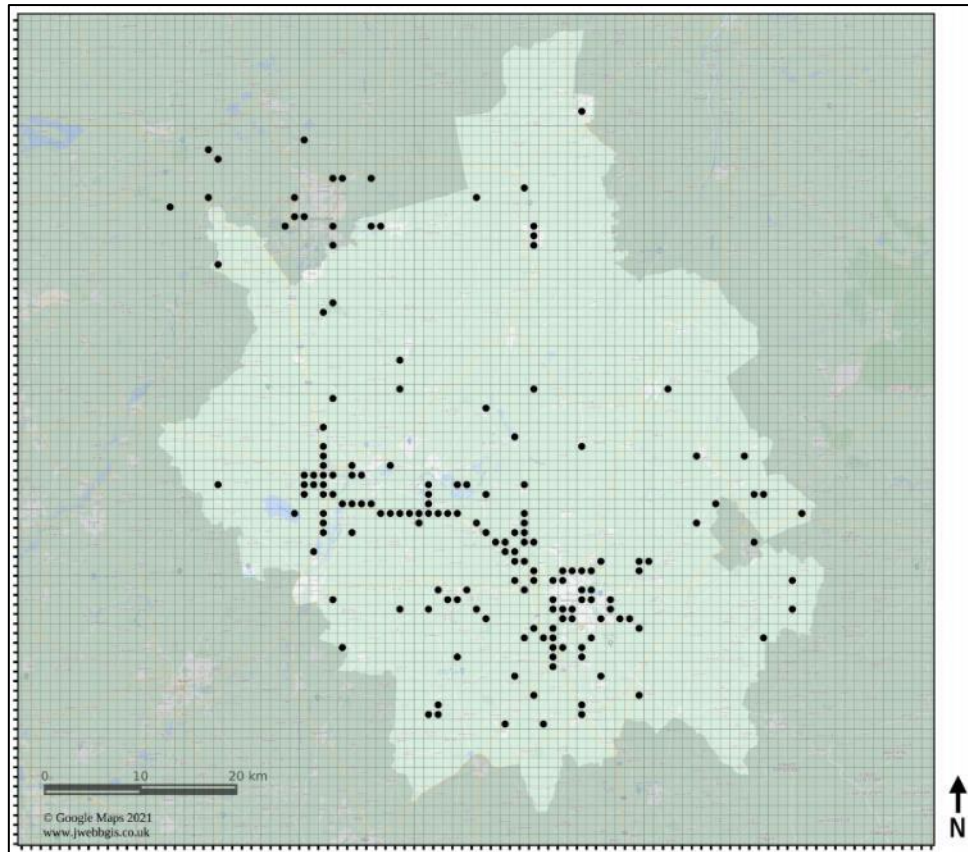


Figure 15: Distribution map, noctule.

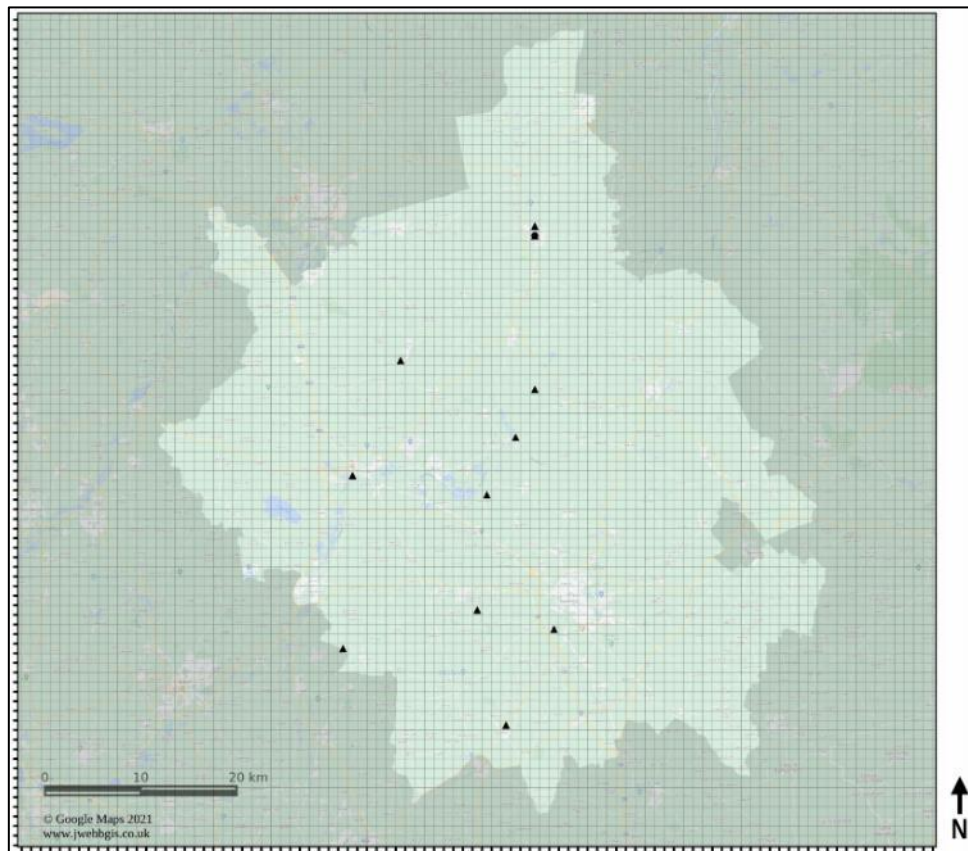


Figure 16: Roost distribution map, noctule.

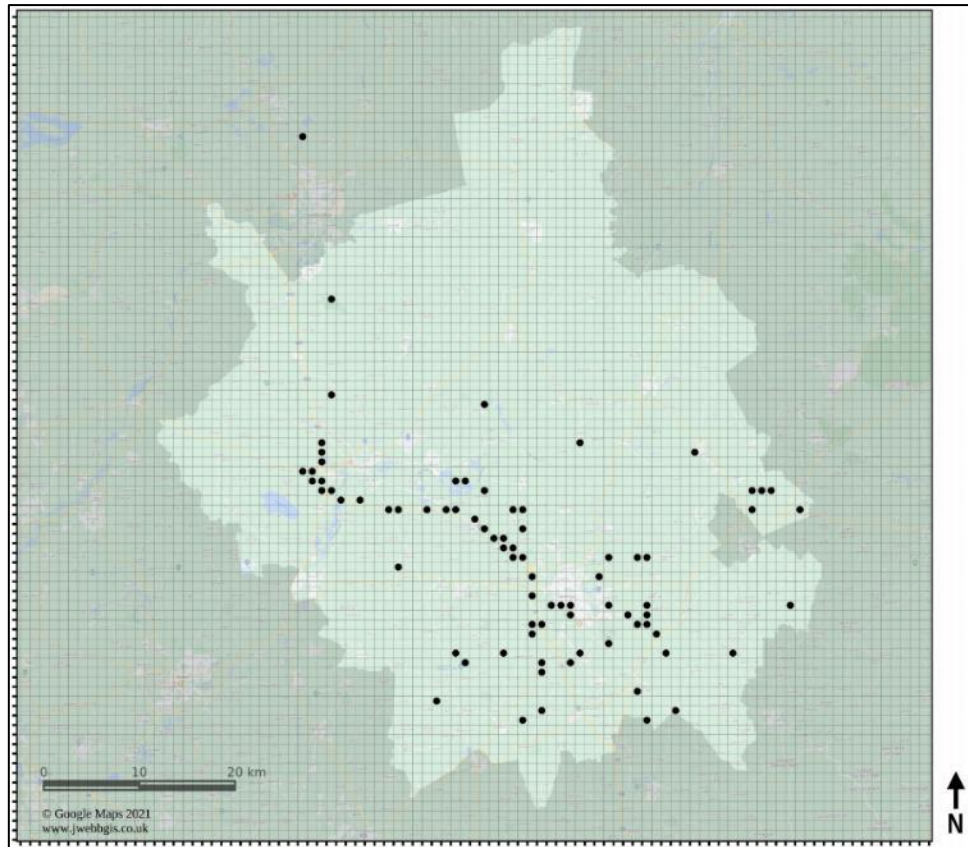


Figure 17: Distribution map, serotine.

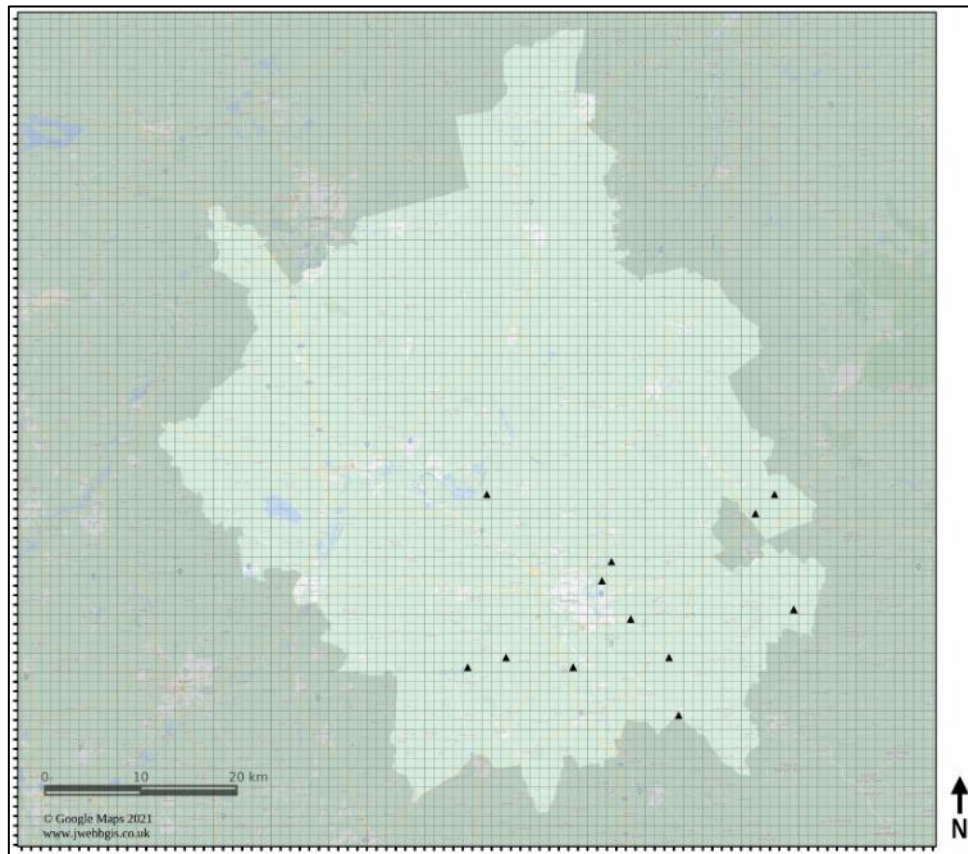


Figure 18: Roost distribution map, serotine.

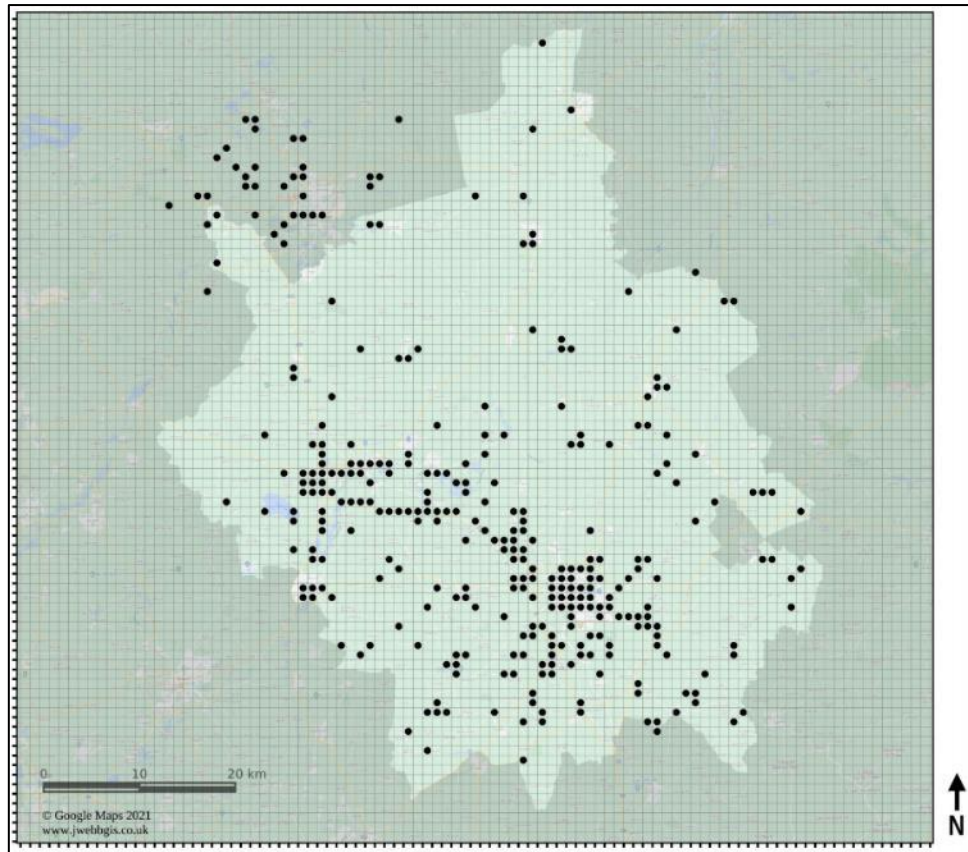


Figure 19: Distribution map, soprano pipistrelle.

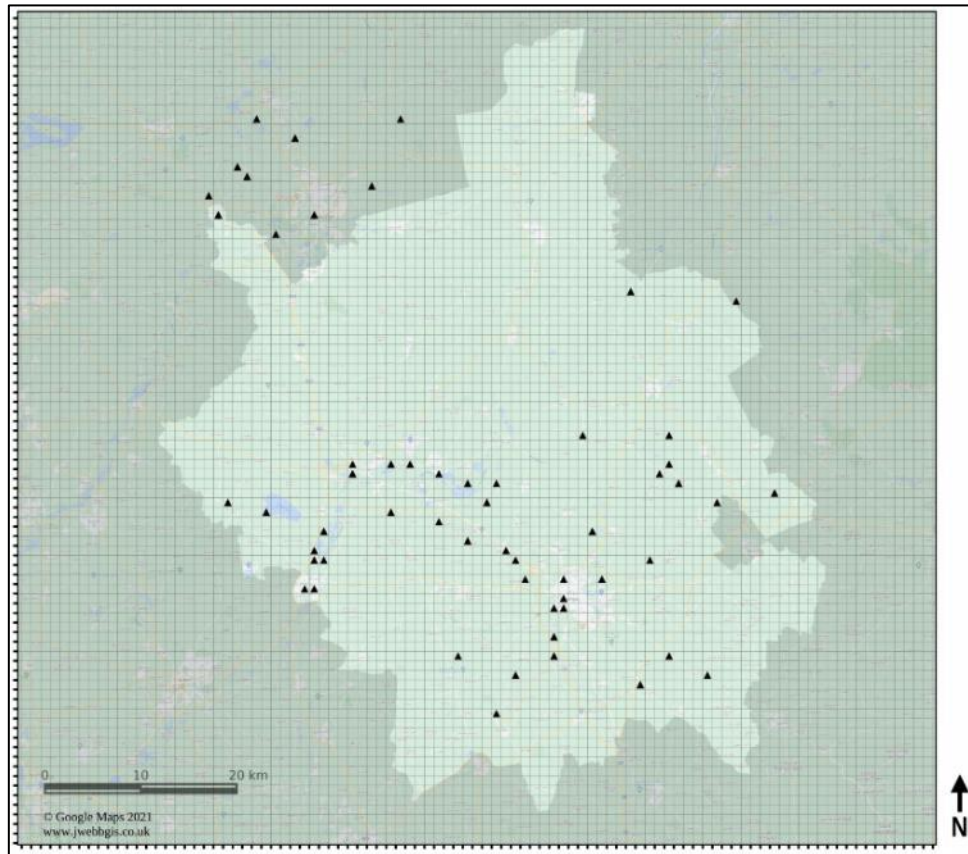


Figure 20: Roost distribution map, soprano pipistrelle.

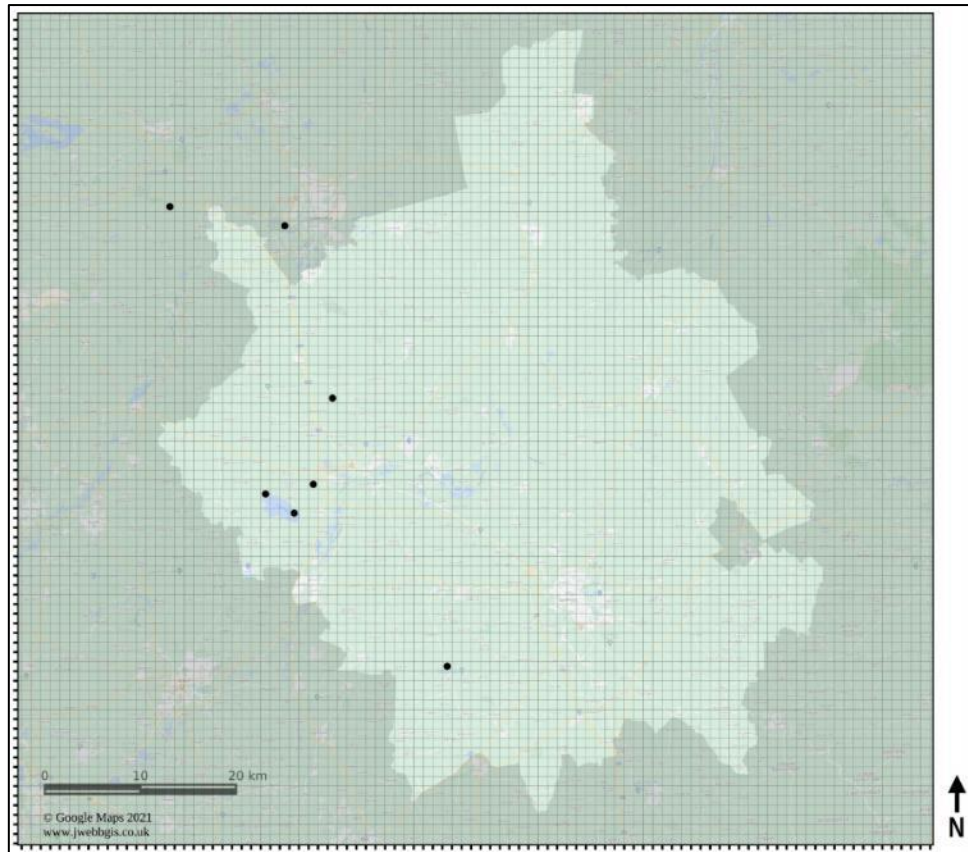


Figure 21: Distribution map, whiskered bat.

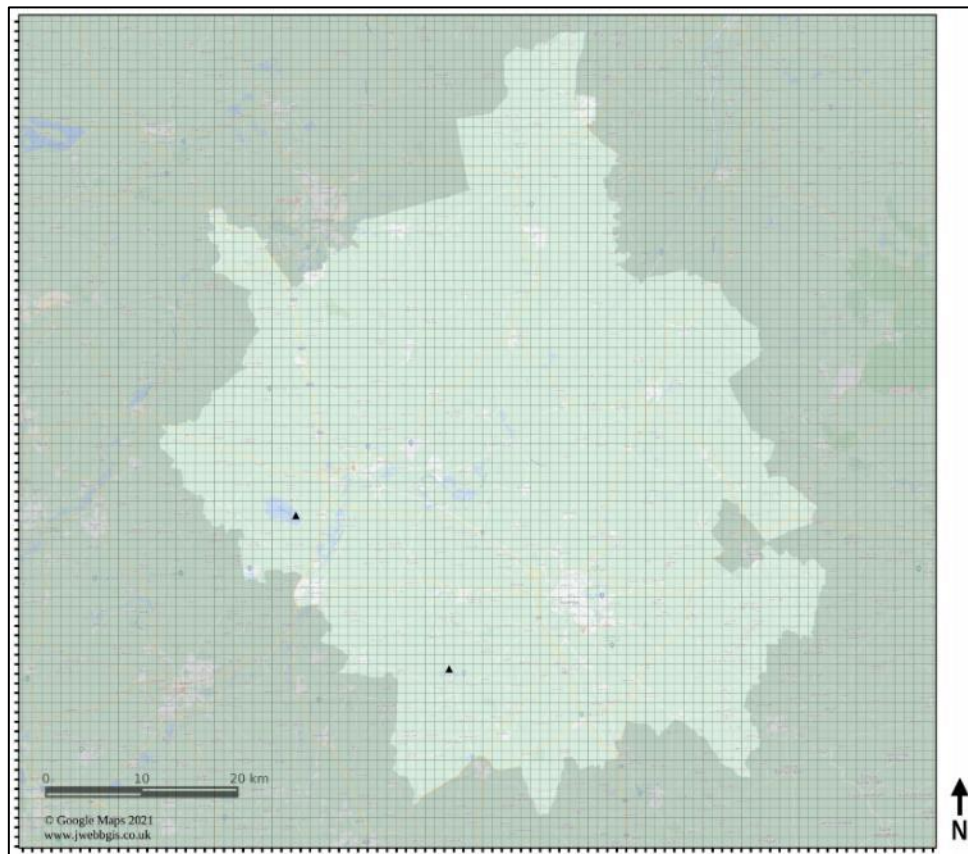


Figure 22: Roost distribution map, whiskered bat.

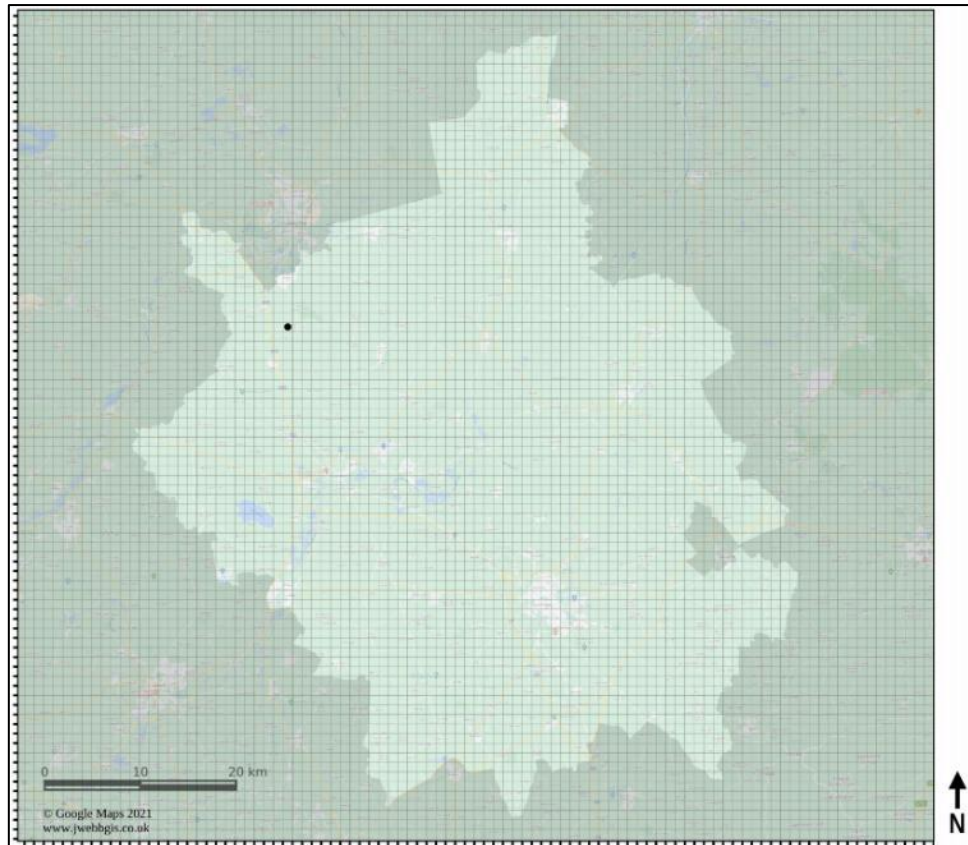


Figure 23: Distribution/roost map, Brandt's bat.

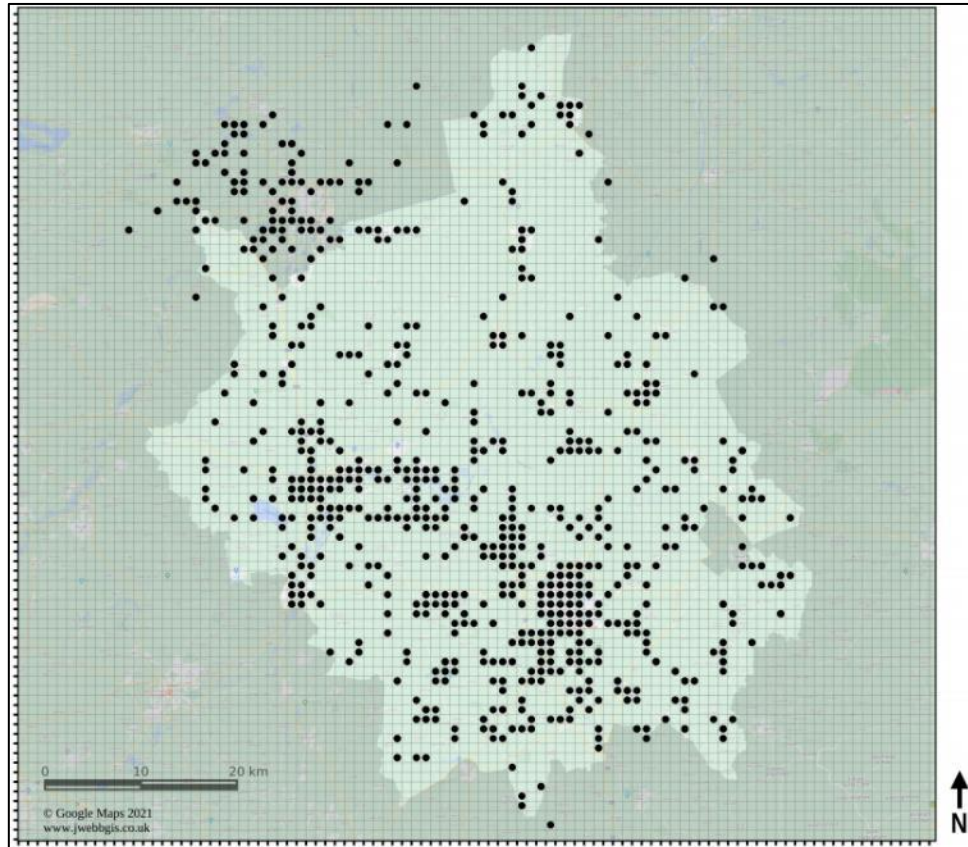


Figure 24: Distribution map, ALL RECORDS.

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Changing the maps of urban bat distribution

Morgan Hughes¹, Scott K. Brown², Simon T. Maddock¹ and Christopher H. Young¹;

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Abstract

Over three decades after the establishment of the Birmingham and Black Country Bat Group, the results of just a few years of targeted advanced surveys at woodland sites in the green belt of the county have begun to challenge the misconceptions of bat assemblages in urban areas. The data from the Urban Bat Project have altered the distribution maps of species previously thought to be ‘rare’, ‘very rare’ or ‘locally extinct’ in the county. The rediscovery of Brandt’s bat *Myotis brandti* and the re-assessment of the rarity scores of nine of the remaining 11 extant county species is likely not due to a legitimate increase in their numbers or a broadening of their distribution. It is, rather, attributable to the increase in recent years of higher quality acoustic monitoring devices and also to a concerted increase in the recording of cryptic and non-ubiquitous species in a previously under-studied and under-valued landscape.

Introduction

Mammals are generally under-recorded (Mammal Watch South East, 2015), with bats being a relatively understudied group (Jung and Kalko, 2010) and urban bats even more so (Kubista and Bruckner, 2015). Studies of urban bat assemblages have concluded that one or two adaptable species often dominate the urban landscape, typically accounting for more than 50% of bat records (Hourigan *et al.*, 2010) which, in the case of Birmingham and the Black Country, is accurate, with common pipistrelle *Pipistrellus pipistrellus* accounting for 46% of total bat records, 56% of all records identified to genus level and 64% of all records identified to species level at the start of the study (EcoRecord, 2018). This dominance by one or few species contributes to the general assumption that urban bat species richness is low, comprising only synurbic or synanthropic species that are well-adapted to light and noise. This assumption perpetuates a culture of under-recording within the conurbation which Teagle (1978) attributed to the preference of enthusiasts pursuing their interests in ‘quieter, cleaner wilder places with more aesthetic appeal’.

In his seminal work, ‘The Endless Village’, Teagle (1978) undertook the first published work to explore the relationship between industry, culture and biodiversity in Birmingham and the Black Country and, though (as no bat records held by the local Biological Records Centre date from prior to 1983) there is no species list therein, he refers to the potential importance to bats of the disused limestone mines in Dudley. Robert Stebbings (1997) undertook surveys of the mines (arguably the most urban swarming site in the UK) and recorded the first (and until this study, only) county record for Brandt’s bat. Up to and including 1996, the county database comprised 425 species-level records of seven species: Daubenton’s bat *M. daubentonii*, whiskered bat *M. mystacinus*, Natterer’s bat *M. nattereri*, noctule *Nyctalus noctula*, common pipistrelle and brown long-eared bat *Plecotus auritus*. Recording continued for another 20 years, with the species richness increasing to 11 by 2017 (Table 1).

Table 1: Published accounts of bat species assemblage of Birmingham and the Black Country.

Year	Publication	Spp.
1978	The Endless Village (Teagle, 1978)	?
1997	Survey for Bats: Dudley Limestone Mines (Stebbing, 1997)	7
2000	Bats Biodiversity Action Plan (EcoRecord, 2000)	8*
2003	A Provisional Atlas of Mammals of Birmingham and the Black Country (Wyatt, 2003)	10
2007	The Endless Village Revisited (Shirley, 2007)	12
2010	Biodiversity Action Plan (The Birmingham and Black Country LBAP Review Group, 2010)	10
2017	A Standard Species Rarity Index (Slater and Carvalho, 2018)	11**
2017	Provisional Batlas of Birmingham and the Black Country (Jones, 2017)	11**

* In 1996 were two phonic types of common pipistrelle were found to be roosting separately (Park *et al.*, 1996) and in 1999 were separated into two species: common pipistrelle and soprano pipistrelle *P. pygmaeus* (PTES, 2018) and as such prior to this date records of common pipistrelle have been retroactively assumed to be *P. pipistrellus sensu lato* but are likely to have represented both species rather than the actual county richness increasing after this date.

** The SSRI and Batlas included all records up to 15 and 10 years old, respectively at the dates of the assessments (with the SSRI comprising records from 2002 - 2017 and the Batlas from 2004 - 2014), both of which excluded Stebbing's record of Brandt's bat. The species was considered to be extinct in the region in 2017.

Most studies of the effects of the anthropogenic environment on bats focus on the urban areas of Europe and North America (Jung and Threlfall, 2016). In general, these tend to focus on areas of either dense urbanisation, urban parks and gardens and industrial areas. A recent review of terminology and literature (Fischer *et al.*, 2015) places emphasis on the importance of 'natural' areas in proximity to urban areas, but relatively little work has been undertaken to assess the importance of, or the bat assemblages within, urban fringe woodlands in temperate climates. Woodlands in metropolitan areas may be particularly important for bats (Avila-Flores and Fenton, 2005) but information on the effects of management of urban forests for bats is extremely limited (Smith and Gehrt, 2010). With increasing pressure to release green belt sites to meet rising housing needs (Birmingham City Council, 2017; Hearn, 2018), the under-valuing of urban fringe habitats is a threat to bat conservation in urban areas. With that in mind, in the spring of 2017 (two decades after Stebbing recorded the county's eighth species), the Birmingham and Black Country Bat Group prepared a plan for the Urban Bat Project and submitted a project licence application to begin advanced surveys in August of that year with a view to addressing the gaps in recording of urban woodland sites and the ultimate aim of producing a more accurate set of distribution data for bat species in the county.

Materials and Methods

Since August of 2017, advanced bat surveys have been undertaken at eleven woodlands (Figure 1) in the administrative area of Birmingham and the Black Country. Each site was subject to a minimum of three visits across each active bat season, comprising a total of 89 surveys. Surveys took place under Natural England project licences (2017-20732-SCI-SCI, 2018-33578-SCI-SCI, 2019-39455-SCI-SCI and 2019-44132-SCI-SCI) using standard

methodology (Kunz and Kurta, 1988; Barlow, 1999; Collins, 2016). As per Battersby (2010) and Collins (2016), surveys commenced at dusk; they continued for five trapping hours unless weather conditions curtailed the surveys.

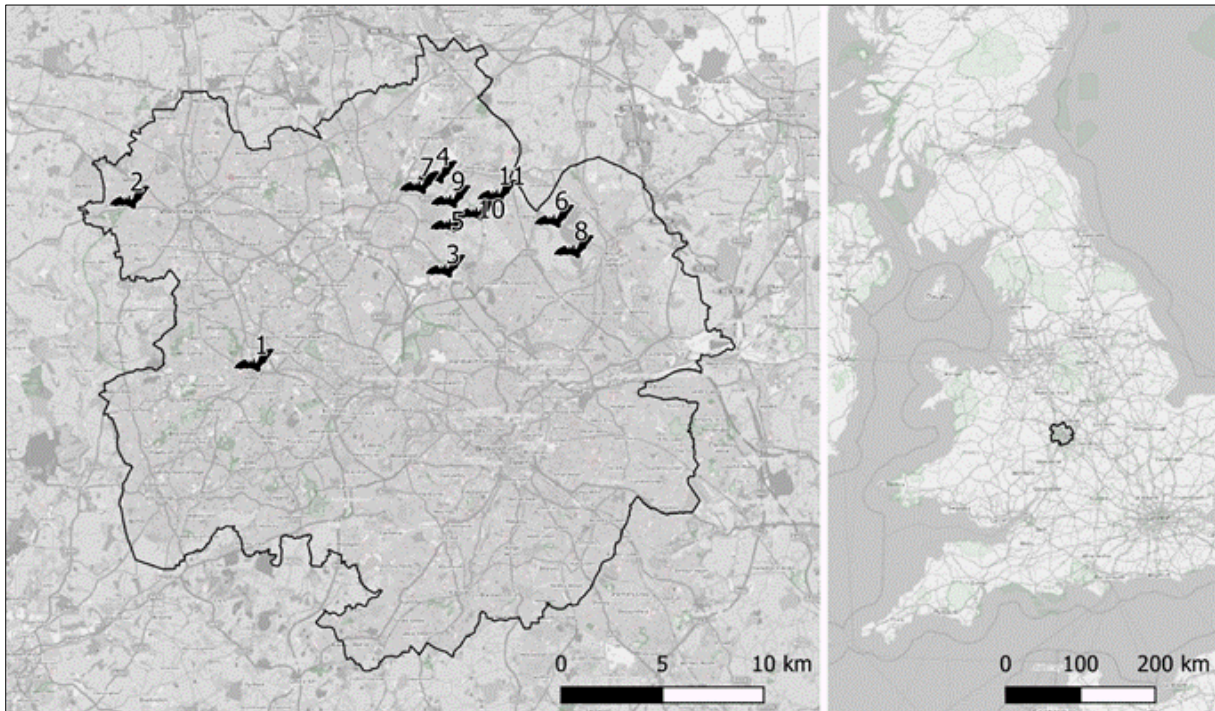


Figure 1: Location of woodland survey sites (numbered icons) within Birmingham and the Black Country (black) administrative boundary in its UK context. © OpenStreetMap 2020.



Figure 2: Surveyor setting up a harp trap at Park Lime Pits. © Gary Hughes.

Ecotone standard 4-shelf (2.4m high) mist nets were assembled into double-high arrangements in 6m, 9m or 12m lengths as canopy height allowed, supplemented by two

triple-bank Austbat harp traps deployed with Apodemus Batlure acoustic lures. Equipment at each survey was deployed to provide a minimum of two trap nights (Collins, 2016) and ten net hours (Pereira *et al.*, 2009) per night. As per Bat Conservation Trust guidelines (Collins, 2016) acoustic monitoring supplemented the survey, with two Elekon Batlogger M bat detectors deployed for the duration of each survey. Data were collected utilising Epicollect5 (Imperial College London, 2019) and later compiled in SPSS (IBM Corp., 2016). Sound analysis was undertaken using Bat Explorer (Elekon AG, 2019) and records of catch data and acoustic monitoring were entered into the county database on MapMate (Mapmate Ltd., 2018) and imported into QGIS (QGIS Development Team, 2018) for graphical display using the TomBio plugin (Burkmar, 2020). Catch data were used to re-evaluate the county species assemblage utilising the Slater and Carvalho (2018) species rarity matrix (Figure 3).

Description		No. of Monads	No. of Tetrads	No. of 5km squares
Total Squares in Region		747	202	40
A	Abundant	over 682	over 190	over 38
VC	Very Common	501 — 682	141 — 190	28 — 38
C	Common	215 — 500	61 — 140	12 — 27
F	Frequent	86 — 214	24 — 60	5 — 11
U	Uncommon	31 — 85	9 — 23	2 — 4
R	Rare	7 — 30	2 — 8	1 & 3+ rec
VR	Very Rare	1 — 6	1	1 & < 3 rec
PE	Presumed Extinct	0	0	0
ABS	Absent	0	0	0

Figure 3: Criteria for rarity assessment (Reproduced with permission) (Slater and Carvalho, 2018).

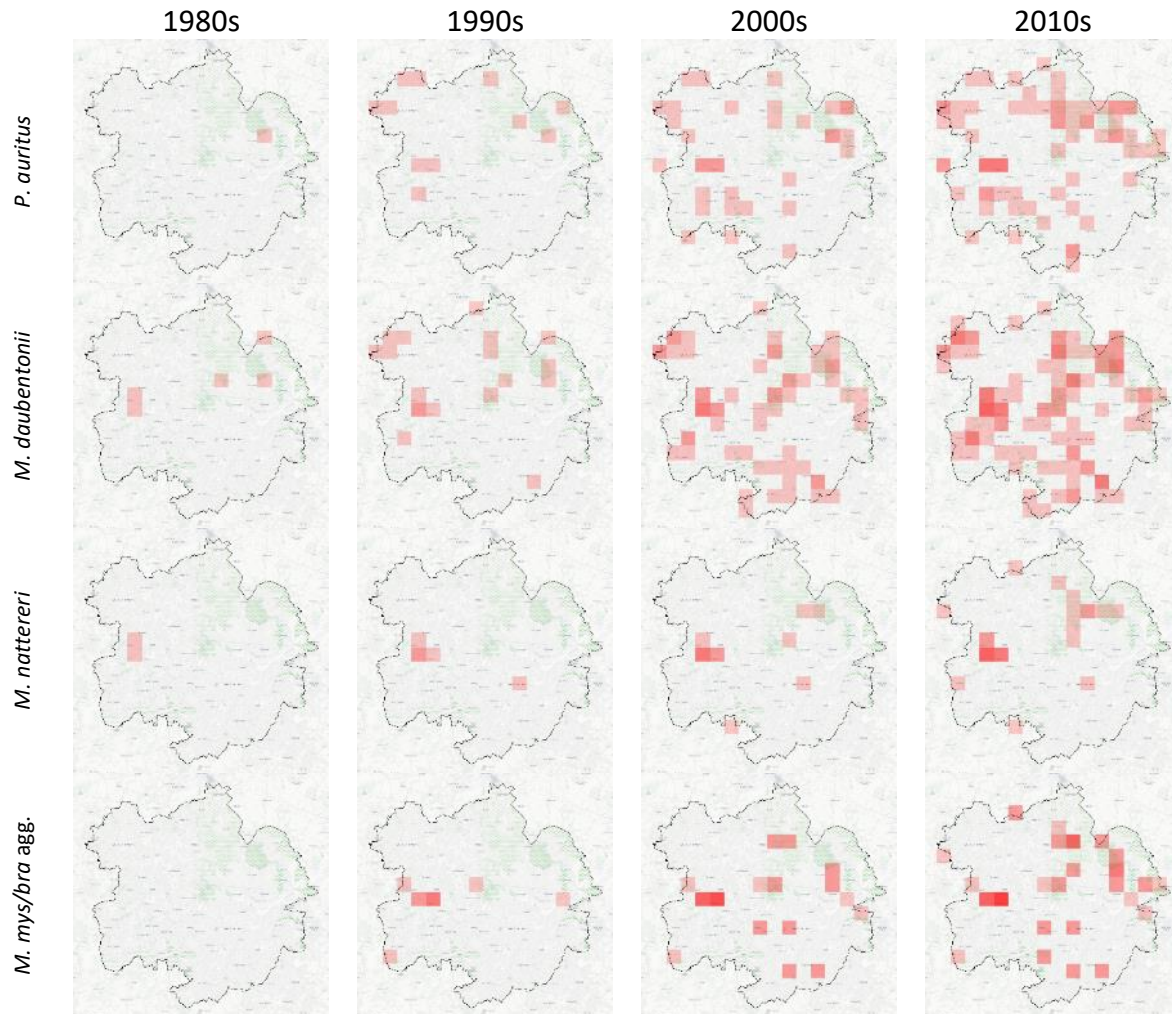
Results

A total of 699 bats have been caught so far comprising ten species: common pipistrelle (165), brown long-eared bat (152), Daubenton's bat (149), Natterer's bat (88), soprano pipistrelle (69), noctule (55), whiskered bat (12), Brandt's bat (5), lesser horseshoe bat *Rhinolophus hipposideros* (2) and Leisler's bat *N. leisleri* (1), with a further two species (serotine *Eptesicus serotinus* and Nathusius' pipistrelle *P. nathusii*) recorded on detectors. Based on monad count criteria, the data would warrant the reassessment of ten of the 12 county species (Table 2). Record density for key species by tetrad shows a notable increase in cumulative records (Table 3).

Table 2: Changes in count species rarity assessments based on the Standard Species Rarity Index (Slater and Carvalho, 2018) monads count.

Taxon	First recorded	2017 Monads	2017 Rarity	2020 Monads	2020 Rarity	Rarity Change	2020 Records
Noctule	1983	104	F	169	F	NC	638
Common pipistrelle	1985	365	C	566	VC	↑1	2942
Brown long-eared bat	1985	41	U	94	F	↑1	380
Daubenton's bat	1985	69	U	118	F	↑1	649
Whiskered bat	1986	2	VR	17	R	↑1	31
Natterer's bat	1988	10	R	23	R	NC	147
Brandt's bat	1997	0	PE	4	VR	↑1	7
Soprano pipistrelle	2000	99	F	218	C	↑1	729
Nathusius' pipistrelle	2002	4	VR	14	R	↑1	27
Serotine	2003	6	VR	20	R	↑1	28
Lesser horseshoe bat	2005	5	VR	9	R	↑1	26
Leisler's bat	2007	5	VR	26	R	↑1	48

Table 3: Changes in all-time record density per species (or aggregate) by decade. (Continued on next page.)



England – Midlands

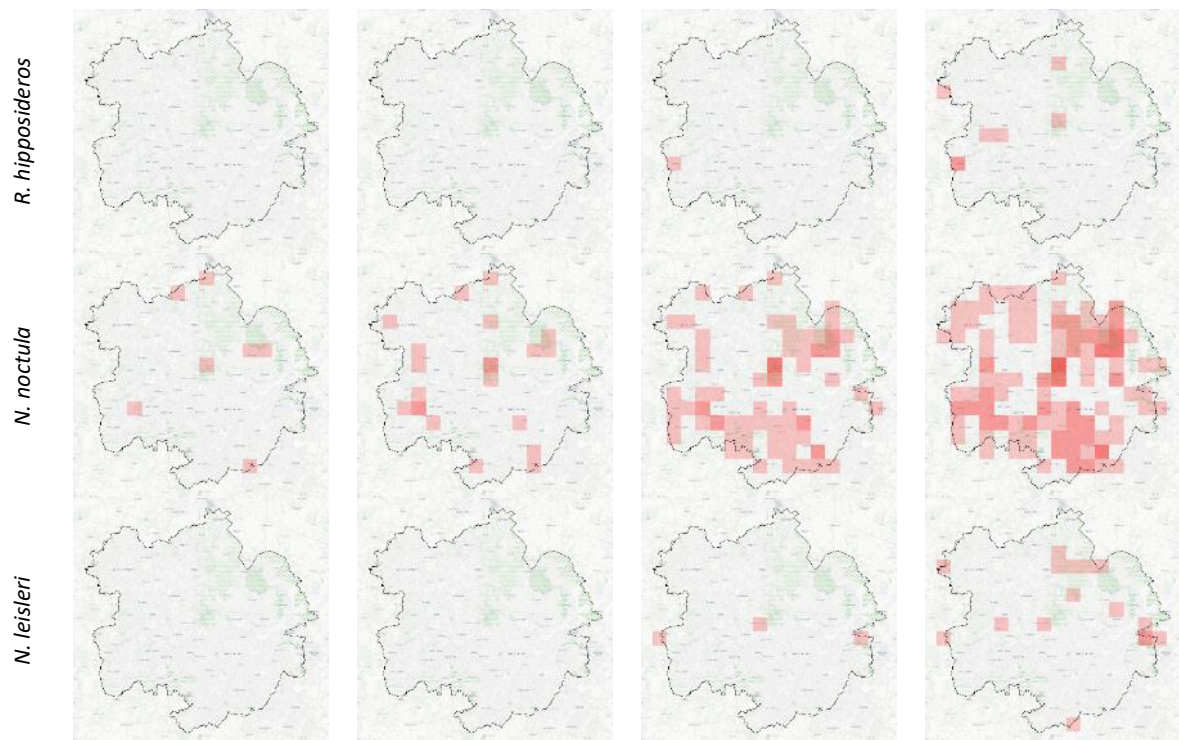


Figure 4: Brandt's bat, previously thought to be locally extinct; now found in four monads and widespread across the conurbation. © Morgan Hughes.

Numerous factors influence the quality, number and resolution of records in any county dataset. Improvements in recording equipment and sound analysis software, an increase in social media use and public engagement by NGOs, conservation organisations and universities, and the ongoing training of volunteers submitting their own records all contribute. There are numerous potential sources of species records in the county other than the surveys carried out in this study. These sources include bat care records, roost visits, surveys, and those submitted on an ad-hoc basis directly to record repositories.

However, an analysis of sources/recorders for the 2,199 species-specific records submitted since July 2017 shows that 80% derive directly from this study.

The findings of the study have demonstrated that the targeted surveying of a relatively small area (comprising just 2.9% of the area's woodland (Forestry Commission, 2018) and 0.9% of Birmingham and the Black Country's green belt (Natural England and CPRE, 2010)) has changed rarity assessments of all but two of the county's urban bat species. This indicates that there is a high degree of under-recording, with woodlands in the study area supporting a richer bat assemblage than previously assumed. Contributing factors to this under-recording may include recorder bias and the favouring of 'hot spots' and leaving the majority of the conurbation un-surveyed and its assemblage underestimated.

According to the EcoRecord criteria, none of the species within Birmingham and the Black Country now qualifies as 'Very Rare'. This is unlikely to represent an increase in abundance or distribution, but rather an increase in recording effort in a previously under-studied and under-valued environment.

Acknowledgments

The authors would like to thank Natural England for issuing research licences, the volunteers of the Birmingham and Black Country Bat Group for fieldwork assistance, EcoRecord for the provision of data, Elekon for Bat Explorer Pro software licence, the University of Wolverhampton ABWC Journal Club for support and to the Merrions Wood Trust, Walsall Council, Sutton Park Rangers, Wolverhampton Council and Dudley Zoological Gardens for access to sites.

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The State of Herefordshire Bats
Producing the Herefordshire Bat Atlas - 2014 to 2020

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Introduction

Herefordshire is situated in the West Midlands and is bordered by Shropshire to the north, Worcestershire to the east, Gloucestershire to the south-east and Wales (Monmouthshire and Powys) to the west. Herefordshire has the fourth lowest population density in England with an estimated population of 192,800 (2019), a quarter of the population being aged 65 or over. Approximately 95% of the county is predominantly rural with farming practices including forestry, dairy, poultry and beef farming and Herefordshire is famous for its apple and pear orchards, potatoes, strawberries and hops. There is a strong tendency towards intensive farming with consequent adverse effects on the local natural environment.

Even though Herefordshire's land is heavily managed there are some prime habitats within the county, including the famous River Wye. The Wye rises in the mountains of mid-Wales and flows south for about 150 miles, becoming part of the border between Wales and England before meeting the River Severn at Chepstow. It meanders for 45 miles through the Wye Valley Area of Outstanding Natural Beauty, from just south of Hereford down to Chepstow.

Other prime habitats include eight key rivers, a National Nature Reserve (NNR), Special Areas of Conservation (SAC), specifically the River Wye, and 24 Sites of Special Scientific Interest (SSSI). Small areas of both the Malvern Hills and the Wye Valley Areas of Outstanding Natural Beauty (AONB) are also located in Herefordshire. However tree coverage is generally considered to be low in the county and amounts only to around 15%.

Herefordshire is known to be rich in bat species and 15 of the 17 UK breeding species have been recorded in the county. In addition, a 16th species, the cryptic Alcaethoe bat *Myotis alcathoe*, new to science in 2001 and only confirmed in Britain in 2009, has been recorded from DNA analysis of a dropping collected near Worcester and so the species is also likely to be present in Herefordshire. Thus only one of the known British breeding species, the grey long-eared bat *Plecotus austriacus* – at the very limit of its European range in the southern counties of England – is likely to be absent from Herefordshire.

Table 1: The bat species of Herefordshire.

Scientific Name	Common Name	Abbreviated Name
<i>Barbastella barbastellus</i>	Barbastelle	B.bar
<i>Eptesicus serotinus</i>	Serotine	E.ser
<i>Myotis alcathoe</i>	Alcathoe bat	M.alc
<i>Myotis bechsteinii</i>	Bechstein's bat	M.bec
<i>Myotis brandtii</i>	Brandt's bat	M.bra
<i>Myotis daubentonii</i>	Daubenton's bat	M.dau
<i>Myotis mystacinus</i>	Whiskered bat	M.mys
<i>Myotis nattereri</i>	Natterer's bat	M.nat
<i>Myotis species</i>	<i>Myotis species</i>	Myo.spp

Scientific Name	Common Name	Abbreviated Name
<i>Nyctalus leisleri</i>	Leisler's bat	N.lei
<i>Nyctalus noctula</i>	Noctule	N.noc
<i>Nyctalus species</i>	<i>Nyctalus</i> species	Nyt.spp
<i>Pipistrellus nathusii</i>	Nathusius' pipistrelle	P.nat
<i>Pipistrellus pipistrellus</i>	Common pipistrelle	P.pip
<i>Pipistrellus pygmaeus</i>	Soprano pipistrelle	P.pyg
<i>Plecotus auritus</i>	Brown long-eared bat	P.aur
<i>Rhinolophus ferrumequinum</i>	Greater horseshoe bat	R.fer
<i>Rhinolophus hipposideros</i>	Lesser horseshoe bat	R.hip

Baseline Bat Atlas

In 2014, following a meeting of interested parties held at the Herefordshire Biological Records Centre (HBRC), it was decided that an attempt should be made to produce a county mammal atlas to cover the first two decades of the millennium. Atlases of the six mammalian orders were to be prepared individually and in June 2016 the present authors (DF and DL) produced the first of these - a baseline atlas for the Chiroptera, compiled from records available up to the end of 2015, to inform the existing state of bat records in Herefordshire. Distribution maps were produced for individual bat species at a resolution of 1km (based on Ordnance Survey 'monad' grid squares). The main maps showed the distribution of records post-millennium (2000-2015) with earlier records (1960-2000) mapped separately, for comparison.

At that time a total of 12,406 records were available from HBRC and a further 1,144 records were obtained from the National Biodiversity Network (NBN) – a grand total of 13,850 records. Of these 12,746 were dated 2000-2015 with only 1,104 (8%) from the period 1960 to 2000.

The bulk of HBRC bat records originate from commercial ecological surveys, largely abstracted from planning application documents by record centre staff, and so are heavily biased towards agricultural and domestic properties, with little coverage of woodlands, water features or churches, which are so important for bat species. Since the Church of England faculty system is independent of county planning control, ecological surveys of church premises do not come readily into the public domain.

Records were generally of good quality with widespread coverage of species that are expected to be common and are easily identified. However other species are not so easily identified, either by bat detector or in the hand, or are more likely to occur in woodlands or around water bodies where records are sparse, and it is not clear whether small numbers of records imply that such species are rare or merely under recorded. Species difficult to identify by bat detector are especially likely to be under-recorded – in particular 45% of *Myotis* records from 2000-2015 were identified only to genus. Also, nearly 10% of records from the *Nyctalus/Eptesicus* group were not identified to species and more than 90% of the remainder recorded as noctule, with few records of either serotine or Leisler's bat. This led us to wonder whether these two species also may have been under-recorded.

Towards the Millennium Atlas

It became clear from the baseline atlas that there were systematic biases and uncertainties in the data and that it was likely that these would persist in any future contributed records. Consequently, it was decided that we should take action to attempt to ‘fill in the gaps’. Since 2013 we had been conducting a study comparing the biodiversity of bat species in managed plantations with biodiversity in deciduous and ancient woodlands. This study was proving very productive and highlighted the synergy of combining trapping techniques and the deployment of static detectors. However a separate project licence had to be obtained from Natural England (NE) for every woodland we wished to survey, so initially only a small number of sites – principally Forestry Commission sites – had been selected for detailed study.

A project plan was drawn up specifically for work towards the bat atlas – to complement the ongoing woodland bat project - and a single licence was obtained from NE permitting us to trap anywhere in Herefordshire for these purposes and additionally permitting the use of marking, ringing and radio-tagging. This has allowed us to extend survey effort for uncommon and rare bats to a wider range of woodlands and non-woodlands sites such as waterbodies, orchards, grassland habitats, parkland and suspected swarming sites at disused railway tunnels.

Local Projects

Between 2014 and the completion of the atlas in 2020, data was contributed from a variety of local projects as follows:

- Woodland Bat Project
- Herefordshire Bat Atlas Project (targeting non-woodland sites)
- Bats and Roadside Mammals project (Driven Detector Transects)
- Bats and Swifts in Churches Project
- Bat Box Monitoring
- NBMP monitoring and Natural England Volunteer Bat Roost Visits (VBRV)
- Bat Care
- Other *ad hoc* surveys

Woodland Bat Project

The Woodland Bat Project was our first trapping project – it commenced in 2013 and is ongoing. The initial aim was a comparison of species diversity in managed plantations and ancient woodlands - particularly the effects of varying proportions of conifer. Initial efforts were mainly concentrated in a limited number of Forestry Commission sites; however since obtaining a county-wide project licence we have been able to extend coverage to a wider range of private woodlands and Wildlife Trust reserves and hence generated records over a wide area of Herefordshire.

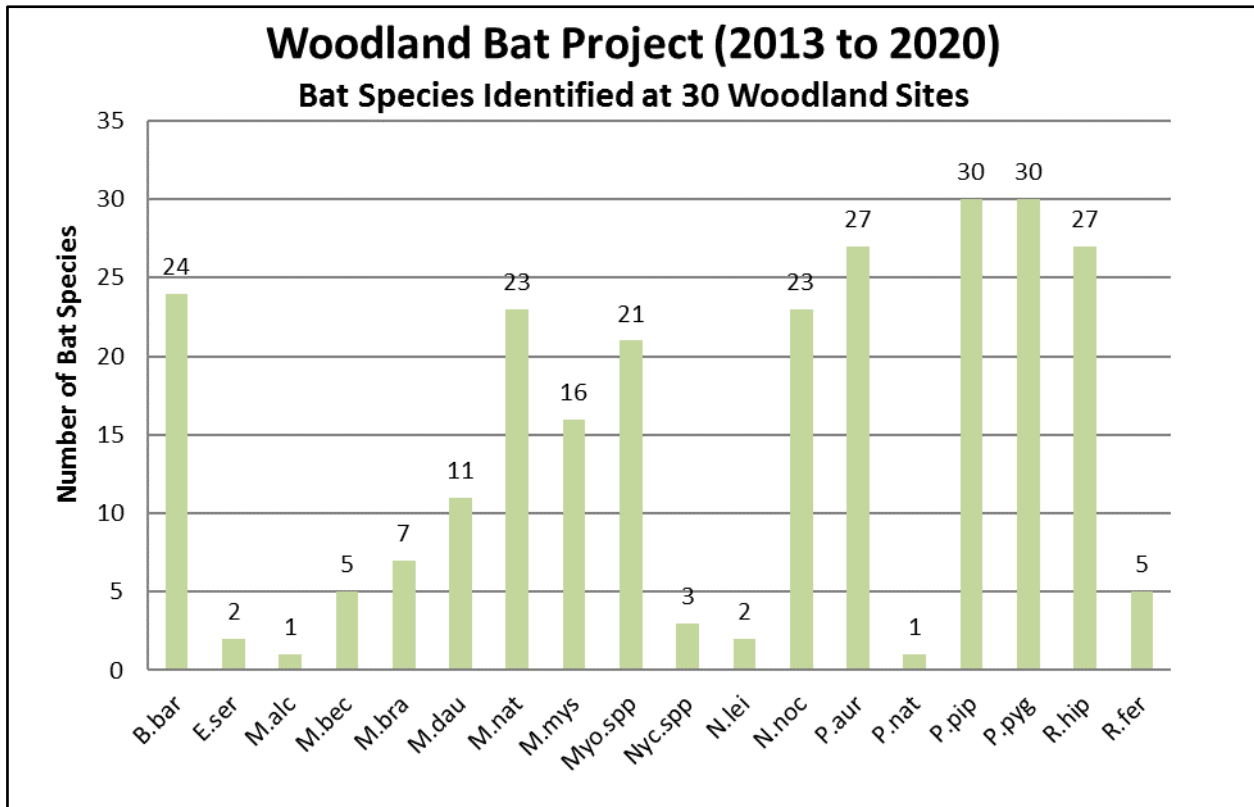


Figure 1: Bat diversity at 30 woodland sites in Herefordshire. Included are bat records that are not identified to species (*Myotis* and *Nyctalus*). See Table 1 for key to species abbreviations.

In order to maximize the recording effort, surveys utilize a combination of bat detector and trapping techniques. Detectors provide a broad picture of bat activity and valuable information about the times of appearance whilst trapping permits more accurate species identification and assessment of age, condition and breeding status of individual animals. Automatic recording detectors are placed around the trapping sites for later analysis of the calls and bats are caught using mist nets – including an 8m high canopy net system – and harp traps. Acoustic lures, playing recordings of ultrasonic bat social calls, are also used to attract bats that forage at low densities or high in the canopy and that would otherwise have a low probability of being trapped.

Overall, 72 trapping surveys have been carried out in a total of 30 woodland sites and nearly 600 bats were caught. Figure 1 shows the species diversity recorded at these sites. It was encouraging that barbastelles were recorded in 80% of woodlands surveyed – particularly since our original project plan was criticized by NE on the grounds that we would be unlikely to catch barbastelles at such a high altitude!



Figure 2: Barbastelles were recorded at 24 of 30 woodlands and nine of 18 non-woodland sites.

Herefordshire Bat Atlas Project (non-woodland habitats)

With the extension of our licence to cover the entire county we were able to extend our trapping surveys to include a wider range of habitats, including non-woodland waterbodies, orchards, grassland habitats, parklands and disused railway tunnels. The same protocols were used as in the woodland project and a further 22 surveys were carried out at 18 sites, generating 301 additional records. The species diversity at these sites is shown in Figure 4. Once again, the incidence of barbastelles was very much higher than was expected – the species being recorded at 50% of these sites.



Figure 3: Harp trap set at a non-woodland water body.

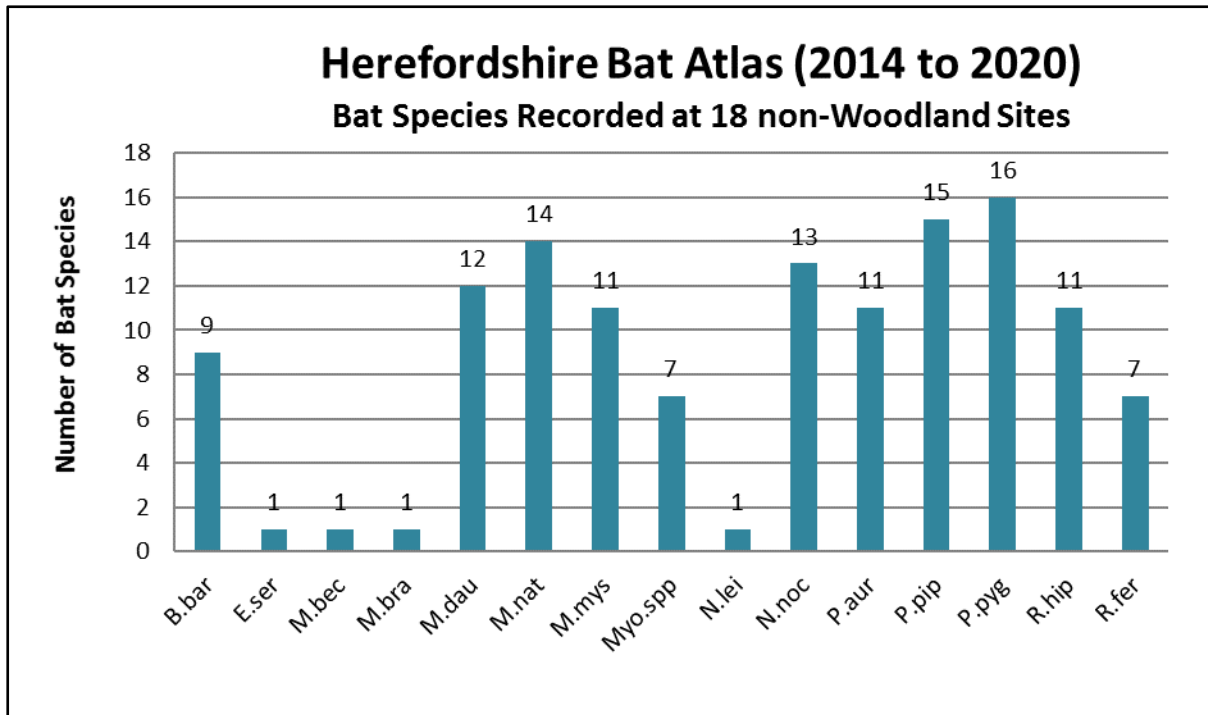


Figure 4: Bat diversity at 18 non-woodland sites (including *Myotis* bats not identified to species). See Table 1 for key to species abbreviations.

Bats and Roadside Mammals Project

The Bats and Roadside Mammals transect project was developed in 2015 in order to gather mammal records rapidly and economically from as many additional grid squares as possible. The protocol was loosely based upon the original Bat Conservation Trust (BCT)/Mammals Trust project (2005-2008) and pairs of volunteers were asked to drive a transect of their own choice at 15mph whilst recording georeferenced bat calls using an Anabat Express bat detector with built-in GPS receiver (Figure 5).



Figure 5: Road Transect survey setup - Anabat Express with window mounted microphone.

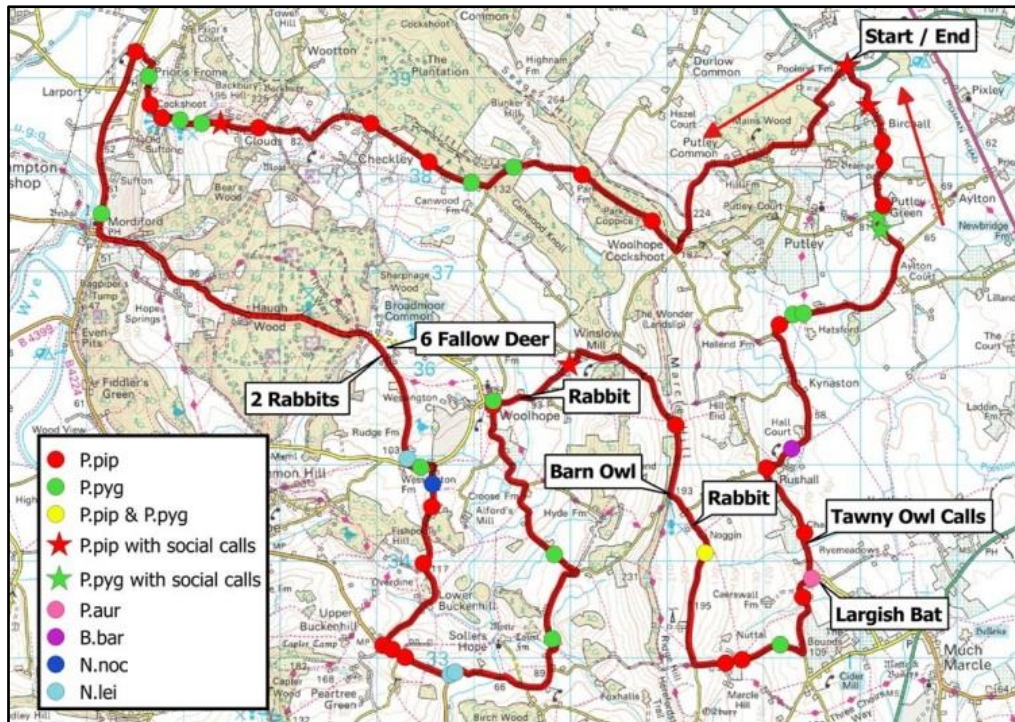


Figure 6: Typical Driven Transect Survey result (39km). See Table 1 for key to species abbreviations.

During each transect the co-driver recorded any incidental observations of other night-time wildlife. Figure 6 shows the results of a typical transect survey. Between 2015 and 2017 members of Herefordshire Mammal Group drove (or cycled) 33 transects with lengths between 25 and 55km, covering a total of 1115km of Herefordshire by-roads. In addition, volunteers were encouraged to deploy the detectors in their gardens for one or two nights before passing on the equipment to the next team and a total of 27 garden surveys were carried out at 12 locations. Together with walking transects carried out in larger woodlands, a total of 2,752 records were generated.

Bats and Swifts in Churches Project

In 2014 we began a project to assess the level of bat usage in Herefordshire's Church of England (C of E) churches. The aim was to identify churches where bats were causing, or may be likely to cause, conflict and to offer advice and support where appropriate. Swifts were included in the scheme as 'honorary bats' since they face exactly the same challenges to their nest sites. Initial brief visits are made by volunteers to assess evidence for signs of bat use and/or roosting potential and where there is evidence of significant bat activity a full internal and external inspection is carried out, together with an emergence survey where appropriate. To date, with the assistance of volunteers from Herefordshire Mammal Group and Herefordshire Ornithological Club (HOC), basic surveys have been carried out at 108 out of the 247 Herefordshire C of E churches of which only 18 showed no signs of bat activity. Encouragingly the presence of bats is usually tolerated and so far there has only been serious conflict in four churches (the main culprits being Natterer's bats). However close collaboration with the Diocese of Hereford and church architects has led to a large increase in requests for a Natural England Volunteer Bat Roost Visit and where there is significant evidence of bat usage an emergence survey is always included in these visits. In total, full inspections and activity surveys have been carried out at 33 churches.

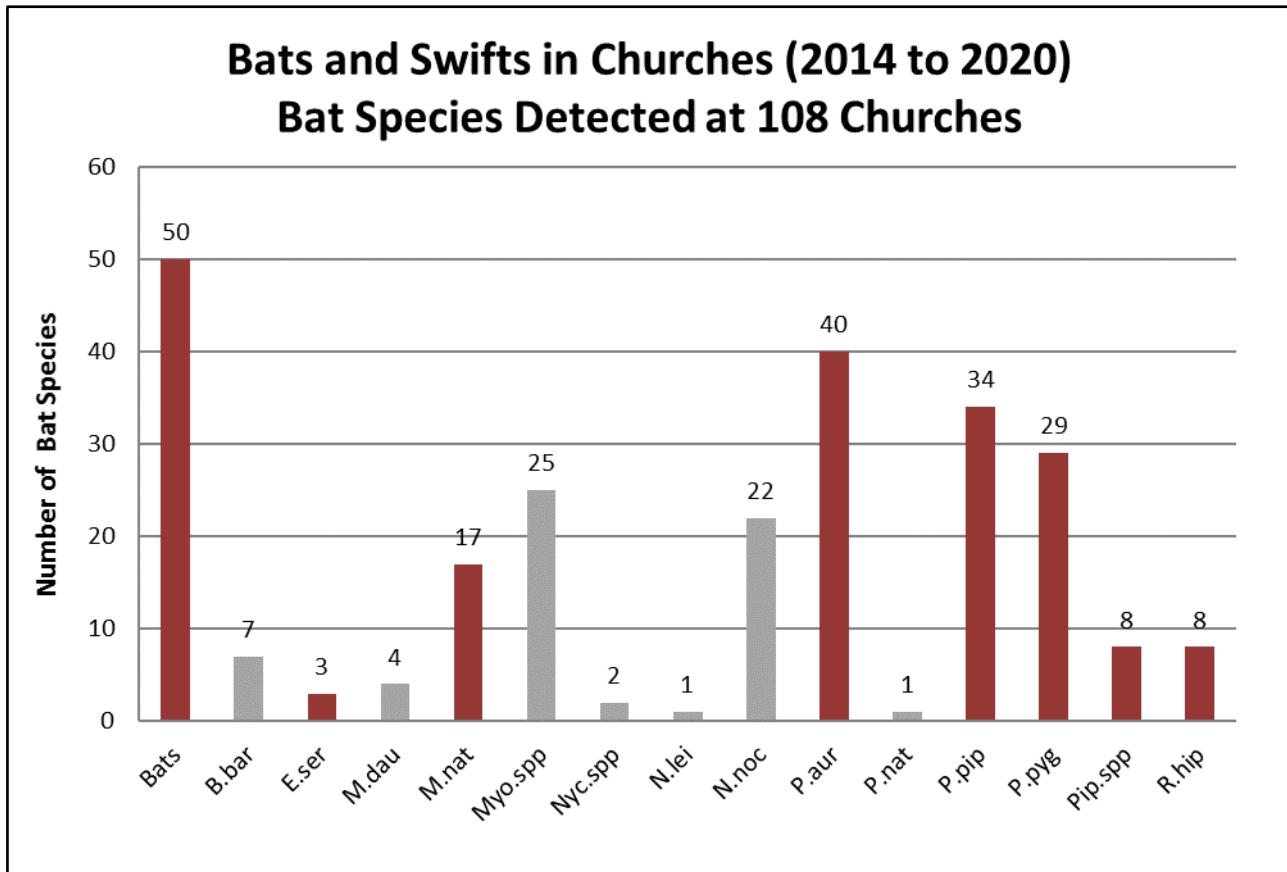


Figure 7: The graph shows the bat diversity at 108 Herefordshire churches. Bats were recorded at a total of 83% of churches surveyed. See Table 1 for key to species abbreviations. Red columns: Species using church buildings (externally and internally). Grey columns: Species recorded only during night-time bat activity surveys.

A grant of £4,900 was awarded to the project in 2015 by the Heritage Lottery Fund (HLF), providing bat and swift boxes and educational material for a total of 11 churches. Subsequent monitoring of these boxes has shown evidence of bat usage at seven of these churches – including boxes installed inside towers. Whilst not its primary aim, the project has generated a total of 297 additional bat records. Figure 7 shows the species diversity of bats both using the church buildings themselves and foraging in the vicinity of the buildings.



Figure 8: Brown long-eared bats were recorded in 40 of a total of 108 churches surveyed.

Bat Box Monitoring



Figure 9: The authors monitoring bat boxes in a Herefordshire Wildlife Trust (HWT) reserve.

Bat boxes are monitored at ten woodland sites in the county. Of these nine have been *in situ* for more than ten years and mainly comprise Schwegler 2FN and 1FF boxes together with a smaller number of 1FS colony boxes. However following receipt of our trapping survey report, the Forestry Commission funded an installation of 65 bat boxes in one of their woodlands near Ledbury. This has given us the opportunity to compare various other box designs. Unfortunately, bat box uptake at this site has so far been rather disappointing, despite consistently high trapping success in the woodland.

Boxes are monitored at least twice between April and October and between 2014 and 2019 more than 150 box checks have been carried out generating 479 records of seven bat species. Table 2 shows the species diversity of bats across the bat box sites.

We also have two ongoing ringing projects: one following a maternity colony of Bechstein's bats in a private woodland and the other a maternity colony of brown long-eared bats in a Wildlife Trust reserve.



Figure 10: Natterer's bat maternity colony routinely encountered at one of HWT's nature reserves.

Table 2: Bat species found using bat boxes at ten Herefordshire sites. Both brown long-eared bats and soprano pipistrelles have been recorded at every site.

Scientific Name	Common Name	Bat Box Sites
<i>Pipistrellus pygmaeus</i>	Soprano pipistrelle	10/10
<i>Plecotus auritus</i>	Brown long-eared bat	10/10
<i>Nyctalus noctula</i>	Noctule	6/10
<i>Pipistrellus pipistrellus</i>	Common pipistrelle	3/10
<i>Myotis nattereri</i>	Natterer's bat	2/10
<i>Barbastella barbastellus</i>	Barbastelle	2/10
<i>Myotis bechsteinii</i>	Bechstein's bat	1/10

Ad hoc Surveys, Bat Care, NBMP Surveys and Natural England Roost Visits

A total of 87 records were collected from other bat activities, such as bat care, Natural England Volunteer Bat Roost Visits, the National Bat Monitoring Programme (NBMP) and other *ad hoc* surveys.

Results

Overall, between 2014 and 2020 a total of 543 surveys of all types were carried out – generating 4,986 bat records (Figures 11 and 12).

The most productive surveys by far, in terms of the number of records generated, were the Road Transects, which were very popular amongst volunteers. Together with the associated garden surveys these contributed a total of 2,752 records (more than half of our total), including Nathusius' pipistrelle, barbastelle, serotine and greater horseshoe bat, which are amongst the county's least recorded species.

The Woodland Bat project raised a great level of interest at the start but local volunteer effort rapidly dwindled due to the late nights/early mornings and long periods of waiting around in the dark! However we were fortunate to have the willing assistance of experienced bat workers from outside the county. These surveys produced the highest diversity of species – all 15 of the species known in the county were either caught or recorded. Barbastelles were caught in 80% of the woodlands and Bechstein's bats at five sites out of 30.

The complementary Bat Atlas Project focused on non-woodland sites, including water bodies, railway tunnels, parkland, orchards, commons etc. A total of 14 species were either caught or recorded, including barbastelle at 50% and greater horseshoe bat at 38% of sites.

The churches project delivered the most widespread records - covering 108 of the 247 Herefordshire churches. Since many of the initial surveys were carried out by less experienced volunteers much of the data was simply bat presence/absence. However this was still very valuable information and led to the targeting of more rigorous surveys. The most common species using the interior of church buildings was the brown long-eared bat, with Natterer's bat the only species causing real conflict. There has been significant evidence of occupation of bat boxes (installed with HLF support) in some churches, particularly in the towers.

Bat box monitoring has produced consistent data for local bat populations, with our two ringing studies additionally producing a valuable history of individual colonies of bats. However bat box schemes alone do not provide an accurate picture of bat usage in a wood. This is nicely illustrated by the results whilst trapping at one of our bat box sites in woodland near Ledbury, where the boxes had been *in situ* for more than ten years. During all this time boxes had only ever been occupied by soprano pipistrelles and the occasional brown long-eared bat. However combined trapping and detector surveys revealed that ten species of bat were using the wood – including whiskered bats, Brandt's bats, Natterer's bats and Bechstein's bats.

The additional information obtained from combined trapping and static detector surveys is invaluable – especially for informing forestry management practice. A good example is Forestry Commission woodland where we carried out several trapping surveys close to a compartment that was up for sale for firewood. Detector recordings revealed very early appearance of three species of which trapped individuals showed evidence of recent lactating. This suggested nearby maternity roosts and, on the evidence of our survey report, the compartment was withdrawn from sale and the Forestry Commission funded the installation of an extensive bat box scheme (together with dormouse boxes).

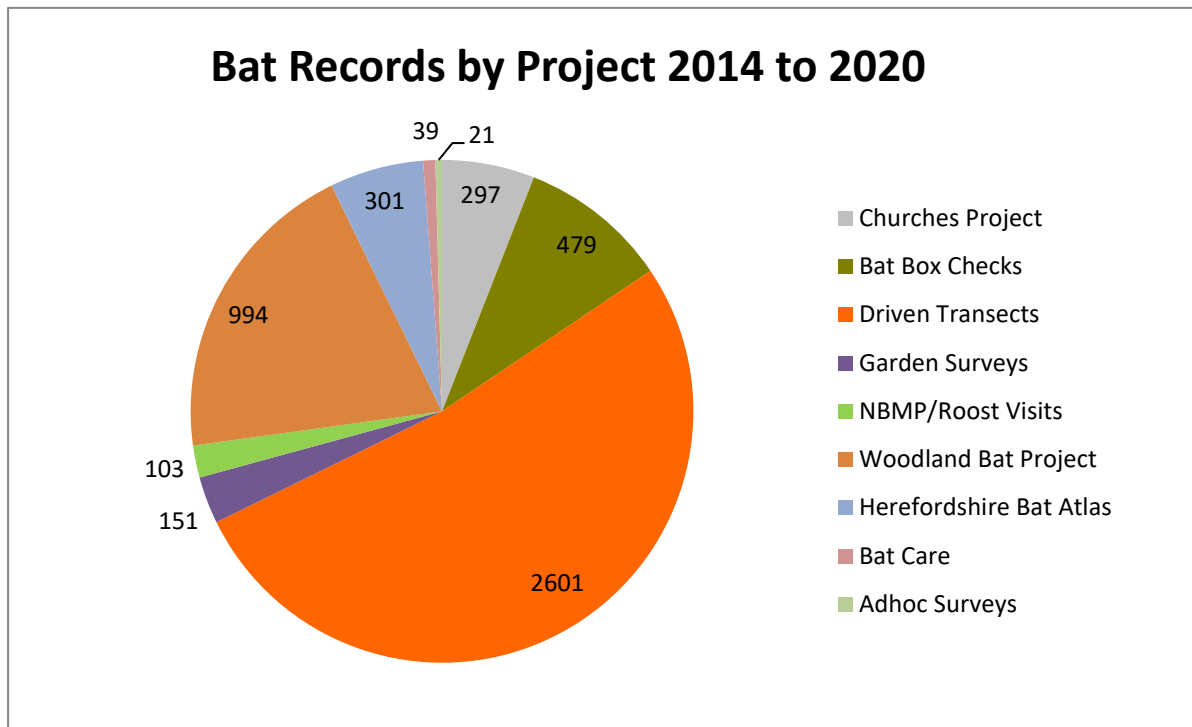


Figure 11: Bat records collected from each local project from 2014 to 2020. (Total records: 4,986).

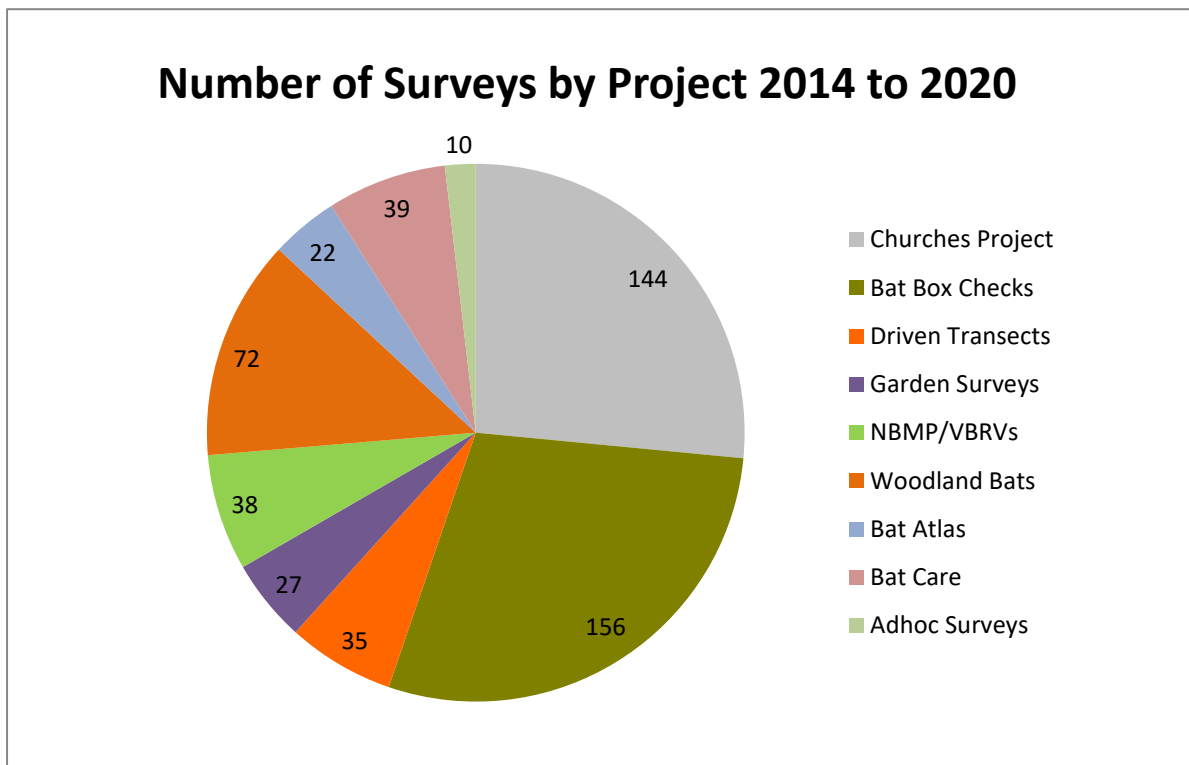


Figure 12: Bat surveys carried out by local volunteers from 2014 to 2020. (Total surveys: 543).

The species diversity recorded by each of the local projects is illustrated in Figure 13.

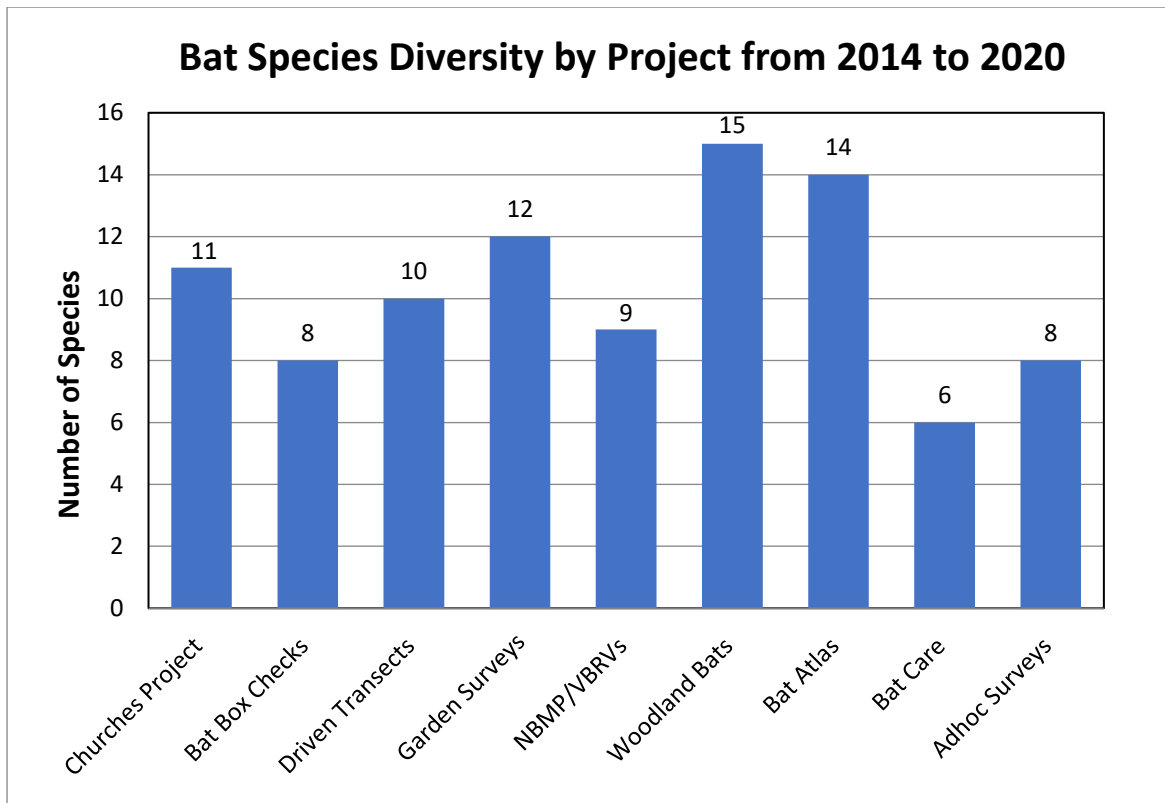


Figure 13: Number of bat species recorded by each project.

2020 Bat Atlas

The Herefordshire Bat Atlas has recently been updated to cover the target period of 21 years from 2000 to 2020 and the latest version is available to download from the BCT website at <https://bit.ly/2OAxkAA>.

A total of 23,410 bat records was available from this period - from the local record centre (HBRC), together with additional records available from the NBN - representing a very large increase of more than 80% over the number available for the 2015 baseline atlas. At the time of the preparation of the first edition the HBRC was recovering from a financial crisis which had almost led to its closure. Consequently, this had led to a backlog in the processing of new records so a proportion of these 'new' records date from between 2000 and 2015. Figure 14 shows the distribution of records of all bats recorded to species at resolution of 1km or better in the years from 2000 to 2020 as dark blue squares. Additional historical records dating back to 1960 are shown in light blue. A total of 1341 × 1km² grid squares ('monads') contain bat records and since the total area of Herefordshire is 2181km² this represents coverage of 62% of the county. (Note that atlas maps indicate recorded presence only – no records of absence are available and the distribution maps do not imply abundance).

The total numbers of available records per species from between 2000 and 2020 are shown in Figure 15 and Figure 16 shows the distribution of records in terms of the number of monads containing records for each species. Note the logarithmic scales used in these two figures.

The extent of bat records from local survey efforts between 2014 and 2020 is indicated in Figure 14 by yellow dots. Fairly good coverage has been achieved over most of the county, apart from the more remote regions to the north-west, towards the borders with Wales and Shropshire. A total of 740 monads contain bat records from these local surveys – representing a third of the area of Herefordshire and covering 55% of the overall total of ‘occupied’ squares. Records from our local projects from between 2014 and 2020 account for 20% of all the bat records dating from the beginning of 2000 held by HBRC.

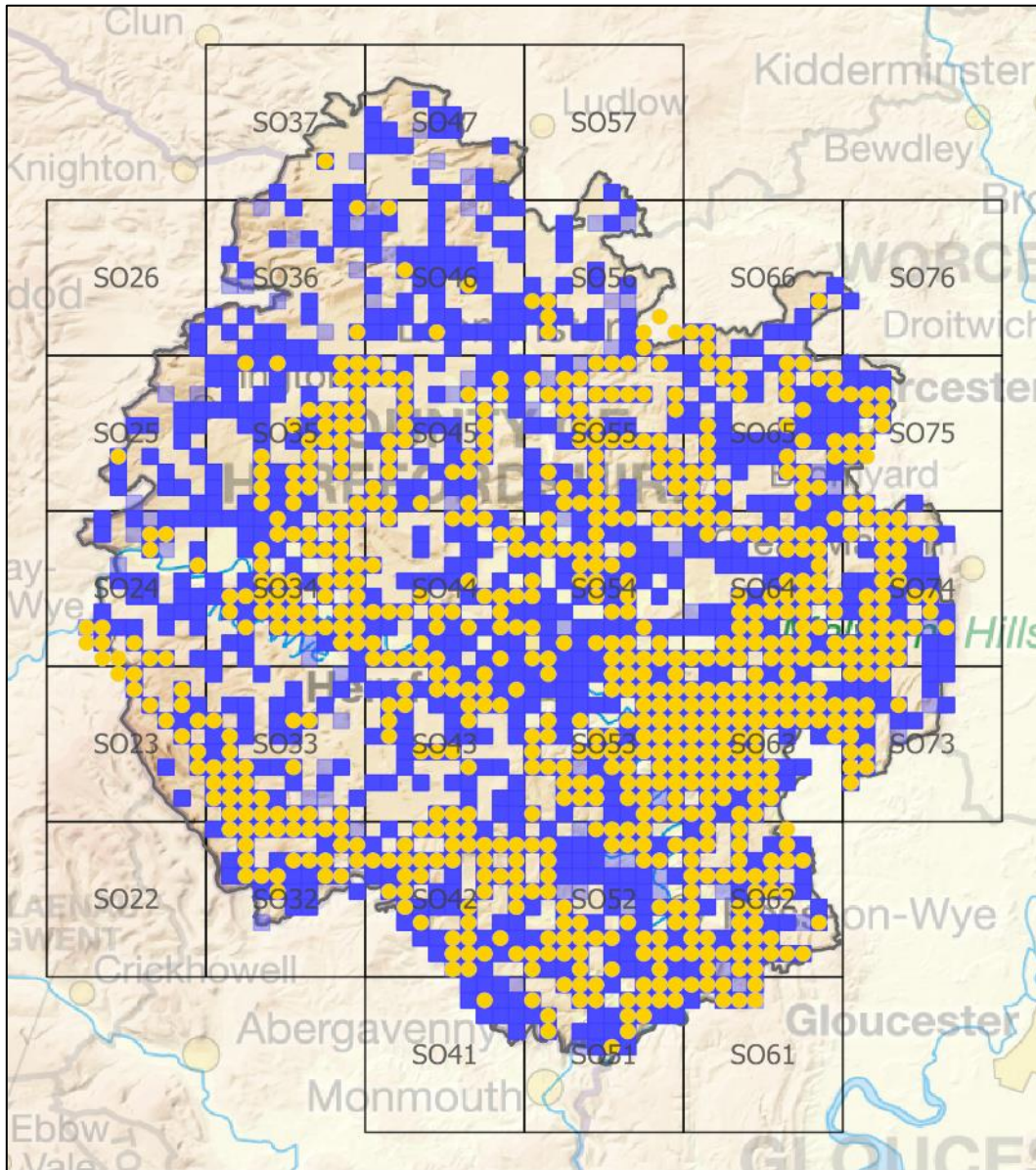


Figure 14: Distribution of all bat records from 2000 to 2020 (dark blue squares). Light blue squares indicate additional records from between 1960 and 1999 and yellow circles indicate distribution of records collected from local bat projects from 2014 to 2020. Note that the map represents bat presence, not abundance.

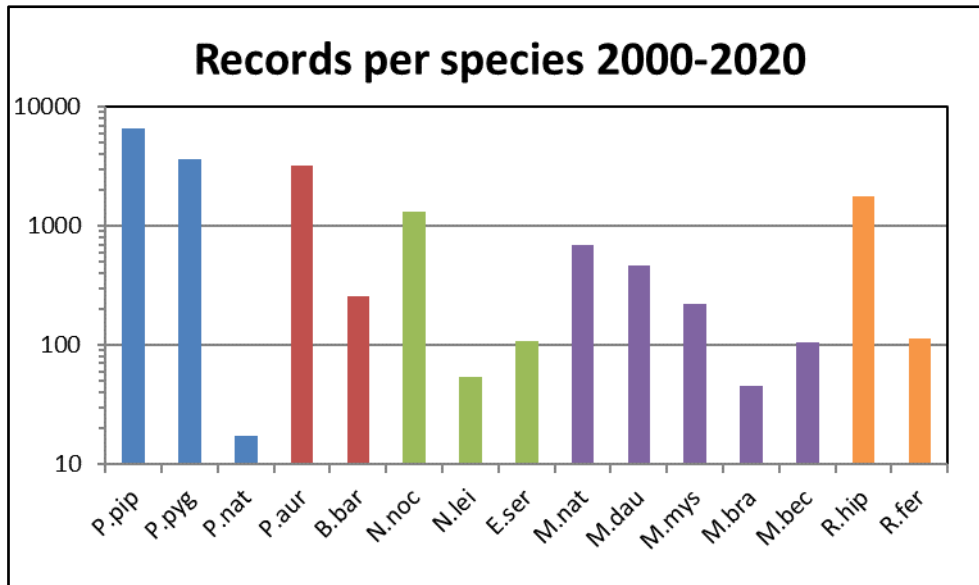


Figure 15: Total available records per species used for the 2000-2020 bat atlas. See Table 1 for key to species abbreviations.

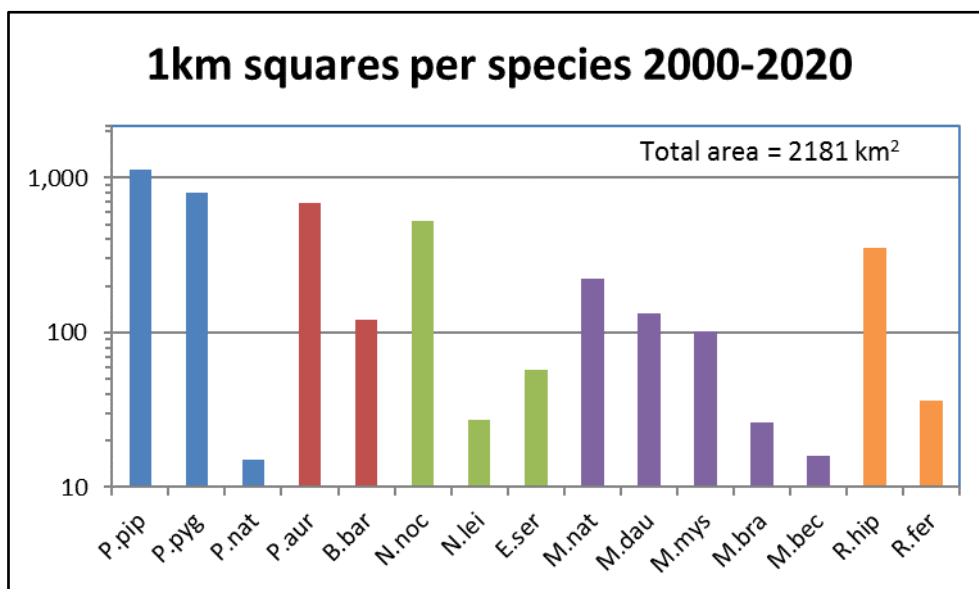


Figure 16: Number of monad squares with records for each species (total county area = 2181km²). See Table 1 for key to species abbreviations.

Discussion

A common metric of the quality of a taxonomic atlas is the 'nettle test' i.e. the extent of coverage of a common taxon that should be expected to occur almost everywhere. To this end, Figure 17 shows the distribution map of common pipistrelle records from the latest version of the bat atlas. Whilst the most commonly recorded species, it has been recorded in only about half the monad squares and whilst present across the whole county the distribution is somewhat patchy, with concentrations in the most highly populated areas and few records in remote areas such as the north of the county and around the Golden Valley, in the south-west.

This is not unexpected given that such a large proportion of records has originated from commercial pre-development surveys and so will be biased towards agricultural and domestic properties. This has to be borne in mind when interpreting the distribution maps of less common species – particularly those favouring habitats such as woodland and water bodies where commercial surveys are far less likely to occur. Since local projects have specifically targeted such habitats we should be in a position to comment on these results.

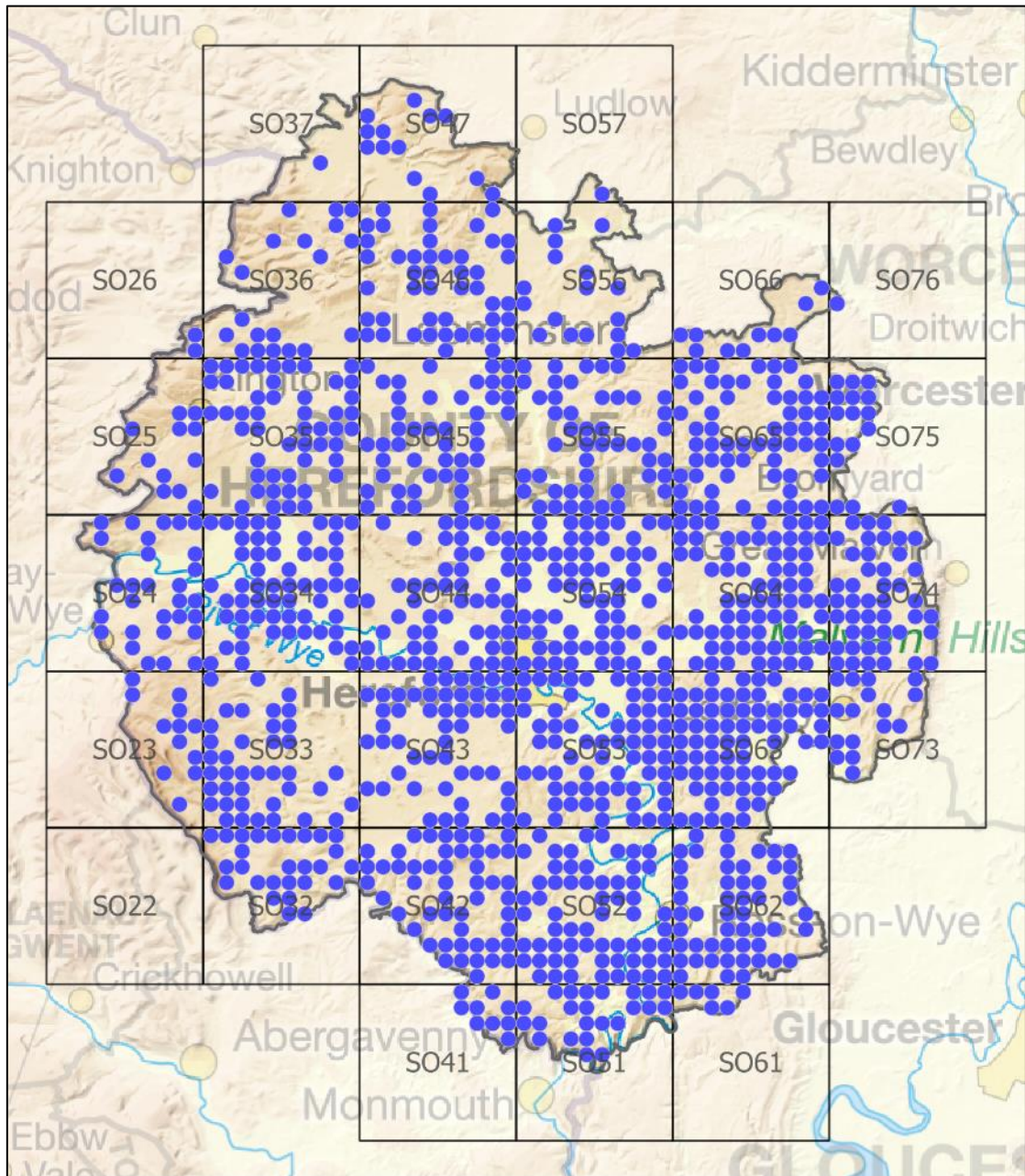


Figure 17: The 'Nettle Test' - distribution of common pipistrelle records 2000-2020.

Individual distribution maps of all species can be viewed in the latest edition of the atlas, available via the BCT website at the address below.

Pipistrellus

Common and soprano pipistrelles both show a fairly uniform distribution of records across the county. Common pipistrelle is recorded in 52% of square in comparison with 37% for soprano pipistrelle. However the total number of common pipistrelle records is greater than that of soprano pipistrelle by around 80%. A similar difference (74%) is reflected in the numbers of records from local projects.

Nathusius' pipistrelle is rarely recorded, with records in only 15 grid squares; however these are widely distributed around the county. We have made strenuous efforts to catch this species, particularly around water bodies, including routinely using an acoustic lure playing Nathusius' pipistrelle social calls, so far without success and the species has only been recorded twice in any of our detector surveys. Thus it appears that this species is genuinely rare in Herefordshire.

Plecotus

The *Plecotus* species bat is the third most commonly recorded species in the county both in terms of number of records and distribution, with records covering 31% of grid squares. However it is also one of the most common bats to be found roosting inside domestic properties and so will especially be likely to be recorded during pre-development surveys. It is interesting to note that only 25% of *Plecotus* records are identified to species, which is further evidence that the majority of recorders are experienced bat workers who are fully aware of the difficulties of distinguishing cryptic species. However it is safe to assume that these records will all be brown long-eared bat since Herefordshire is so far outside the known range of the grey long-eared bat.

Barbastelle

Barbastelle records are distributed fairly uniformly but sparsely across the county with records in only 6% of grid squares. However we have caught barbastelles in 80% of our woodland sites and in 50% of our other trapping sites which suggests that this species may be seriously under recorded.

Myotis

Identification of bats in the genus *Myotis* is a particular problem since the form of their echolocation calls tends to overlap between species and so they are very difficult to distinguish from one another. Whilst 'auto identification' analysis software is constantly improving this remains a highly contentious subject. Consequently only 52% of available records were identified to species and unidentified *Myotis* have been recorded in 25% of grid squares in the county.

The most recorded *Myotis* species are Natterer's bat and Daubenton's bat, recorded in 10% and 6% of grid squares respectively, both distributed uniformly across the county. However these spatial abundances are both very much smaller than that of unidentified *Myotis* and so it is likely that either or both of these species may be under-recorded. In contrast Natterer's bat was caught in 77% of our woodland and 78% of non-woodland trapping sites and Daubenton's bat in 37% of woodlands and 67% of others. (The higher incidence of Daubenton's bat in non-woodland sites is consistent with the increased number of water

features). In addition Natterer's bats were recorded using 16% of the 108 churches we surveyed.

The small *Myotis* species are even more of a problem since these are cryptic species that are difficult to identify even in the hand. There are small numbers of records claiming to be whiskered bat or Brandt's bat, scattered uniformly across the county, but these account for only 5% and 1% of grid squares respectively, which is negligible in comparison with the wide distribution of unidentified *Myotis* records. However trapping surveys have revealed whiskered bat in over 50% of woodland and 60% of non-woodland sites. Brandt's bat proved to be somewhat less common and more of a woodland specialist – appearing in 23% of woodlands but only one non-woodland site. This suggests that both these species are probably much more common than the records would suggest.

The third small *Myotis* – the Alcahoie bat – is an enigma. Whilst there are no records of this bat in Herefordshire we did catch an animal at a site near Leominster whose appearance and biometrics seemed to be a perfect match for the species. Unfortunately the bat could not be persuaded to provide a dropping and without support from mitochondrial DNA analysis the record has to remain unconfirmed.

Finally, Bechstein's bat is another enigmatic species. It is generally thought to be a very rare species and there are only records from 16 × 1km grid squares, in clusters around the county. However calls are very quiet and difficult to record and easily overlooked. Bechstein's bats tend to roost in woodlands with a dense understorey in old woodpecker holes that are difficult to find, and they also tend to forage high in the canopy and so are difficult to catch without the use of an ultrasonic lure. However we have been monitoring a colony of Bechstein's bats for many years in private woodland near Malvern and have caught Bechstein's bats in five of our woodlands and one non-woodland trapping site as well as in several woodland sites close-by, in neighbouring Gloucestershire. Radio tracking of bats caught in the Woolhope dome and at Berrington Hall (near Leominster) has led us to five new maternity roosts. Our suspicion is that Bechstein's bat is probably more common in Herefordshire than the records would suggest – although localized in woodlands with suitable habitat.

'Big Bats'

The noctule is the fifth most commonly recorded bat in Herefordshire with records in 24% of 1km squares. Conversely Leisler's bat and serotine are amongst the least recorded with records covering only about 1% and 2.5% of grid squares respectively. Records of noctules and Leisler's bat are well distributed across the county whereas serotine records appear to be concentrated in the south-east quadrant, although with so few records it is difficult to assess whether this distribution is significant.

Noctules were commonly recorded in all our project work with very few records of Leisler's bat or serotine and all serotine records (from three trapping surveys plus a single bat using a church building) were all from the south-east of the county.

Horseshoe Bats

The lesser horseshoe bat is the fourth most commonly recorded bat in Herefordshire, with records in 16% of grid squares. Distribution is mainly concentrated in the southern half of the county although there are also clusters in the north and north-west, close to the borders with Wales and Shropshire. Lesser horseshoe bats were caught or recorded in 90% of our woodland and 60% of non-woodlands sites as well as using parts of eight church buildings. Several maternity roosts are monitored in the county as well as hibernacula in disused railway tunnels, basements and other underground sites. Clearly this species is abundant, particularly in the southern parts of Herefordshire - which is perhaps not surprising given the proximity to the Forest of Dean and Wye Valley Horseshoe Bat Special Area of Conservation!

In contrast, the greater horseshoe bat is much less commonly recorded with records mainly concentrated in the south of the county in the area of the Lower Wye, towards the Forest of Dean. So far records have only been reported in 36 × 1km squares, however there does appear to be a gradual migration of this species towards the north, with new records appearing close to Malvern, in the Woolhope Dome and as far north as Bromyard. We have records of greater horseshoes from 17% of our woodland and 40% of non-woodland sites and small numbers have been found hibernating in disused railway tunnels.

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Reference

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Harem roosts of soprano pipistrelles *Pipistrellus pygmaeus* in north Shropshire. Patterns of assembly of females and males

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Introduction

This study arose out of a small Shropshire Bat Group project to monitor a group of bat boxes which had been deployed in 2004 around the wooded perimeter of a large working quarry in north Shropshire, close to the Welsh border. The working part of the quarry is the residue of an amalgamation of several older quarries, whose abandoned workings and waste have been colonised by regenerating, mainly broadleaf, woodland with some larch and other conifers. The quarried strata are mainly massive carboniferous limestone. The bat group was not involved in or consulted about the original deployment of bat boxes but was invited to monitor them subsequently. The boxes had been examined once in late November 2006 but not subsequently until we began to check them regularly from April 2012 (Phase 1 of this project). They were inspected twice in that year and then three times each year until 2019. In 2016, it was evident that some of the boxes which were used by groups of female soprano pipistrelles *Pipistrellus pygmaeus* and only one male were probably ‘harem roosts’, used for mating. In 2017 we began to fit rings to the bats (Phase 2) and sometimes radio transmitters. No boxes were inspected during 2020 because of coronavirus constraints. This paper is therefore a report of work in progress and is also a call for collaboration with other bat workers who may have relevant data.

Methods

The core team was myself, Eileen Bowen, Simon Cope and Nicola Wheeler. Simon is an experienced arborist and he and Nicola opened and inspected all the boxes, and retrieved and returned the bats, using a rope for security and to facilitate access where appropriate.

We all shared handling, ringing and attaching radio tags, under supervision at first if in training. We were assisted on many occasions by other members of Shropshire Bat Group, Montgomeryshire Bat Group and other bat groups.

The boxes were all Schwegler models, mostly types 2FN, 1FD or 1FF. These had all been attached to trees, at heights between three and five metres. These box types are well known, all are made of ‘woodcrete’. The 2FN is a simple cylindrical box with a rather large access opening. The 1FD is a similar shape but with a smaller bat access opening and a pair of internal ridged partitions attached to the front door, providing crevice-type habitat. The 1FF is a flat box with a door hinged at the bottom and open at the top. All three types can be opened allowing bats to be captured and examined. However, it is difficult to prevent bats escaping from the 1FF type when the door is opened. Additionally, one box of type 1FW, the large ‘hibernation’ box, had been attached to a low cliff and one type 1FQ had been attached to a small disused circular stone-built explosive store in woodland. We have never found bats in these latter two boxes and they will not be considered further.

We found that the boxes had been deployed mostly in groups of the same type. There were three groups of type 1FD boxes, two groups of 1FF boxes and a large group of 2FN boxes in

an elevated situation near the southern edge of the site. A single 2FN box had been placed between the most north-easterly pair of 1FD boxes (Figure 1).

In October 2012 one of the 2FN boxes was found to be destroyed and was replaced on a different tree nearby with a new box of type 1FD (number 85). This was done in an effort to augment the existing grouping of similar boxes, which we considered would make it difficult to discriminate between any apparent preferences for box type as against box location.

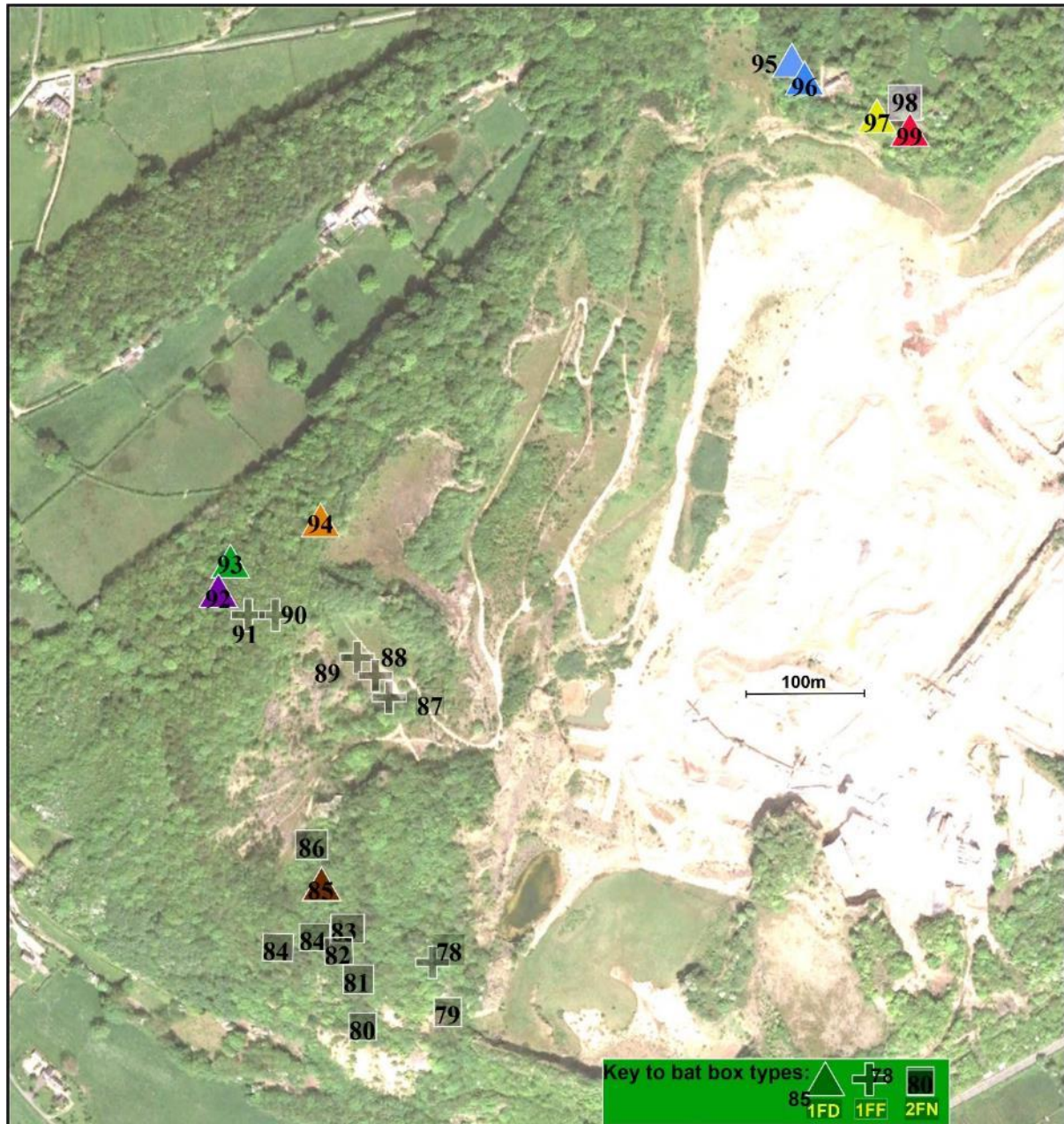


Figure 1: Locations, ring colour allocations and Schwegler models of the bat boxes (Google Maps, 2010).

Standard lipped open bat rings (Porzana) were used (24mm narrow, the size recommended for our target species). For colouring, they were cleaned and polished by tumbling, etched with dilute sodium hydroxide and then clamped against an aluminium or, later, titanium

anode and anodised in dilute sulphuric acid with an aluminium cathode. They were then dyed using a variety of dyes as used commercially for this purpose, following a suggestion by Geoff Billington. They were sealed by boiling for one hour in water. Different coloured rings were used for bats from each box. Rings were fitted to the right forearm of female bats and to the left forearm of male bats.

Radio transmitters were fitted to some bats in late April 2017 and 2018. These were from Holohil, type LB-2X, weighing 0.27g (12 day battery life) or sometimes 0.22g (seven day battery life). The transmitter weight was selected for each bat so as to be no more than 5% of the bat's own weight. Transmitters were attached with colostomy adhesive (Salts, Birmingham, UK) behind the shoulder after clipping a patch of fur. The bats were returned to their respective boxes after retaining for about ten minutes in a bag to allow the adhesive to set.

Colours were assigned mostly to individual 'harem' boxes, but an adjacent pair of 1FD boxes, which we had found to be less used than the others, shared a colour (blue). For ease of reference, I will refer to the boxes which were used as harems by the ring colour assigned to them. All of these were type 1FD. I will refer to bats with rings by the colour of their ring, or in one case, by the colour assigned to the box where it was ringed. I will refer to bats captured without a ring as 'new' bats. Unless stated otherwise, these were always then fitted with a ring of a colour appropriate to the box where they were captured. Bats captured in boxes which were not used as harem roosts, none of which were type 1FD, were fitted with plain, un-coloured rings. Only *Pipistrellus* bats were ringed. During Phase 1 of the study, wing vein patterns of each bat were photographed over a period of two years and were consistently of the soprano pipistrelle type (Dietz *et al.*, 2009). Identification was occasionally confirmed by sonograms of bats which flew from boxes after examination and return. Because we had encountered only soprano pipistrelles in the harem boxes during the earlier phase of this study, we did not subject the bats to intensive investigation to determine species. We consider that they were all soprano pipistrelles.

Results

Phase 1

In April and October of each year, many of the type 1FD boxes were occupied by groups of female soprano pipistrelles (Figure 2), sometimes with one male, especially in the autumn. We never found more than one male with the females (Figure 3). They used the same groups of boxes in spring as in autumn. On one occasion in July, we found two males in the same box, but this box was not one of the ones used by groups of females. Sometimes 1FF boxes were used by single *Pipistrellus* bats, and once by three females. The 2FN boxes were occasionally occupied by single soprano pipistrelles, but never by aggregates of females. They were also sometimes used by brown long-eared bats *Plecotus auritus*, especially during the summer. These will not be further referred to here.

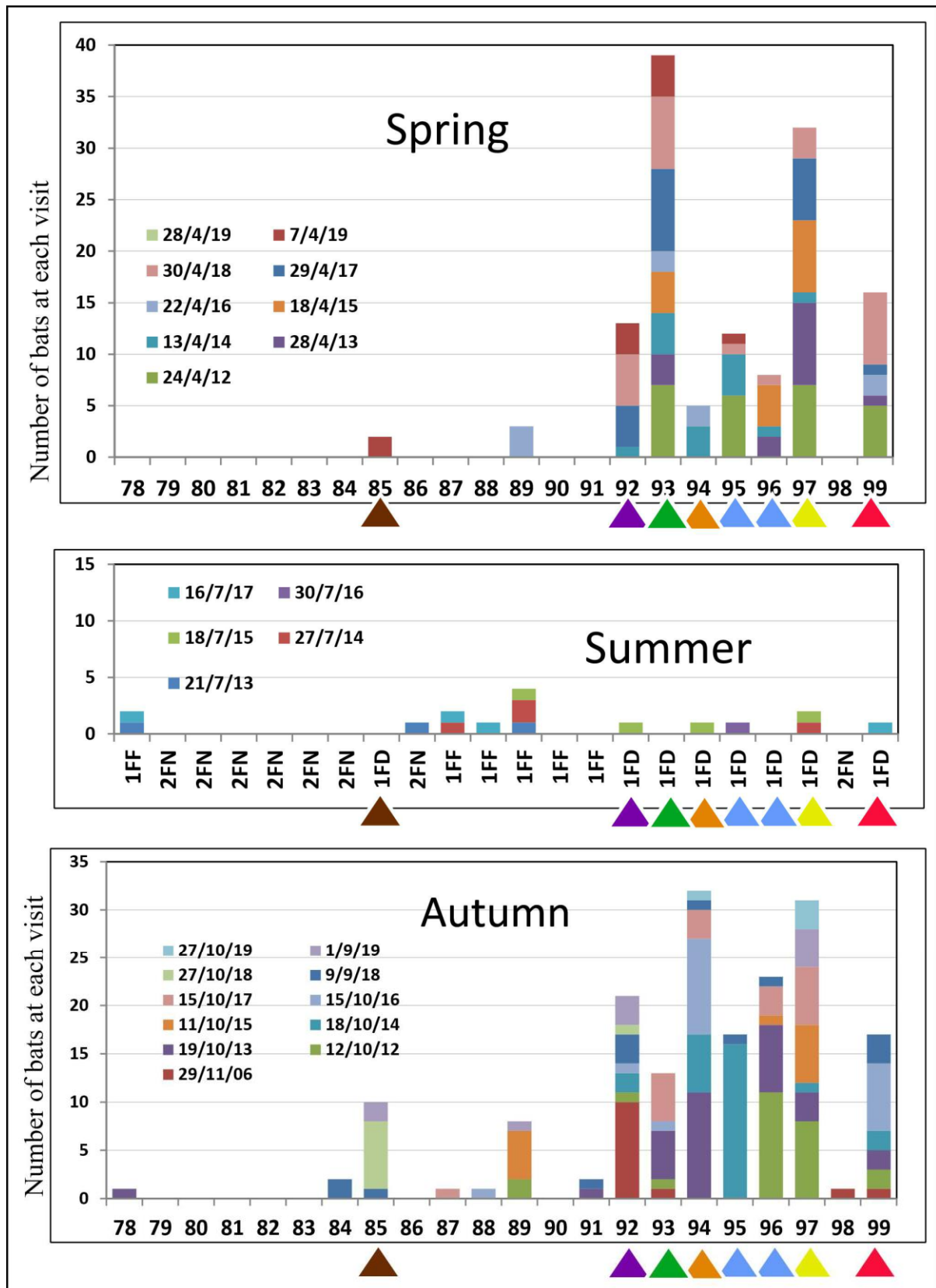


Figure 2: Cumulated soprano pipistrelle counts to 2019. Coloured segments of bars show numbers of bats at each visit. Triangles below show colours assigned to boxes and ringed bats. Box types are shown in the summer panel, corresponding box identification numbers in the others. The colours are as referred to under Methods.

Males were encountered more frequently in the autumn than in the spring, but any such seasonal difference was much less marked for females (Figure 3). The smaller numbers of both sexes during the summer inspections is marked but is exaggerated in this figure because we did not inspect in summer after 2017.

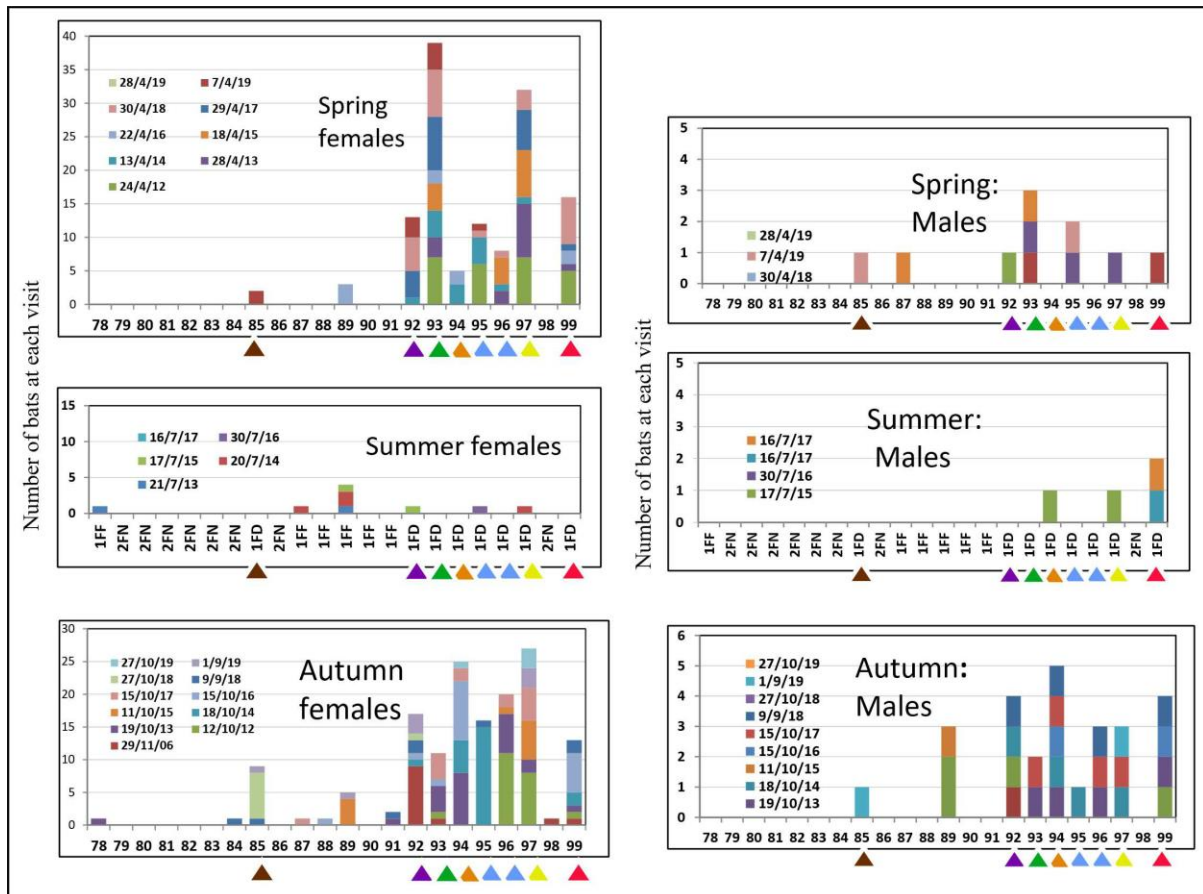


Figure 3: Occupancy by males and by females at different seasons to 2019. Note the difference in vertical scale between males and females.

There was a much greater tendency for aggregates of females to be accompanied by a male in the autumn than in the spring (Figures 4 and 5).

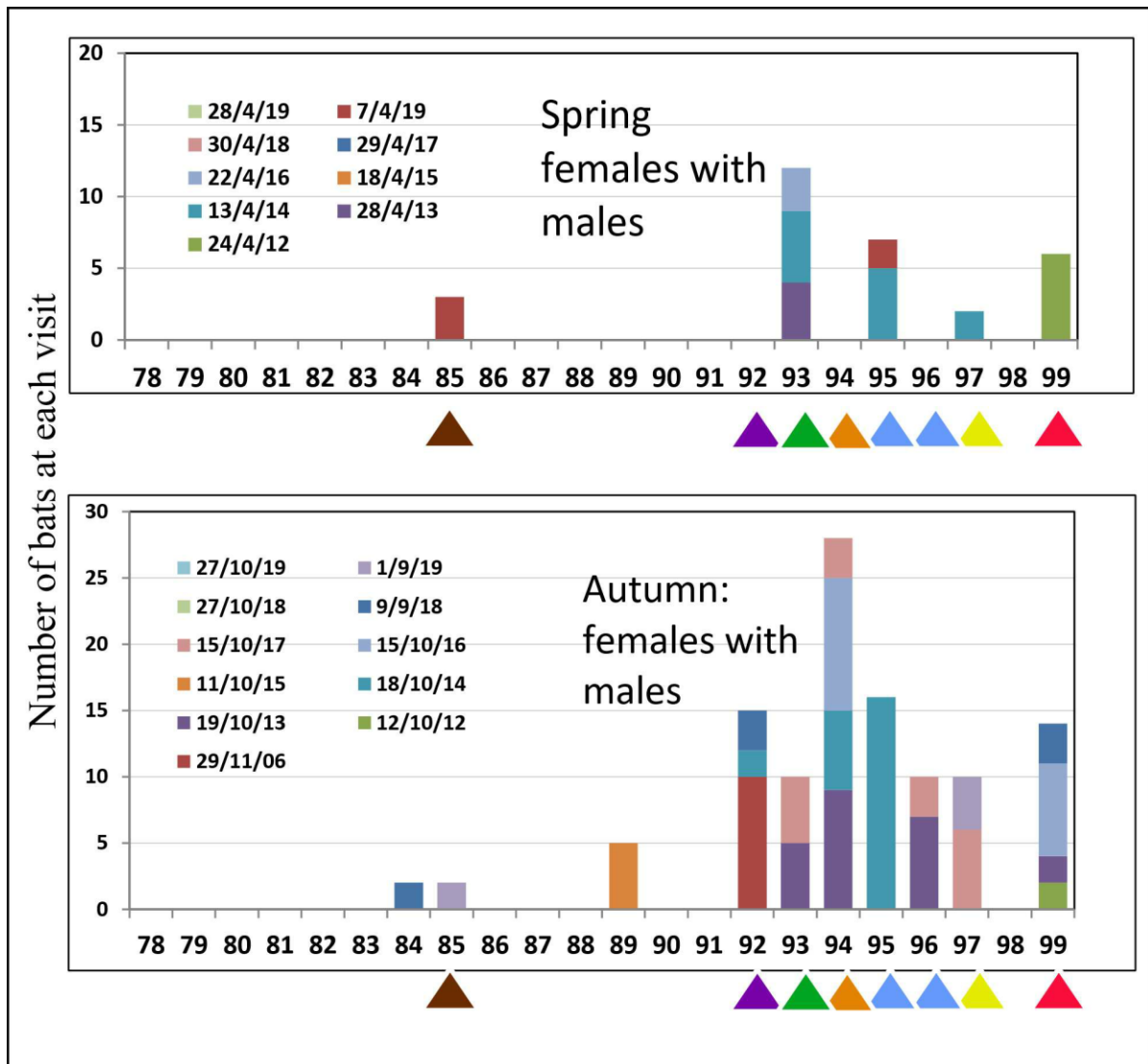


Figure 4: Occurrence of males with females at different seasons to 2019. There were no males with females during the summer.

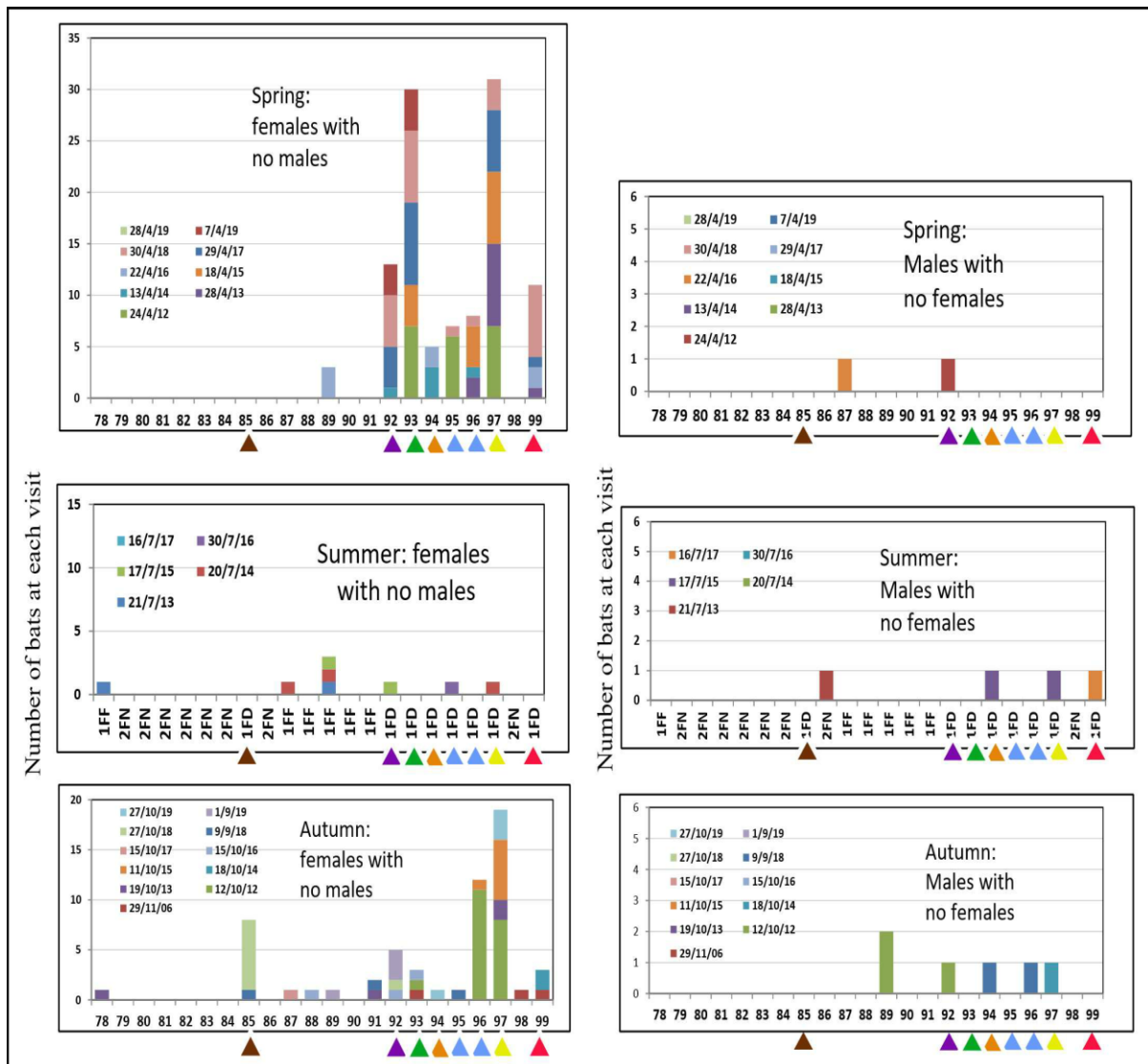


Figure 5: Occurrence of females without males and males without females at different seasons to 2019.

For simplicity and clarity, I have combined the Phase 1 results with the later phases in the above figures. The pattern of occupation was maintained throughout the study.

Phase 2

In order to investigate the patterns of usage of these boxes, especially loyalty and movement between boxes and locations of related maternity roosts, a project licence was obtained from Natural England to ring and radio-tag bats.

The captures of bats and the recoveries of ringed bats are summarised in Table 1. Additional notes follow.

Table 1: Summary of bat captures, ringing and recoveries in Phase 2.

	Box number and colour							
	99	97	96	95	94	93	92	85
Date								Other boxes
29/04/2017		7 new F				7 new F	4 new F	
16/07/2017	1 new M							
15/10/2017		1 red M	1 new M		1 new M	1 green F		
		2 yellow F	2 new F		2 new F	1 violet F		
		3 new F				1 new M		Box 87
						2 new F		1 new F
30/04/2018	1 yellow F	2 yellow F		1 blue F		1 green F	1 violet F	
	6 new F					1 violet F	1 plain F	
						5 new F	3 green F	
09/09/2018	1 red M	Hornets	1 new M	1 new F	1 orange F		1 green M	1 plain F
	2 yellow F						1 violet F	Box 84
							2 new F	1 new M
27/10/2018							1 green F	1 plain F
								1 green F
								5 new F
11/01/2019	1 blue (ring only)		2 red					
07/04/2019				1 new M	1 green F	1 violet F	1 brown F	
				1 new F	1 violet F	1 green F	1 plain M	
					2 new F	1 new F	1 new F	
28/04/2019		1 blue F						Box 88
								1 brown F
01/09/2019		1 red M					1 orange F	1 plain M
		1 yellow F					2 new F	1 green F
		1 blue F						
		1 new F						
27/10/2019		3 new F			1 orange F			

On 29th April 2017 we radio-tagged and followed four of the female bats which had been captured and ringed, two yellow and two green. We lost contact with one of them on the first evening and the other three were tracked to different transient roosts. Within the lifetime of the tags (maximum 18 days) all of these three bats had settled in the same house about 1km to the south west.

On 15th October 2017 the radio-tagged bat which had eluded us in April was among those recovered, in the same box from which it was captured in April.

In 2018 we visited on 9th September, rather than midsummer, in order to gain some knowledge of the timing of arrival of the bats. One box (yellow), in which we had previously found frequent aggregations of females, was occupied by hornets and presumably no bats. It appeared that the bats displaced from the yellow box had simply moved next door.

Having found evidence to answer most of our initial questions relating to loyalty and an associated maternity roost, we began to try to find out more about the timings of

occupation by females and males. We looked into the boxes very briefly on 11th January 2019, noting only any ring colours without capture, so as to avoid disturbance.

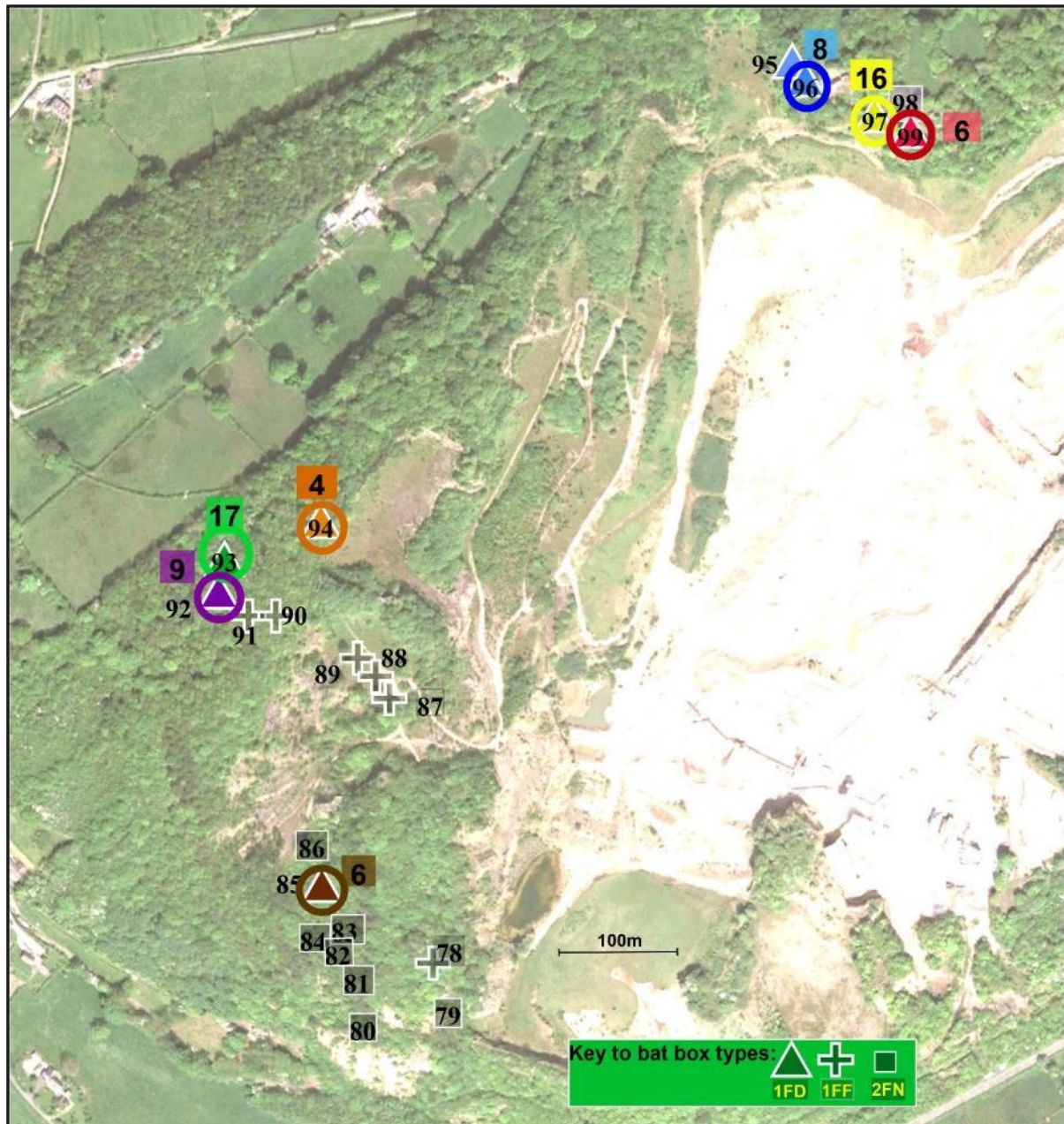


Figure 6: Numbers ringed at each box up to October 2019. Numbers of each colour are shown in the coloured squares (Google Maps, 2010).

The recoveries of rings in relation to the boxes where they were applied are shown in Table 2. It is evident that in general, the bats do tend to return to the same boxes, in spring and autumn, or to a closely adjacent box. It appears that the red and yellow boxes were used by one group of bats (perhaps the territory of one male), while the green and violet boxes were used by a second group. Later on, the newly installed 1FD box (brown) was used by new bats and also by bats recruited from the green box and nearby 2FN boxes.

Table 2: Ring recaptures by box. The 'Box number and colour' column is coloured according to the ring colour allocated to the box. The 'Ring number', 'Date ringed', 'Ring colour' and 'Date found' columns are coloured according to the recovered ring.

Box number & colour	Ring number	Date ringed	Ring colour	Date found	Sex
99	4096	29/04/2017	Yellow	09/09/2018	F
99	4097	29/04/2017	Yellow	09/09/2018	F
99	4255	16/07/2017	Red	09/09/2018	M
99	4264	15/10/2017	Yellow	30/04/2018	F
97	4080	07/04/2019	Blue	28/04/2019	F
97	4089	29/04/2017	Yellow	30/04/2018	F
97	4096	29/04/2017	Yellow	15/10/2017	F
97	4097	29/04/2017	Yellow	15/10/2017	F
97	4255	16/07/2017	Red	15/10/2017	M
97	4255	16/07/2017	Red	01/09/2019	M
97	4279	15/10/2017	Yellow	30/04/2018	F
95	4075	15/10/2017	Blue	30/04/2018	F
94	4065	15/10/2017	Orange	09/09/2018	M
93	4054	29/04/2017	Violet	15/10/2017	F
93	4055	29/04/2017	Violet	30/04/2018	F
93	4055	29/04/2017	Violet	07/04/2019	F
93	4256	15/10/2017	Green	07/04/2019	F
93	5964	29/04/2017	Green	30/04/2018	F
93	5994	29/04/2017	Green	15/10/2017	F
92	4054	29/04/2017	Violet	30/04/2018	F
92	4054	29/04/2017	Violet	09/09/2018	F
92	4054	29/04/2017	Violet	07/04/2019	F
92	4074	15/10/2017	Orange	01/09/2019	F
92	4256	15/10/2017	Green	30/04/2018	F
92	4256	15/10/2017	Green	27/10/2018	F
92	4274	15/10/2017	Green	09/09/2018	F
92	4282	15/10/2017	Plain	30/04/2018	F
92	4286	27/10/2018	Brown	07/04/2019	F
92	5965	29/04/2017	Green	30/04/2018	F
92	5999	29/04/2017	Green	30/04/2018	F
88	4295	07/04/2019	Brown	28/04/2019	F
85	4282	15/10/2017	Plain	09/09/2018	F
85	4282	15/10/2017	Plain	27/10/2018	F
85	4283	09/09/2018	Plain	07/04/2019	M
85	4283	09/09/2018	Plain	01/09/2019	M
85	4296	27/10/2018	Brown	07/04/2019	F
85	5964	29/04/2017	Green	27/10/2018	F
85	5964	29/04/2017	Green	01/09/2019	F
84	5964	29/04/2017	Green	09/09/2018	F

Meanwhile the occupancy data from Phase 1 had been supplemented by the continued accumulation of data during Phase 2. The patterns of occupancy by males and females continued and is summarised in Figure 5.

In the autumn, aggregates of females usually, but not always, included a male (Figures 4 and 5). In the spring, association of males with females was much less frequent. We never found males with females in July. The number of occurrences of males without females was so small that meaningful comparisons cannot be made, but there were no clear seasonal changes in their usage.

We never found a harem (females with a male) in both yellow and red, or in both green and violet. These are both adjacent pairs (less than 30m apart). We did on one occasion find harems simultaneously in blue and yellow, and also in orange and green. From our limited results it would seem that red with yellow constitute a single territory, and similarly for green and violet.

Discussion

We have shown strong but not absolute loyalty to boxes in both the autumn and spring, although there is not enough data to demonstrate whether there was loyalty of females to males or indeed of males to specific boxes. There was a clear tendency among females for loyalty to small groups of adjacent boxes.

We found evidence that all of the boxes in our study were associated with a single summer roost.

The concept of 'harem' roosts was introduced by Gerell and Lundberg (1985) as a result of their study of social organisation in soprano pipistrelles in relation to their use of bat boxes for mating. Their studies were done in a pine forest in Sweden between 1982 and 1990.

Although they refer to their bats as common pipistrelle *P. pipistrellus*, this was at a time when the separate existence of soprano pipistrelle was only just being recognised, and it is accepted that their bats were the latter. This study was near the northern extreme of the range of the species and in a pine forest with few natural tree cavities. This is not typical of the habitats in much of the British Islands. The authors note that there were very few naturally occurring roost cavities, so that their bat boxes were the only such resource available, and were occupied very quickly and competitively. They reported that males occupied all the bat harem boxes, and also the other boxes at all the other stations in their study, each season before the females arrived. The males using the harem boxes tended to occupy the same box for the whole of the summer. The other males were more mobile (Lundberg and Gerell, 1986). Males with harems were observed to make intensive 'song flights' during the period when they were most sexually active, as judged by the condition of their testes and epididymides (Gerell and Lundberg, 1985). The authors inferred that the males attracted the females by calling during these song flights. This interpretation has since been widely followed. Other studies, of common pipistrelles, on the continent of Europe have confirmed that males of that species defend mating roosts, at least partly by calling. It is not common experience in Britain that the majority of bat boxes are occupied by either solitary males or harem roosts. It was certainly not the case with our boxes. Many boxes are

unused. Lone males were relatively more frequent in July than in spring or autumn, but were nonetheless infrequent. We did not inspect our boxes in August, which is when Gerell and Lundberg (1985) reported peak mating activity, so we cannot be sure that the female-only aggregates which we encountered from September onwards did not have a male in August.

The boxes in our study were not all used in any given season, although each of the type 1FD boxes was used by aggregates of females at some time during the study period. None of the other box types was used in this way.

Aggregates of females without a male were frequent in our study. We do not have enough observations in late summer and early autumn to know whether males might have been with those groups earlier in the season and had left, having mated. It is notable that females assemble in the same boxes in the spring, before grouping into larger colonies at maternity roosts (or possibly pre-maternity roosts). Males are found with them less frequently at that time. Therefore, it does appear that female soprano pipistrelles are able to gather in groups in suitable temporary roosts without the stimulus of a male.

While our study provides no evidence to contest the hypothesis that males sing to attract females to mating roosts, our observations are equally compatible with the scenario that females assemble independently of male occupation, and that males might then adopt and defend these aggregates, vocally or otherwise. If females assemble spontaneously, without the need for the presence of a male, then the most efficient mating strategy for a male might be to insert himself into such a group of females and then defend it from other males. Even if the males arrive before the females, it is not difficult to imagine that they have learned, or can detect perhaps by scent, which roosts are favoured by aggregating females, and then anticipate their arrival. There is experimental evidence that songflight calls of soprano and common pipistrelles are often agonistic (Barlow and Jones, 1997) and it has been reported that male common pipistrelles defend territories and appear to attract females migrating between maternity roosts and urban mass hibernation sites in Bayreuth (Sachteleben and von Helversen, 2006). This is a very specific setting, uncommon in the British Islands. Evidence that females are attracted was not presented. Bartonickova *et al.*, (2016) reported that soprano pipistrelles behaved differently in a comparable situation.

Lundberg (1990) reported that non-territorial males were never observed to perform a song flight. She interpreted this to imply that these males would try to mate opportunistically. But it would also imply that there is no vocal competition for females, unlike the inferences of Sachteleben and von Helversen (2006).

Gerell and Lundberg (1985) postulated that the behaviour of the males could be categorised as resource defence polygyny, with the resource being the roost box. Defence of the female aggregates was rejected by these authors on the grounds that individual females were infrequently encountered on successive inspections of each box. However, there were females in each box for the duration of the mating period, and therefore a harem to defend, so that any distinction between defending the harem and defending a roost site is only meaningful if all of the roost sites are occupied for all of the mating season. This appears to have been the case in the Swedish study, where natural roost sites were rare and the bat

boxes were a limited resource. It was not the case in the locality of our study, nor is it likely to be in much of lowland Britain.

Defence of the female aggregates would appear to be a reasonable interpretation of our observations, but we recognise that further observation of larger groups of boxes is needed, especially during August and early September. Our plans to extend our study in this direction were interrupted by COVID-19. More insight might be achieved from the records of bat box usage accumulated by other bat groups, and we would welcome collaboration from other groups in this matter.

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Should I stay or should I go? Factors influencing roost selection within lead mine adits in the North Pennines

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Introduction

Winter hibernacula are an important part of the bat life cycle and the use of lead mine adits in the North Pennines as hibernacula is generally undocumented or under recorded. This study aimed to locate hibernation sites and subsequently to try to understand the factors which make these attractive roosting sites. Winter surveys of hibernating bats within adits in Cumbria and Durham have been undertaken since 2014 and 2018, respectively. The Cumbrian and Durham adit surveys were undertaken by a different team of volunteers working to a similar methodology, but with limited variations including recording dates.

Adits, or levels, are the main access routes into the lead mines, sloping up gradually from the entrances to allow the lead ore to be brought out more easily. The adits are c.1-2m wide and range from c.1.5-2.5m in height and extend a variety of lengths, ranging from the shortest of the surveyed sites which is blocked at 33m, to adits that extend into complex mine systems running several miles underground. The entrances, known as portals, are constructed from small stone blocks, creating multi-layered arching; in many adits this arching continues deep underground, sometimes in intermittent sections divided by rock or shale depending on the geology of the site. The majority of the adits in the study have water flowing through them, creating a humid atmosphere; the water is usually shallow, no more than ankle deep, but occasionally above knee height in places.

This study aimed to determine the importance of the environmental factors which influence winter roost selection by hibernating *Myotis* and *Plecotus* species bats. Physical characteristics were recorded for roost and control locations and data loggers were used to determine if temperature affected roost selection, or influenced roost switching.

Methods

A total of 26 adits have been surveyed as part of this project. These upland sites are all within the North Pennines, with the adits in the study area between 428m and 598m asl.

The adits were surveyed from the portal inwards by small teams of volunteers led by licensed surveyors. Each team comprised of a mix of skill levels, including new volunteers who were paired with experienced surveyors to ensure reliability in survey data and to give everyone the opportunity to gain experience of hibernation surveys. These surveys are a useful way to learn new skills and share the excitement of finding a hibernating bat. To date, 59 people have been involved with this project.

Surveyors walked slowly into the adit and used torches to check the gaps between the stones, ensuring that the crevices were checked from different angles to minimise the chance of a bat being overlooked (Battersby, 2010). Once sites were confirmed as hibernacula, the adits were surveyed at least twice during each winter (Barlow *et al.*, 2015). Known hibernacula have been registered with the Bat Conservation Trust's (BCT) National Bat Monitoring Programme (NBMP).

As the surveys took place between November and March, bats were in torpor and no attempt was made to handle them to avoid undue disturbance (Dietz *et al.*, 2009). When a bat was discovered, it was identified to species/species group level. The two small *Myotis* species bats present in our study area, whiskered bat *Myotis mystacinus* and Brandt's bat *M. brandti*, are difficult to separate visually in hibernation (Barlow *et al.*, 2015; van Schaik *et al.*, 2015); therefore, these two species are referred to as small *Myotis* bats within this study. The other bat species we encountered on our surveys were Natterer's bat *M. nattereri*, Daubenton's bat *M. daubentonii* and brown long-eared bat *Plecotus auritus*.

When a bat was found the data recorded during the survey included: the exact location, the distance to the entrance, the height of the bat, the height of the adit by the bat, distances were recorded using a digital laser measurer, and whether the bat was roosting in a crevice or openly (Neubaum *et al.*, 2006). The height data was used to calculate the relative height of each bat within the available space. A photograph of the roost location was taken; a printed copy of this was then used on subsequent surveys to allow that exact location to be checked for the continued presence, or absence, of the bat. It was recorded if the bat had stayed or moved and the duration that a bat stayed was calculated. The recording process was performed quickly to minimise any disturbance to the bat.

Temperature

From December 2016 data loggers were used to record temperature within the adits. The loggers used were Thermocron ibuttons DS1921G-F5 (Homechip Ltd., Milton Keynes, UK.) set to record temperature every four hours, the maximum time interval available. These are small loggers, 15mm in diameter and 5mm deep which are easy to conceal within the arching without attracting attention. Distance and height were recorded for ibutton locations.

Temperature grids were set up within four adits by deploying data loggers at intervals within the adits. These were used to record the range of temperatures experienced throughout the adit over a period of time at different distances from the portal (Briggler and Prather, 2003). Data from the loggers were used to calculate the start, minimum, average and maximum temperatures and temperature variance for the period between survey visits (Sandel *et al.*, 2001). Two Cumbrian adits were chosen due to the high frequency of bats found within them, which in the context of the North Pennines can be anything upwards of five, along with two Durham adits.

During winter 2016-17, in two Cumbrian adits, the ibuttons were placed at 0, 30, 60, 90 and 120m and were set to record every four hours from December to March. This data confirmed that the ibuttons needed to be placed more regularly closer to the portal to record the temperature fluctuations at a finer scale. With an increased availability of ibuttons in the winters of 2018-19 and 2019-20, ibuttons were placed at 0, 5, 10, 15, 20, 25, 30, 40, 50, 60, 75 and 90m intervals from November to March with the temperature still being recorded at four hourly intervals. The grids for 2018-19 and 2019-20 were used when analysing factors related to temperature in subsequent analyses.

In the Durham adits ibuttons were placed in two adits from January to March 2019. In one adit the ibuttons were placed at 0, 20, 40, 60, 80, 100 and 120m and in the second at 0, 5,

10, 15, 20, 30, 40 and 50m; this adit is blocked at 75m. The ibuttons recorded temperature every four hours.

Data loggers were used to record temperature at the locations of hibernating bats from December 2016. An ibutton was placed in an adjacent crevice to where the bat was found; to reduce undue disturbance to the bat and to reduce the potential for the bat to dislodge the logger when emerging. The data logger was not as deep into the crevice as the bat it was shadowing due to installation/retrieval constraints (Neubaum *et al.*, 2006). On the subsequent survey visit the exact crevice was checked to see if the bat had stayed or if it had moved. If the bat had moved, the ibutton was collected.

The ibutton grid locations were used to provide random control points that had not been selected as roost locations. For each date period when an ibutton was placed with a roosting bat an equivalent date period was selected from the available ibutton location data. To ensure the randomness of the selection of the control data all the available data points were listed alphabetically, a random number was generated using the excel function RANDBETWEEN and then sorted by the lowest number.

Data analysis

Statistical analysis was performed using R Studio (R Core Team, 2019). All variables were tested for normality using the Shapiro-Wilk test.

Wilcoxon rank sum tests were used to determine if there were significant differences between temperature, with start, minimum, average, maximum and temperature variance tested, and distance data, with distance from the entrance, bat height and relative bat height tested, for bats that stayed or moved. Effects of seasonality were tested for in relation to the day number of the year and median day number in the survey period. These tests were performed twice independently, once in relation to bats that stay or moved and then in relation to roost and control sites.

Kruskal-Wallis rank sum tests were used to determine if there were any significant differences in either staying or moving and roost selection by bat species/species group (Wermundsen and Siivonen, 2012). If the Kruskal-Wallis rank sum test was significant, post-hoc analysis using Dunn's test was performed to determine which levels of the independent variable differ from each other level.

Results

The number of adits surveyed has increased during the survey period as new adits were located and more people became involved in the project. Bats have been found within 15 of the 26 adits surveyed to date. The adits in which bats have been found are referred to as C1-C12 for Cumbrian adits and D1-3 for the adits in Durham (Table 1).

Table 1: Number of bat records per adit from the start of the surveys.

Site	Brown long-eared bat	Daubenton's bat	Natterer's bat	Small <i>Myotis</i> bat
C1	0	11	4	0
C2	0	2	3	0
C3	5	5	25	0
C4	0	52	44	10
C5	6	23	0	0
C6	2	14	15	0
C7	5	0	16	6
C8	5	0	0	0
C9	76	60	3	3
C10	0	1	0	0
C11	12	0	0	0
C12	0	29	0	0
D1	2	5	2	3
D2	0	5	0	6
D3	0	0	0	1

Distance

The distance a bat roosted from the portal varied greatly across the sites and by species; the closest a bat was found to a portal was a Natterer's bat at 1.0m in C4 in February 2019. The furthest discovery, also a Natterer's bat, was at 155.8m in C6 in February 2017. Figure 1 shows the distribution of all bats in all adits in 5m distance bands.

The average roost distance for each site and each bat species/species group shows a wide variation across the adits (Figure 2).

England – North

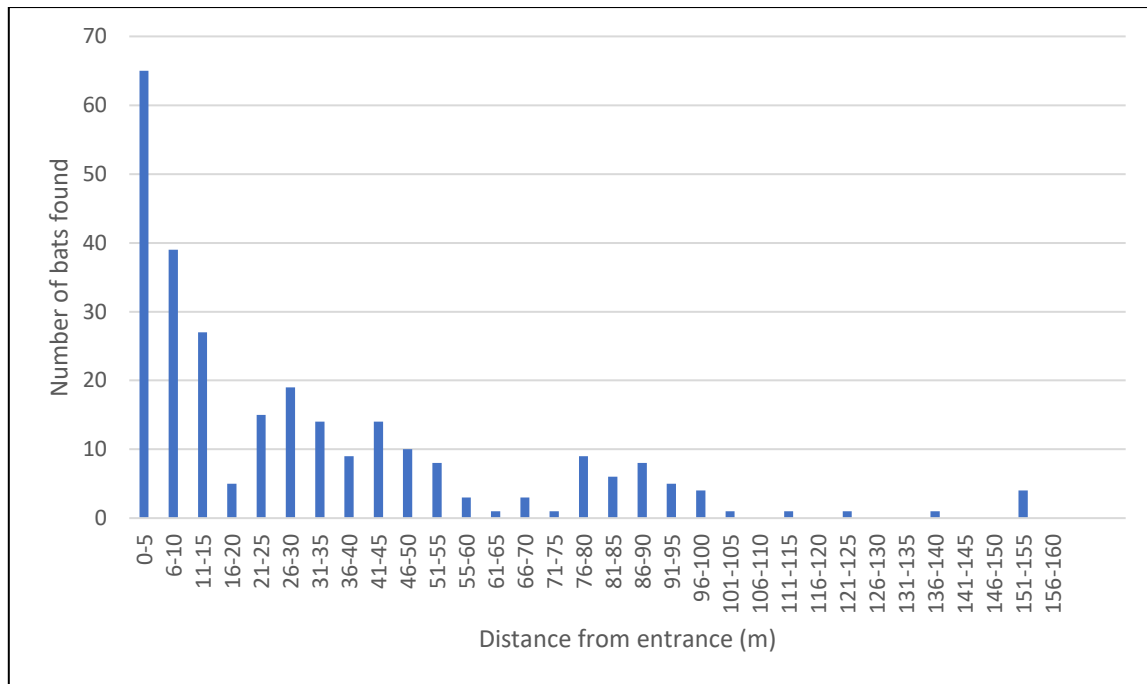


Figure 1: Number of bats found in relation to distance from the entrance across all adits.

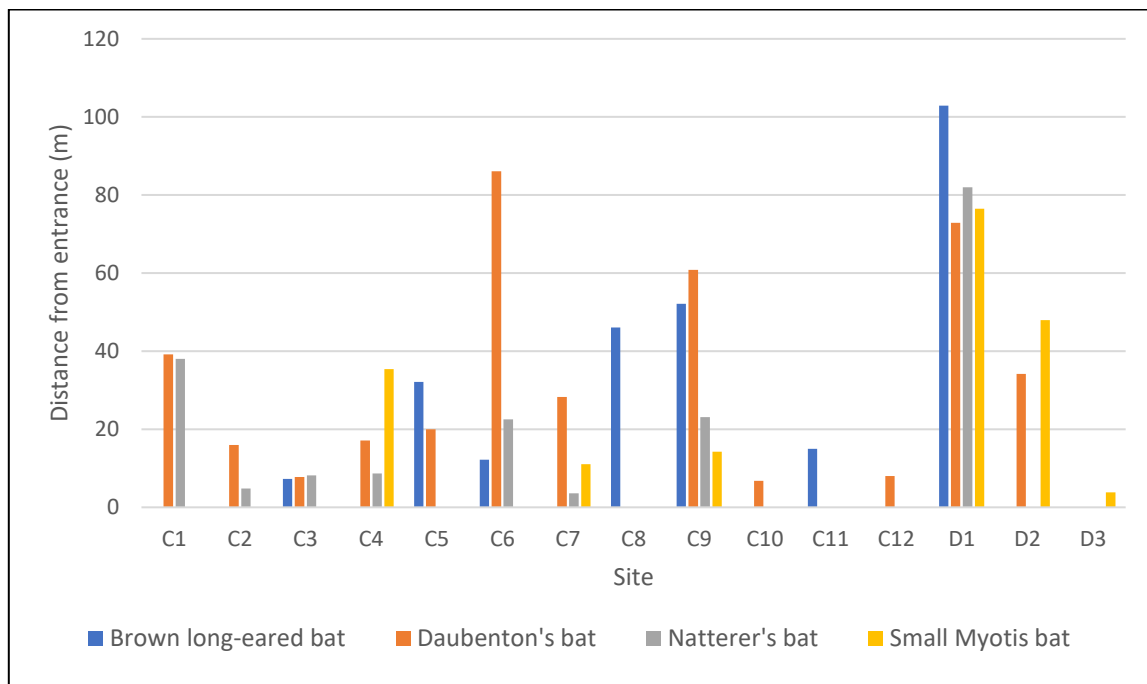


Figure 2: Average distance of roost from entrance for each bat species/species group in each adit.

Height

The roost locations were generally within the upper sections of the adits (Figure 3), although there were notable exceptions. A brown long-eared bat was found hibernating in a small cavity below ground level in D1 in January 2019 and in C9, a brown long-eared bat was found roosting openly at 0.9m in November 2017; a brown long-eared bat was also present in this location on survey visits in December 2017 and January 2018.

England – North

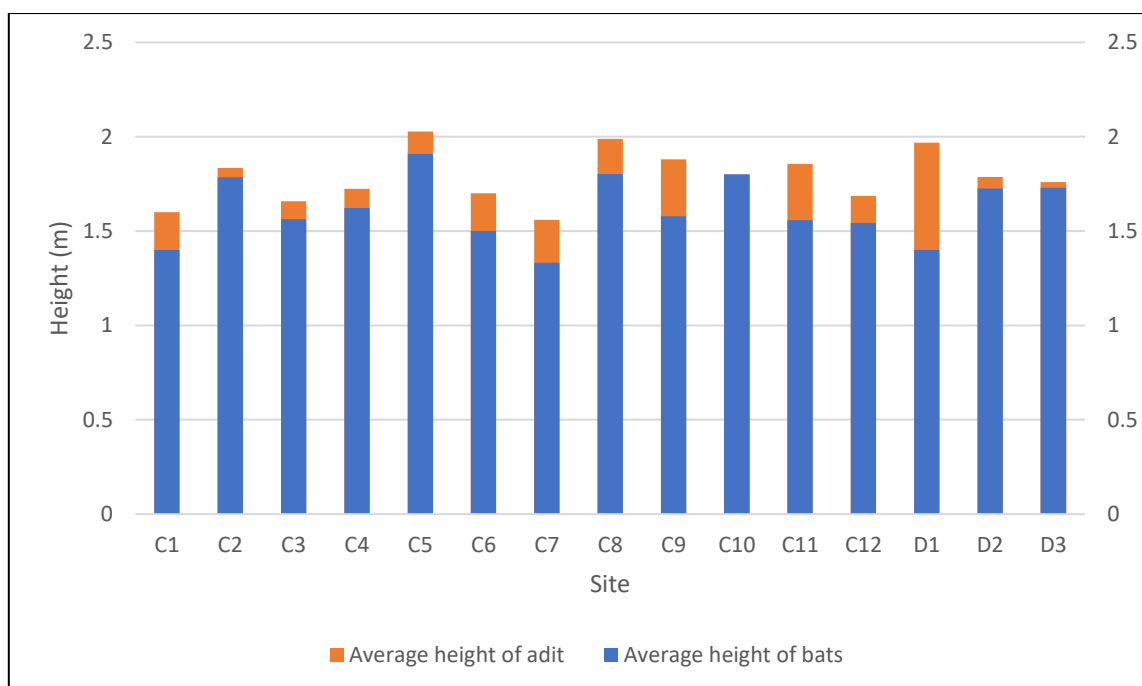


Figure 3: Average height of bat roost locations against average height of adits.

As shown in Figure 4, bats occupied the top 20% of the available height within an adit, with the exception of D1; this data includes the brown long-eared bat which was recorded roosting below ground level.

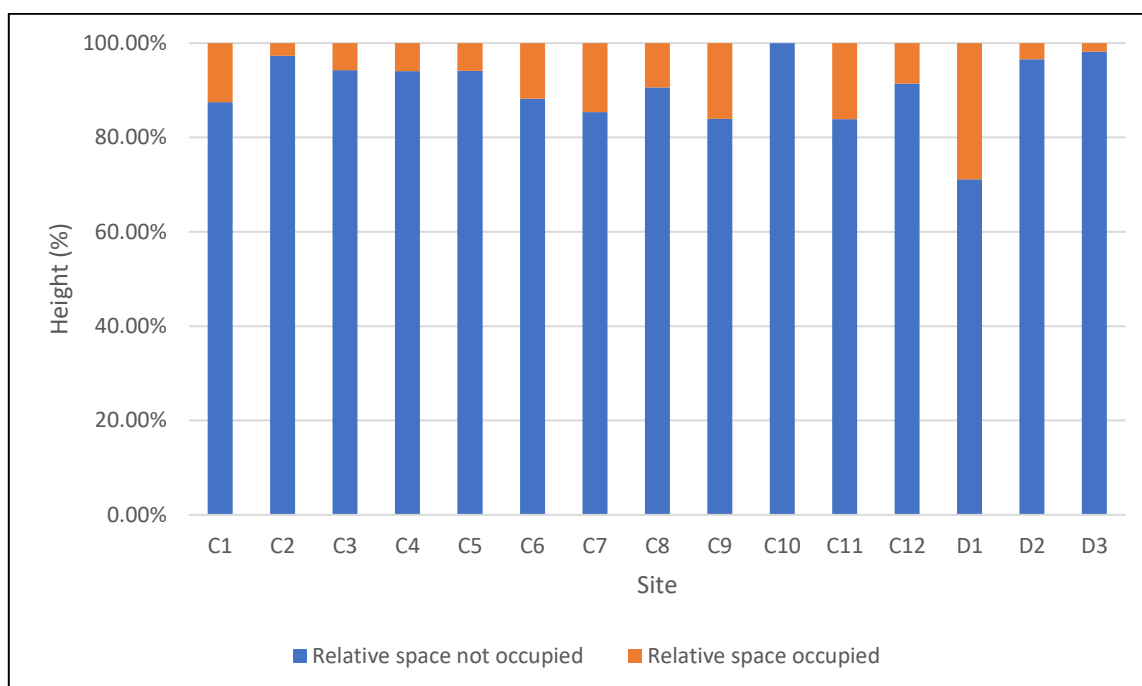


Figure 4: Average relative space occupied by bats per adit.

Temperature

C4 and C9

Within C4 the temperature at 0m varied between -2.5 to 10.5°C, by 30m the temperature was much more stable between 6.0 and 7.0°C and by 90m the temperature varied between

7.5 and 8.5°C suggesting that the temperature fluctuations were greater with proximity to the portal. C9 exhibits a wider temperature range at all depths.

The data across the two years within each site shows very similar trends (Figures 5 and 6), however there are differences between the adits in the depth at which the adit temperature starts to stabilise and the range of temperature variation. In winter 2019/20 the ibutton at 60m in C9 was lost into deep water, hence the gap in the data.

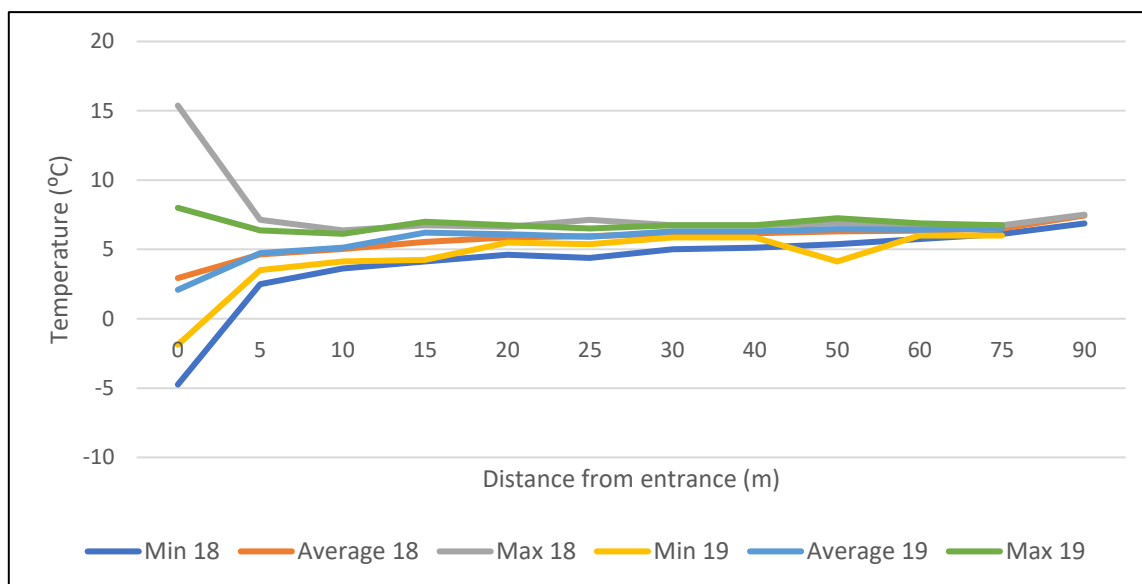


Figure 5: C4 temperature 2018/19 and 2019/20.

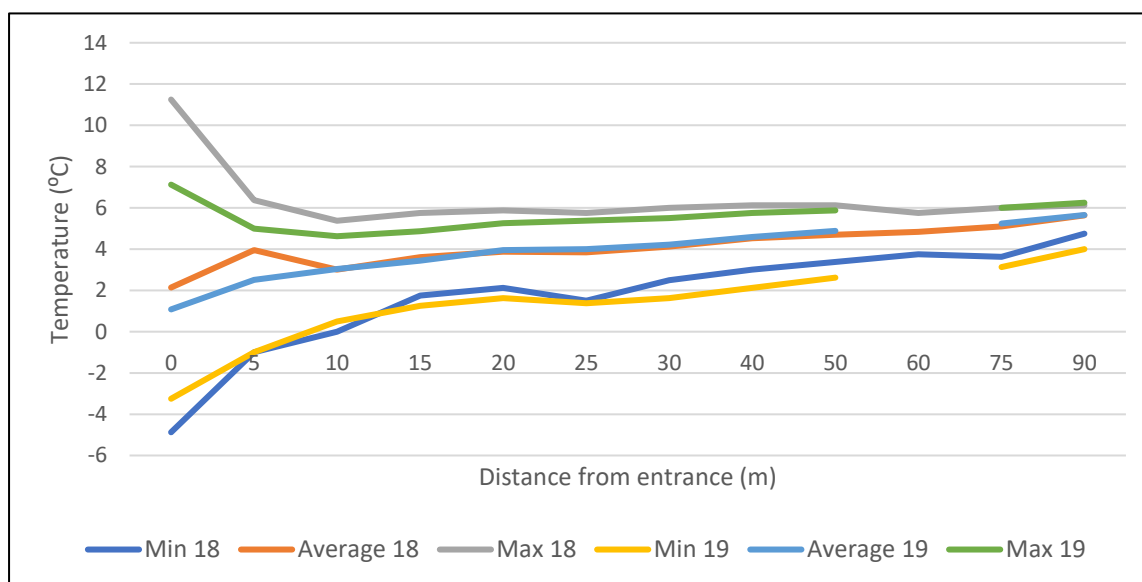


Figure 6: C9 temperature 2018/19 and 2019/20.

D1 and D2

The data shows that the internal temperature fluctuated between 3.0 and 5.5°C at 20m, and 4.75 and 5.625°C at 40m in D1, creating a similar temperature profile to C4 (Figure 7). Disappointingly there was a high failure rate of ibuttons within D2. Data was only reliably recorded at 0, 5, 15, 30 and 40m (Figure 8). The lack of fine scale data makes any interpretation less reliable.

England – North

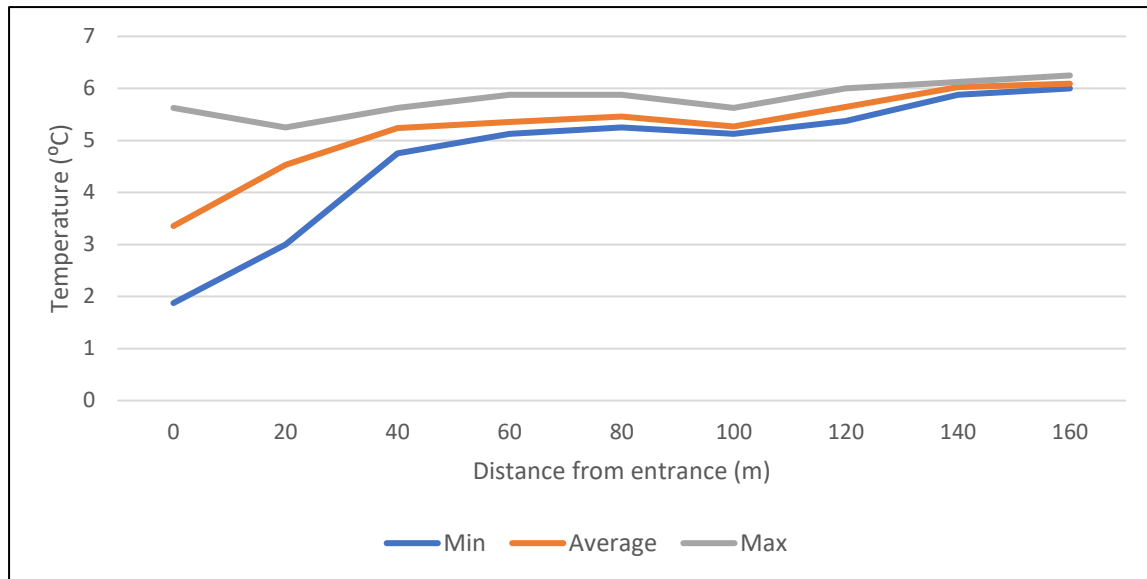


Figure 7: D1 temperature January to March 2019.

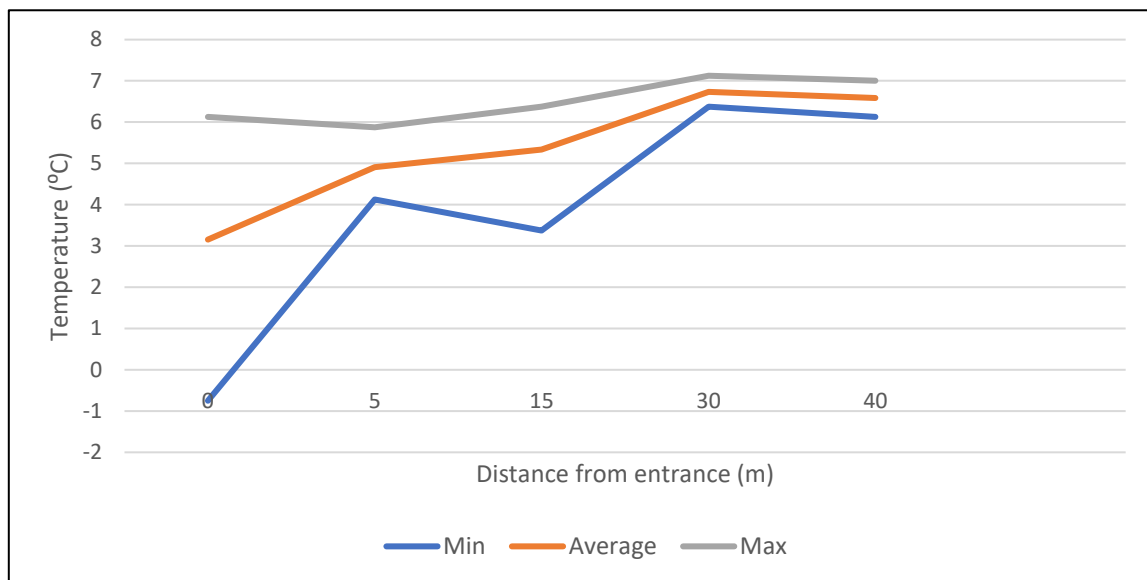


Figure 8: D2 temperature January to March 2019.

ibutton bats

The data from the ibuttons placed near to hibernating bats has been used to plot the distance from the entrance and the start temperature of the roost location in relation to the average temperature of the adit (Figures 9-14).

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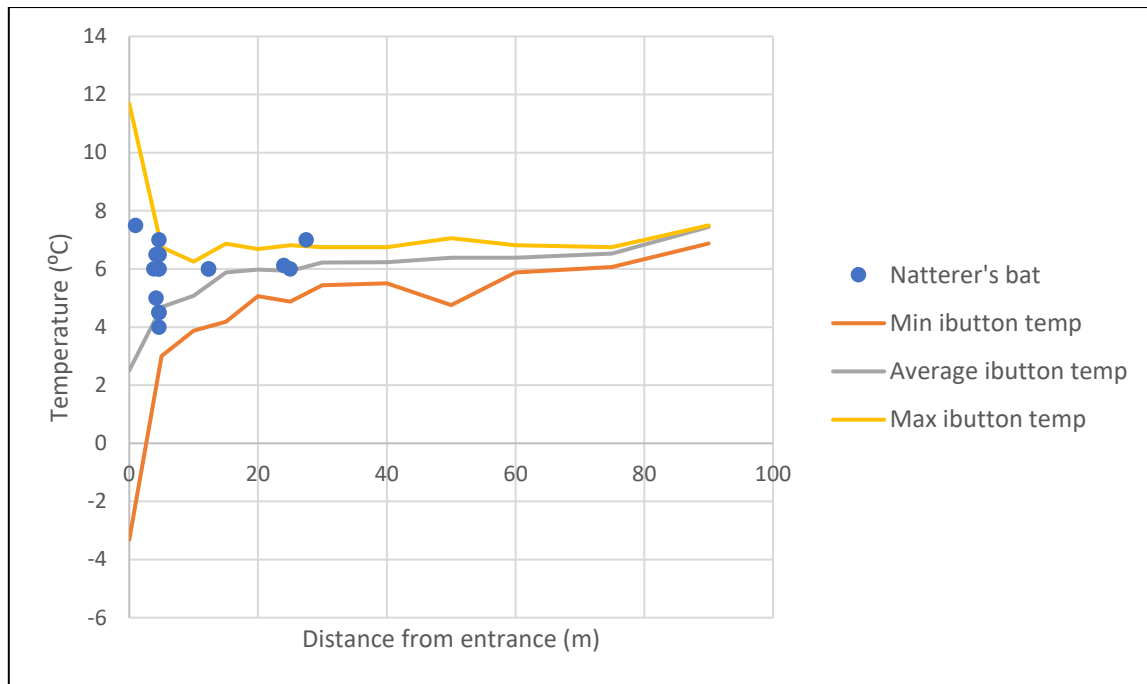


Figure 9: Roost locations of Natterer's bat in C4, December 2016-January 2020.

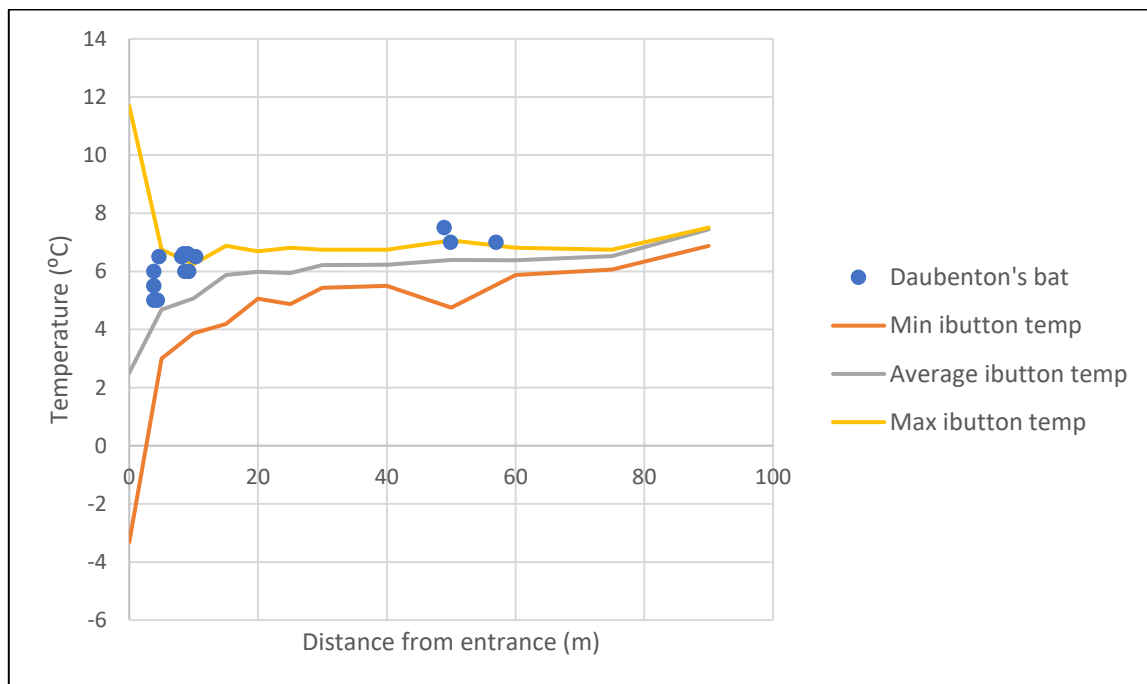


Figure 10: Roost locations of Daubenton's bat in C4, March 2017-January 2019.

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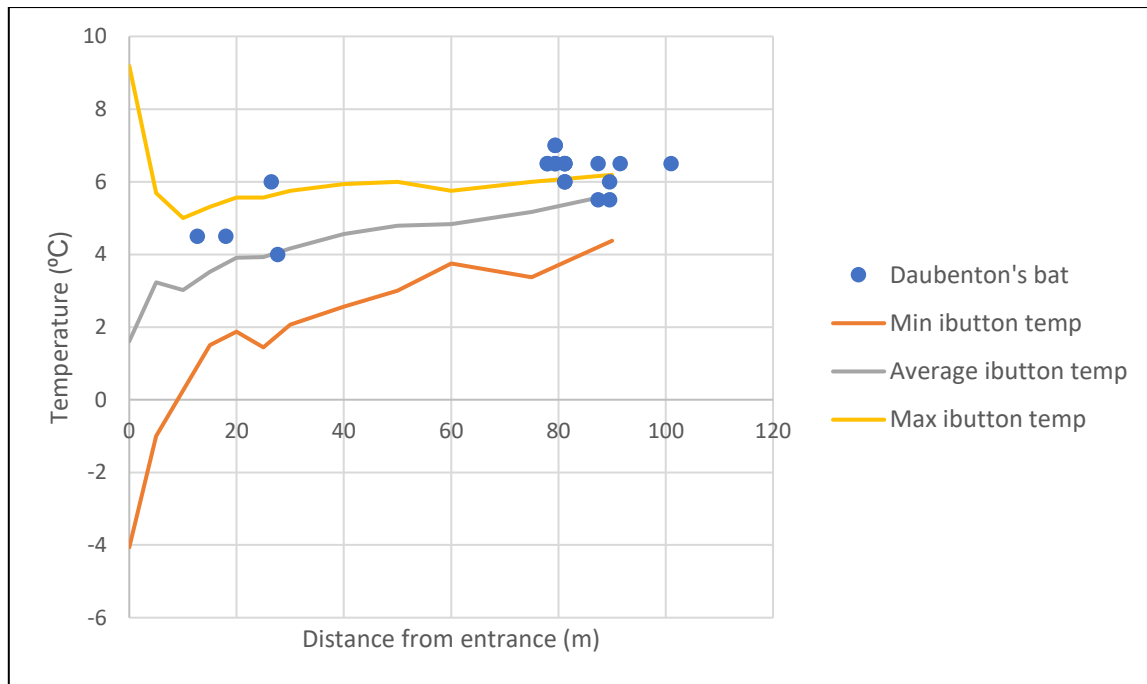


Figure 11: Roost locations of Daubenton's bat in C9, December 2016-January 2020.

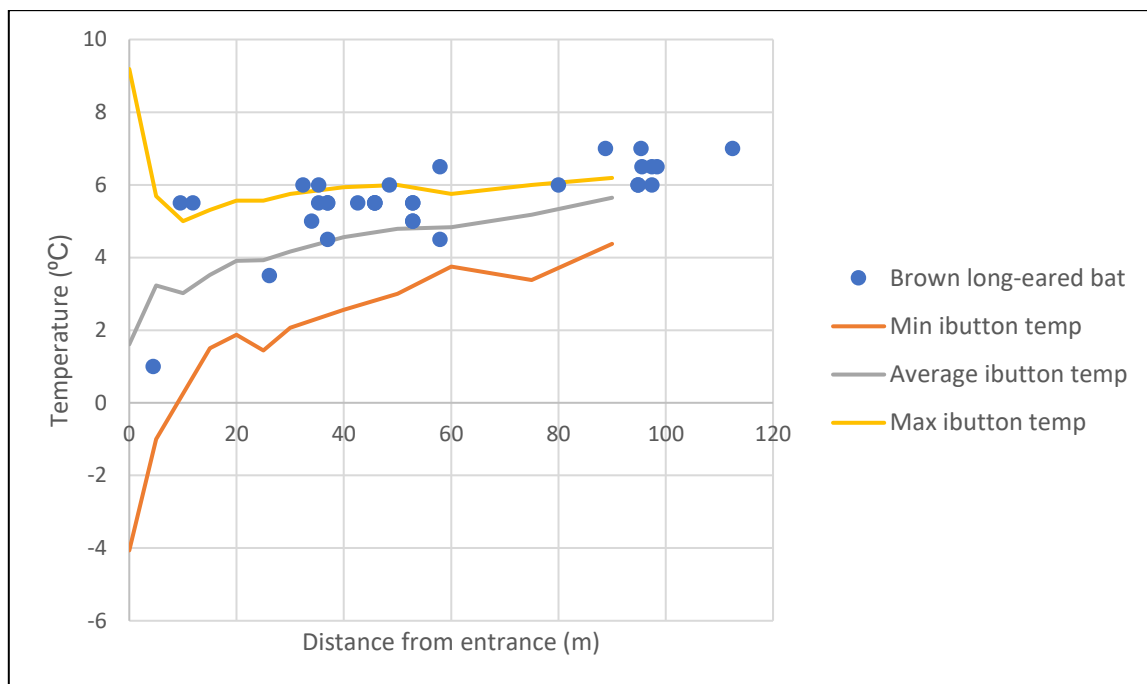


Figure 12: Roost locations of brown long-eared bat in C9, December 2016-January 2020.

England – North

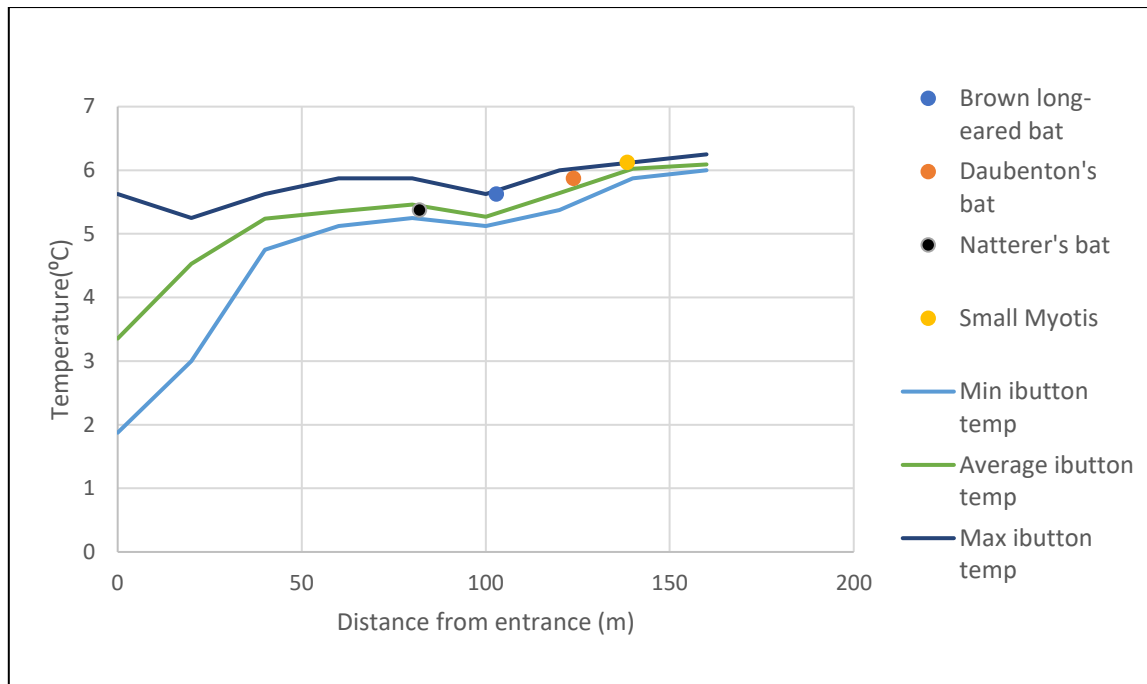


Figure 13: Roost locations of all bat species/species groups in D1, January-February 2019.

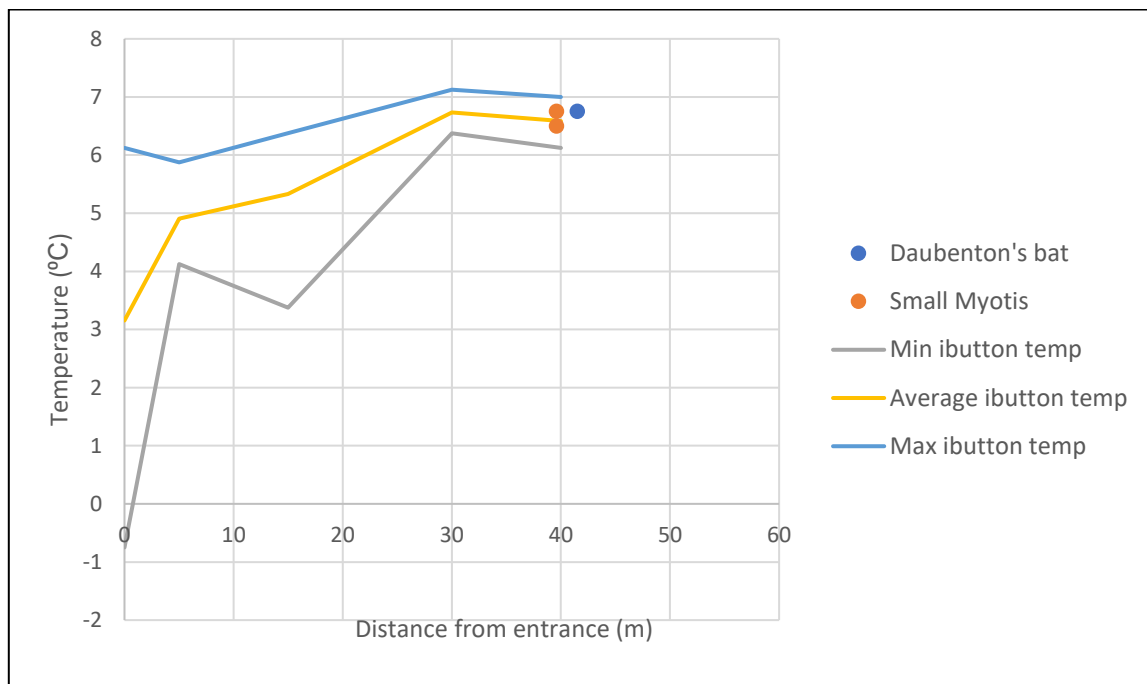


Figure 14: Roost locations of all bat species/species groups in D2, December 2018-January 2019.

Data analysis

There were no factors related to temperature, distance, height or seasonality, which were found to be significant for the bats which stayed or moved (Table 2).

Table 2: Comparison of environmental measurements between bats that stayed and bats that moved. Temperature: the start, minimum, average, maximum and temperature variance; Distance in: distance bat was from portal; Bat height: height of bat from adit floor; Relative bat height: percentage height of bat within available space; Day number: number of days through year; Median day number: median day number in survey period.

Wilcoxon rank sum test	W	df	P
Start temperature	2839.5	147	0.2257
Minimum temperature	2722.5	147	0.4610
Average temperature	2800	147	0.2976
Maximum temperature	2749.5	147	0.3918
Temperature variance	2630	147	0.7155
Distance in	2701.5	147	0.5161
Bat height	2383	147	0.5381
Relative bat height	2450	147	0.7271
Day number	2617.5	147	0.7526
Median day number	2542	147	0.9888

Roost selection was significantly related to distance within the adit (mean $\pm$ standard error roost = 35.724 ± 3.124 ; mean $\pm$ standard error control = 44.857 ± 3.028 ; Wilcoxon rank sum test $W = 11622$, $df = 282$, $P = 0.01919$ (Figure 15)) and the relative bat height within the adit (mean $\pm$ standard error roost = 89.613 ± 1.110 ; mean $\pm$ standard error control = 71.012 ± 0.501 ; Wilcoxon rank sum test $W = 1472$, $df = 282$, $P < 0.001$).

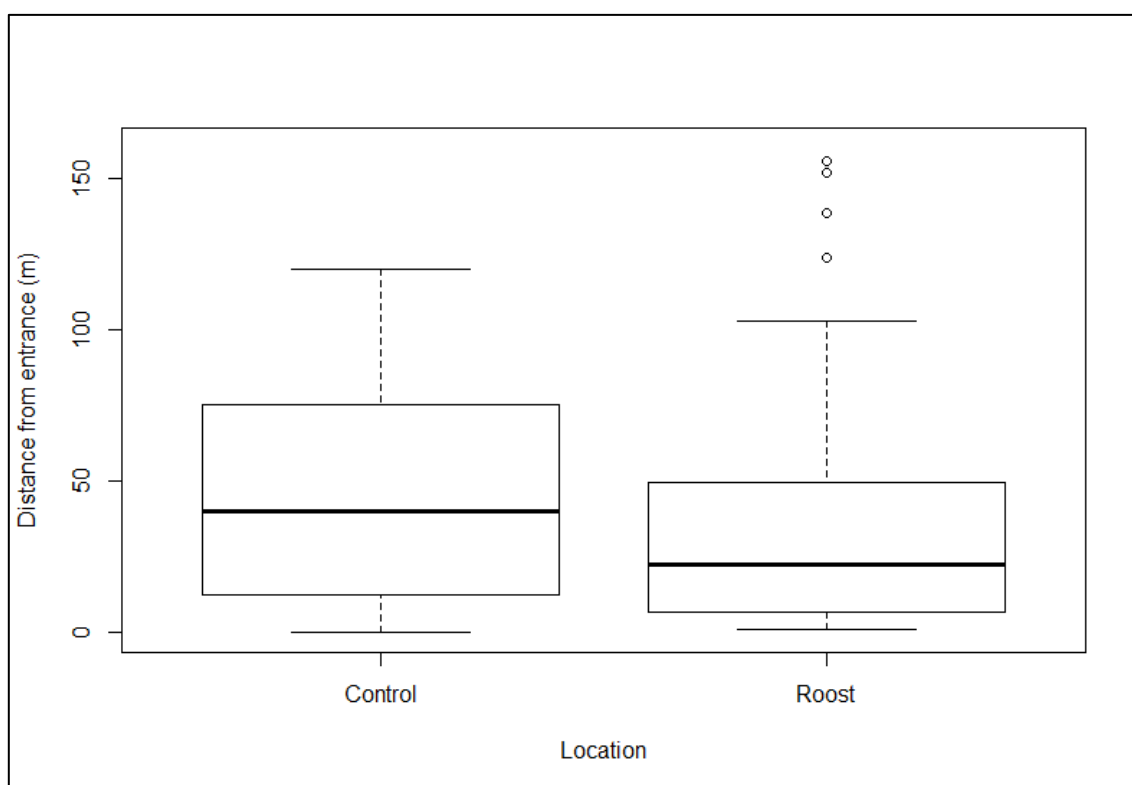


Figure 15: Distance from entrance for roost and control locations. The boxplot shows the mean distance and inter quartile range for roost and control sites.

No significant relationship was found between roost selection and temperature or seasonality (Table 3).

Table 3: Comparison of environmental measurements between roost and control locations. Temperature: the start, minimum, average, maximum and temperature variance; Distance in: distance bat was from the portal; Bat height: height of bat from adit floor; Relative bat height: percentage height of bat within available space; Day number: number of days through year; Median day number: median day number in survey period. * denotes significance.

Wilcoxon rank sum test	W	df	P
Start temperature	9386.5	282	0.3634
Minimum temperature	9668	282	0.6192
Average temperature	9311	282	0.3102
Maximum temperature	9384	282	0.3605
Temperature variance	9648	282	0.5994
Distance in	11622	282	0.01919*
Bat height	1120	282	<0.001*
Relative bat height	1472	282	<0.001*
Day number	9863	282	0.8311
Median day number	10124	282	0.8686

Pairwise comparison among bat species/species groups have shown differences in roost selection by species. The data suggests that Natterer's bats hibernated at lower start, minimum and average temperatures and tolerated the greatest temperature variance, with brown long-eared bat the next most tolerant of these variables (Figures 16 and 17, Table 4). Daubenton's bat was least tolerant of low start temperatures. Small *Myotis* bats and Daubenton's bats tolerated similar minimum and average temperatures. Natterer's bats roosted closest to the entrance, and at the highest relative height, brown long-eared bat hibernated furthest from the portal and at lower overall relative heights (Figure 18, Table 4).

Table 4: Comparison of environmental measurements among four bat species/species group. Temperature: the start, minimum, average, maximum and temperature variance; Distance in: distance the bat was from the portal; Bat height: height of bat from adit floor; Relative bat height: percentage height of bat within available space. * denotes significance for Dunn's test. (Continued on next page.)

		Temperature					Distance in	Bat height	Relative bat height
		Start	Minimum	Average	Maximum	Variance			
Kruskal-Wallis test	K	11.385	22.877	23.646	16.119	24.499	33.772	9.209	25.012
	df	3	3	3	3	3	3	3	3
	P	0.01	< 0.001	< 0.001	0.001072	< 0.001	< 0.001	0.02664	< 0.001
Dunn's test									
Daubenton's bat v small <i>Myotis</i> bat	P	1.0000	1.0000	1.0000	0.0464	0.0125*	1.0000	1.0000	0.3160

England – North

		Temperature					Distance in	Bat height	Relative bat height
		Start	Minimum	Average	Maximum	Variance			
Daubenton's bat v Natterer's bat	P	0.0047*	0.0001*	0.0000*	0.1340	0.0055*	0.0001*	0.9079	0.1687
Daubenton's bat v brown long-eared bat	P	0.0608	0.0300	0.0050*	0.0006*	0.8698	0.0824	0.0873	0.0027*
Small <i>Myotis</i> bat v Natterer's bat	P	0.7191	0.0027*	0.0549	1.0000	0.0000*	0.0379	0.5085	1.0162*
Small <i>Myotis</i> bat v brown long-eared bat	P	1.0000	0.0891	0.5224	1.0000	0.0018*	0.3284	1.0000	1.0000
Natterer's bat v brown long-eared bat	P	1.0000	0.2833	0.4405	0.4610	0.1519	0.0000*	0.0118*	0.0000*

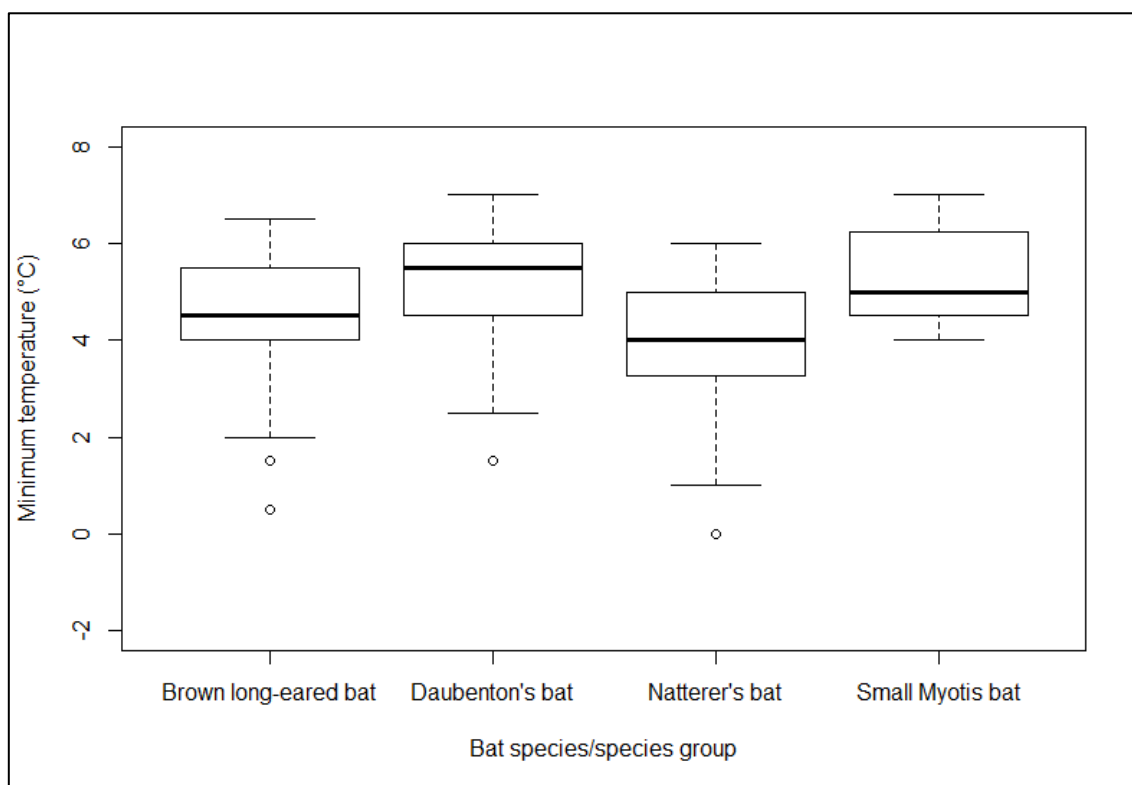


Figure 16: Minimum temperature of roost locations for bat species/species group. The boxplot shows the mean minimum temperature and inter quartile range for roost sites.

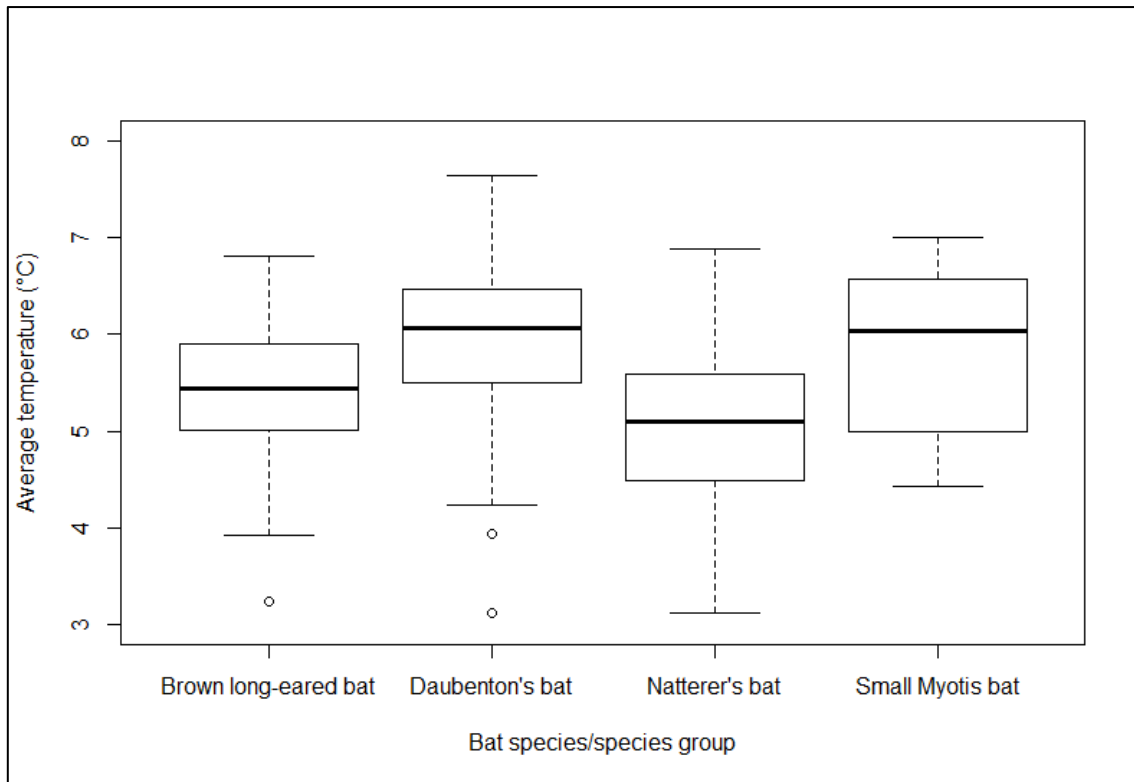


Figure 17: Average temperature of roost locations for bat species/species group. The boxplot shows the mean average temperature and inter quartile range for roost sites.

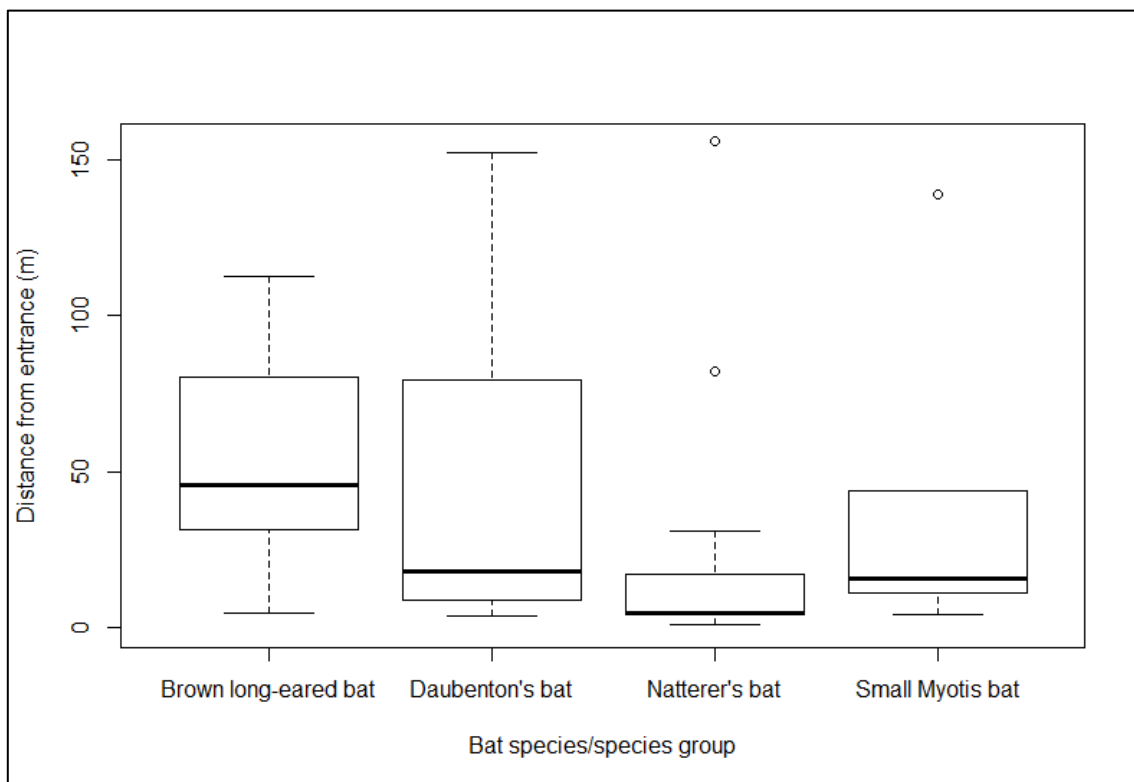


Figure 18: Distance from entrance for bat species/species group. The boxplot shows the mean distance and inter quartile range for roost sites.

Discussion

Survey effort

Surveyors searched for bats carefully, but inevitably there will be bats that are missed; due to the nature of the arching any bats which have moved behind the first line of stones will not be seen. The ability of the experienced surveyors is likely to have increased with time, which may have influenced the number of bats found.

As a result of the way this project has evolved the survey effort was not consistent across the adits within the survey area. Adits which were confirmed as hibernacula early in the project will have been surveyed on more occasions than adits discovered later in the project. Additionally, some sites were more difficult to access and were not checked as frequently and some adits, including the Durham sites, have been surveyed only in the later years of the project.

The level of survey effort does not necessarily correlate to the number of bats found; for example, a single bat was found in C1 in January 2015 but no further bats were recorded hibernating in this site until February 2019 despite the site being surveyed every winter.

Not all adits were searched to the same distance; some adits are extensive and some are blocked. Some blocked sites are finite, for example C7 is blocked at 33m and C9 ends at c.430m; conversely some adits have fallen such that bats could access deep underground where humans cannot follow them, C4 fits this profile. Where adits are not blocked, they lead into complex underground systems which link different mines via underground routes. Casual survey effort has not located a bat at a distance greater than 155.8m even with regular exploration to a depth of c.250m in selected sites.

The mines themselves were not searched for hibernating bats, partly due to time constraints and as the mines maintain a steady underground temperature of 10-12°C it is assumed (possibly in error) that the internal temperature is too high for bats to maintain themselves in torpor.

Distance

It is important to note that distance data does not consider morphology or temperature; it only shows the distance at which the bat was found. Except for C8 and D2, all the adits in this survey have arching at the portal. The extent of the arching is not comparable between sites, the shortest section is 14m in D1; however, in C2, C3 and C12 the arching extends beyond the limits of the survey area. The sections in between the arching are either rock cut or shale, these sections provide less opportunity for roosting out of sight; although there are fissures in the rock, shale plates and depressions in the shale once used to hold candles all of which provide sheltered roosting locations.

In this study, the length of the adit did not correlate directly to where bats choose to roost; bats have not been recorded further than 30.9m within either C2 and C3, these adits are linked underground at c.70m and lead into an extensive mine system; whereas C7 is blocked at 33.0m and bats have been recorded hibernating at 28.2m within this adit. However, previous studies such as Briggler and Prather (2003), did find that cave length was positively correlated with bat presence and that longer caves contained significantly more bats.

Distance into the adit was found to be significantly related to roost selection. Pairwise comparison between species showed that Natterer's bats were statistically more likely to hibernate near to the portal and brown long-eared bat to hibernate furthest from the entrance.

The most numerous bats recorded in C4 were Daubenton's bats and Natterer's bats, with 18 and ten records respectively. Small *Myotis* were recorded on two occasions and brown long-eared bat have not been recorded in this site. Natterer's bats show a preference for roosting near to the portal; there is a seam in the arching at 4.6m which is a favourite roost location. Only three Natterer's bats have been recorded further than 20m from the entrance. Daubenton's bats use two different zones within this site: within 11m of the portal, including using the seam and between 45 and 57m in.

Roost selection shows a different pattern within C9. Daubenton's bats and brown long-eared bats are the most regularly encountered bats here, with 18 and 28 records respectively. Daubenton's bats are more regularly recorded roosting between 77.9 and 101.0m, these roost sites are all open with the bats hanging against shale rather than being concealed in a crevice. Conversely, the roosts selected by Daubenton's bat within 12.7 and 27.8m of the entrance are all crevice roosts within the arching. Brown long-eared bat, the most recorded species at this site, does not show any clear preference for distance in relation to roost selection. These bats have been recorded from 4.5 to 112.5m, with both crevice and open roosts selected. Brown long-eared bat have been recorded roosting deeper within the adit than the grid of buttons. C9 has arching from the portal to 28m; beyond this the site is shale with limited opportunities for bats to tuck themselves into crevices. Both bat species have been found hibernating openly and within shale plates and brown long-eared bats roost within shallow depressions in the shale. Natterer's bat and small *Myotis* bats have also been recorded on one occasion each in this adit, roosting in crevices within the arching.

In this study all Natterer's bat have been recorded hibernating in crevices, apart from one bat roosting openly at the apex in D1 in February 2019; Wermundsen and Siivonen (2012) found that all Natterer's bats used crevices and all other species used a combination of crevice and open roost locations. Crevices shelter bats from airflow, reducing evaporation during torpor (Wermundsen and Siivonen, 2012) suggesting different bat species/species groups have different humidity requirements within hibernation.

Height

Roost sites are predominantly located within the upper 20% of the adit. Relative roost height was found to be significantly related to roost selection (Neubaum *et al.*, 2006); Natterer's bats were statistically more likely to hibernate at the highest relative height and brown long-eared bats selected the lowest relative height. It can be assumed that this choice of roosting height is due to several factors including safety from ground predators (Neubaum *et al.*, 2006); these sites are not only used by bats, as demonstrated by the presence of otter *Lutra lutra* tracks appearing regularly within adits, including beneath the bat roosting openly at 0.9m in winter 2017/18.

As bats are selecting roost locations within the top section of the adits, focusing the survey effort in this area could decrease the time spent searching for bats, and therefore the disturbance caused, without greatly reducing the number of bats found.

Temperature

As ibuttons were carried in bags and pockets during the walk to each adit, the starting temperatures recorded by the ibuttons may have been influenced by residual body heat. To compensate for this, starting temperatures were recorded 24 hours after deployment of the ibutton to allow for acclimatisation.

The ibuttons are not fully waterproof and were left for several months in sites with 90-100% humidity. In the Cumbrian study the ibuttons were stuck to screws and placed into crevices; in the Durham sites the ibuttons were placed in cloth bags. A possible conclusion for the higher failure rate of ibuttons in the Durham sites is that as the ibuttons were in bags the moisture was trapped around the ibuttons, whereas the Cumbrian loggers were exposed to air currents. In future studies ibuttons will be placed inside Ziploc bags in sites with high humidity.

The methods of ibutton deployment that have been developed throughout this study have allowed for the creation of temperature grids, bat roost temperature monitoring and include a recommendation for reduced failure of ibuttons which can be applied to future survey work in similar studies.

In 2018/19 there was a wider range of temperatures recorded at the portals of both Cumbrian adits; these ibuttons are exposed to full winter conditions and this data reflects the colder winter of 2018/19. The average temperatures recorded by the grid are very similar across both years within each adit and show increasing stability with distance underground. The effect of external temperature is limited by 5m in C4; however, this effect is less obvious for C9. C4 is at 466m asl and along a river valley; within 10m this adit is deep underground. C9 is on exposed moorland, at 598m asl, this adit runs close to the surface for much of its length.

There is less data available for the Durham adits; a similar trend can be seen but there is insufficient evidence to draw any firm conclusions.

Each bat had an ibutton placed nearby to record temperature between survey visits. When a bat had moved between subsequent surveys, the date the bat moved was not known, it could have been the day after it was found, or the day before the next survey, only that it was not present on the next survey visit. Acoustic survey was undertaken within the adits, using Anabat Express and AudioMoth bat detectors. This data did not help clarify when the bats moved!

During this project we have recorded temperature data for 40 bats that stayed and 95 bats that moved. Of these 40 bats, 12 bats stayed in place for at least two subsequent visits and one bat was seen on the next three surveys, a total of 36 days. The shortest duration a bat is known to have stayed is eight days, the longest is 60 days for a Natterer's bat in C9 seen in the same crevice in December 2019, January and February 2020. More bats moved than

stayed during this study, suggesting bats may hibernate within adits which allow them to switch roosts internally during winter to select distinct temperature profiles (Briggler and Prather, 2003). Additional bats were located in this period but due to either ibutton loss or failure, or the adit being too disturbed to leave loggers, there is no temperature data available for these bats.

No statistical differences were found between bats that moved and bats that stayed. This was unexpected, it was predicted that the temperature data would show differences between the two groups. Possible explanations are that all sites have suitable microclimates but were not used equally and that a combination of internal and external roost characteristics influence roost selection (Sandel *et al.*, 2001).

Pairwise comparison among bat species/species groups have shown differences in roost selection by species/species groups, with Natterer's bat seeming to be the most tolerant of lower minimum and average temperatures, closely followed by brown long-eared bat (Wermundsen and Siivonen, 2012); conversely Nagel and Nagel (1991) do not record lower hibernating temperatures for Natterer's bat. Daubenton's bats were the least tolerant of low temperatures (Siivonen and Wermundsen, 2008).

Bat roost selection is likely to be due to a combination of some of the factors recorded and discussed within the scope of this report and some factors which have not been recorded. Humidity was not measured for these sites; all adits, except for C11 and D1, have water running within them, it is considered that this may be a factor influencing roost selection.

Acoustic surveying, using Anabat Express and AudioMoth remote detectors has been undertaken at a number of these sites. Bats have been recorded moving within the tunnels in all winter months. Survey visits continued into April and May in 2017 and 2019 at the Cumbrian sites with bats still being recorded into May.

Future work

Further study is planned at these sites to continue monitoring hibernating bats. In addition to this, other planned areas of study include:

- revisiting sites which currently are not known to support hibernating bats and accessing new sites as the opportunities arise
- confirming swarming; the current knowledge of these sites in autumn is limited but does suggest these sites are important during the swarming period
- investigating year-round use; there is potential for these sites to be used as day roosts throughout the year, further survey work is needed to confirm the species present and the type of use

Acknowledgments

The Environmental Records Information Centre North East enabled the purchase of additional ibuttons via the Small Grant Scheme in 2017, Durham Bat Group funded the ibuttons for the Durham adit project.

Thanks are due to Alex Westerberg and Colleen Selwood for help with statistical analysis using R, and for their good humour and patience. Thank you to Katherine Westerberg and Molly Watson for comments on previous drafts of this paper.

And most importantly, thank you to everyone who has been part of the survey team, these surveys have been undertaken by members of Cumberland, Durham and Northumberland bat groups. This project would not have been able to take place without their help. The survey days are a great way to share skills, share cake and most importantly find bats! I hope you have all enjoyed the surveys as much as I have and I hope to see you all out on the fells again. Thank you.

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Volume Two 2021

The Sefton Coast Site of Special Scientific Interest (SSSI) (Figure 1) is located in north Merseyside, adjacent to Liverpool Bay and the Irish Sea. It stretches for c.22km between Liverpool and Southport and is the largest sand dune system in England; it is also recognised as one of the most important dune habitats in North West Europe. The dune system typically comprises of frontal ‘mobile’ dynamic/embryonic dunes and wet slacks, whilst ‘fixed’ dunes dominated by willow scrub and coniferous plantations lie further inland (Figures 2-6). In addition to the dune system important intertidal salt marsh can be found in several places. Whilst the SSSI is extremely botanically rich the species that are more frequently associated and more well-known with the Sefton Coast are red squirrel *Sciurus vulgaris*, natterjack toad *Epidalea calamita* and the sand lizard *Lacerta agilis*.

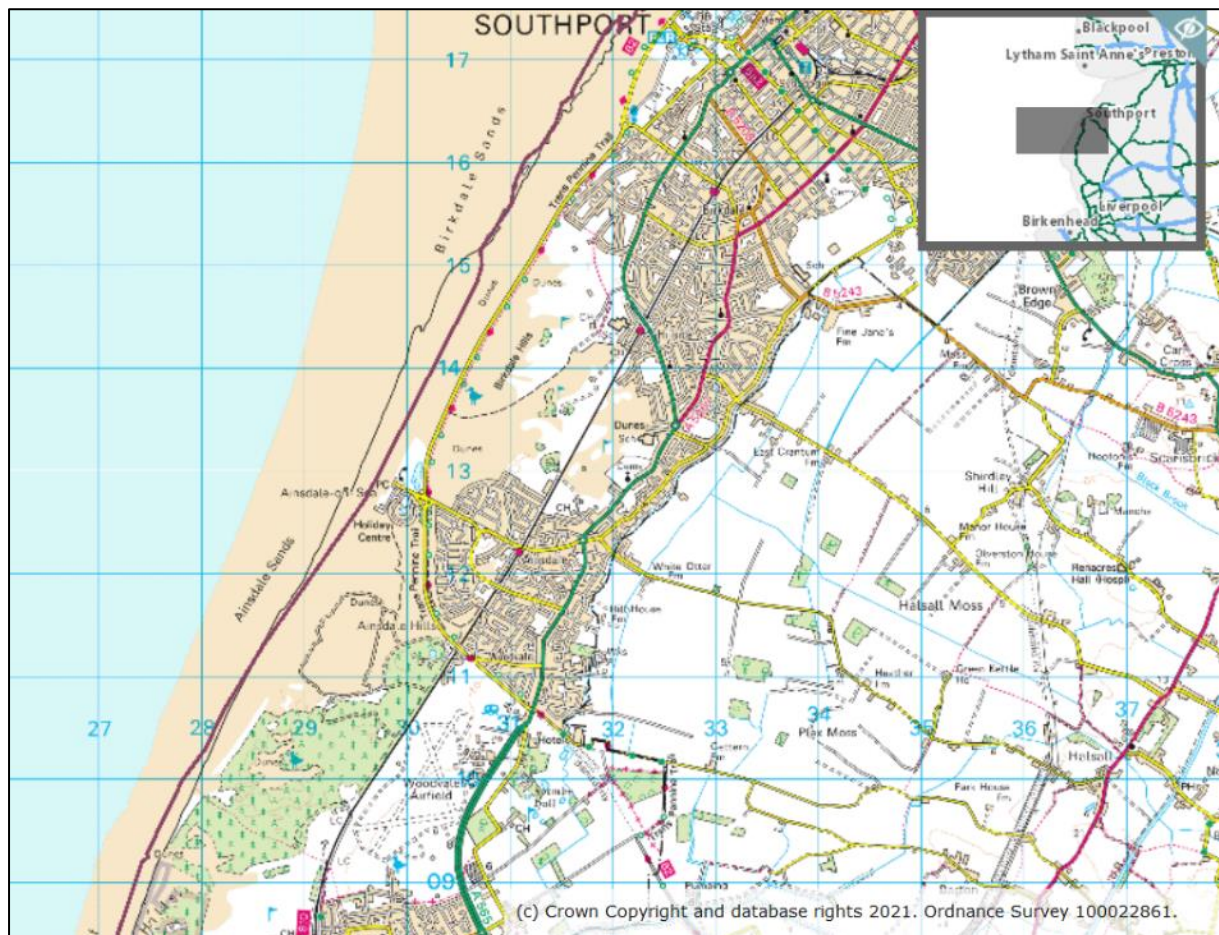


Figure 1: Sefton Coast: SSSI Study area, <https://magic.defra.gov.uk/MagicMap.aspx>.



Figure 2: Frontal mobile/embryonic dunes.



Figure 3: Rear fixed dunes.



Figure 4: Rear coniferous plantation.



Figure 5: Wet slacks within dune system.



Figure 6: Intertidal salt marsh.

Although the Sefton Coast is acclaimed for the aforementioned ecological habitats and species there has never been any systematic attempt to identify bat species that may be present and, if present, where and how they use the coast. To address this omission, I started surveying parts of the coast for bats during 2019-2020 although in 2019 surveys were limited and in 2020 the plans for several teams of surveyors were thwarted by COVID-19. In terms of habitat use I was particularly keen to establish use of the open dunes and shoreline by bats as in previous years I have surveyed many parts of the coniferous woodlands. Also of interest was the presence or absence of Nathusius' pipistrelle *Pipistrellus nathusii* which has previously been recorded in the coastal habitat although in very limited numbers. A number of bat boxes have been erected in Ainsdale National Nature Reserve (NNR) in which common pipistrelle *P. pipistrellus*, noctule *Nyctalus noctula* and brown long-eared bat *Plecotus auritus* have been recorded at various times of the year. Whiskered/Brandt's bat *Myotis mystacinus/brandti* has been recorded on one occasion only, whilst soprano pipistrelle *P. pygmaeus* is yet to be recorded in the coastal zone.

In order to maximise results the survey protocol selected good weather conditions but during one survey in early spring temperatures rapidly dropped to 6°C along with low lying mist; despite the temperature reduction and damp conditions common pipistrelle continued to forage. At certain times of the year Ainsdale NNR and Local Nature Reserve (LNR) are grazed by livestock (Shetland cattle and Herdwick sheep) in order to control scrub and subsequently maintain the open dune system in a favourable condition for rare plants and amphibians for which the SSSI is designated. The surveys were undertaken during time when livestock were both present and absent and results of the surveys during these times compared.

The surveys focussed on three parts of the coast – Ainsdale and Birkdale LNR, Ravenmeols LNR and the Ainsdale NNR (Figures 7 and 8), however the frontal dunes and tideline at Ravenmeols are yet to be surveyed.

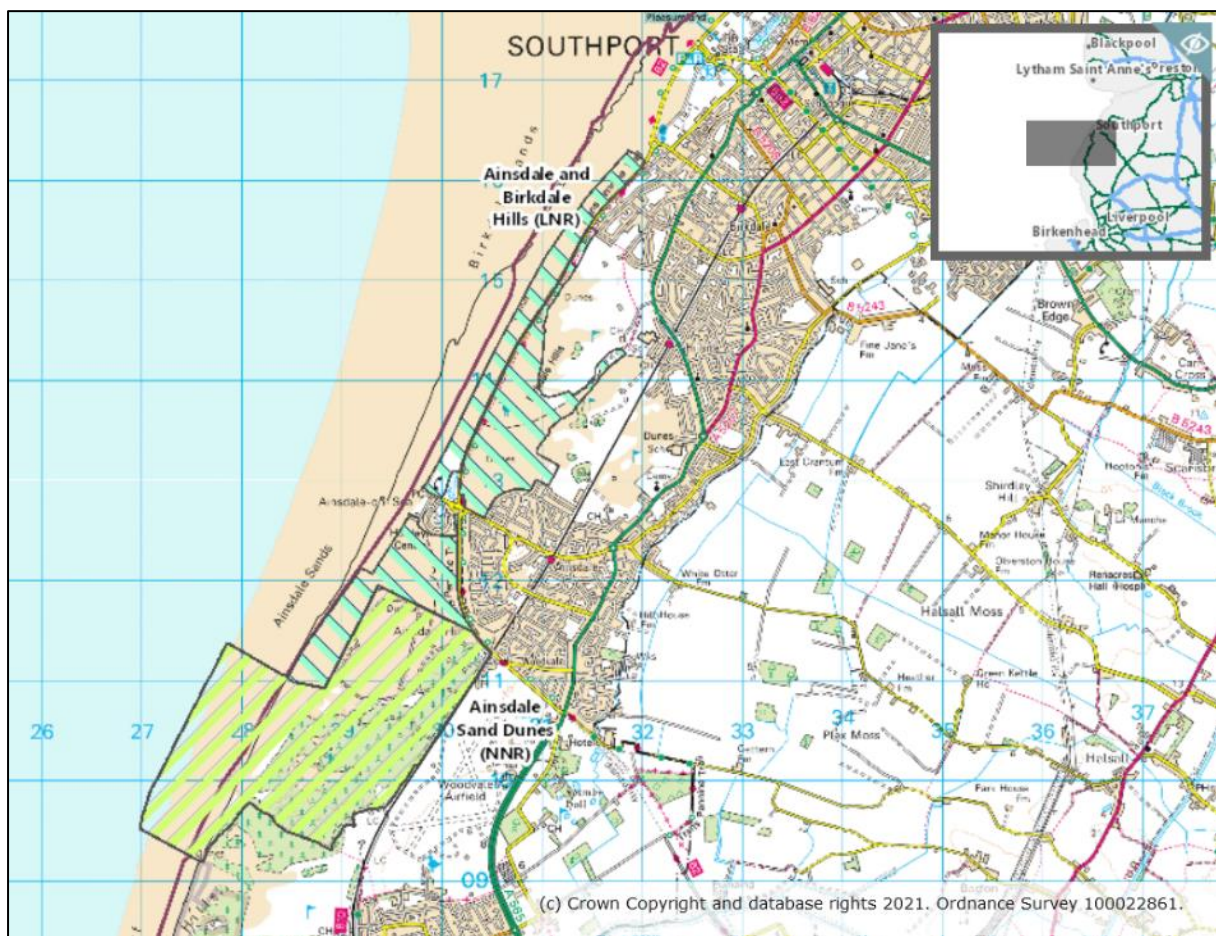


Figure 7: Sefton Coast: Ainsdale and Birkdale Hills LNR, pale green hatching; Ainsdale Sand Dunes NNR, lime hatching. <https://magic.defra.gov.uk/MagicMap.aspx>.



Figure 8: Sefton Coast: Ravenmeols Hills LNR, pale green hatching.

<https://magic.defra.gov.uk/MagicMap.aspx>.

The surveys followed typical transect survey methodology i.e. pre-determined transects including ‘stopping points’ during which time all bat contacts were automatically recorded using an Elekon Bat Logger M. Recordings were subsequently analysed using a combination of Kaleidoscope and Bat Sound software. Transect routes (red lines, Figures 9-13) covered the variable habitats that were of main interest to me i.e. fixed/mobile dunes, slacks, shoreline and intertidal saltmarsh. Five species were recorded notably common and *Nathusius’* pipistrelle, brown long-eared bat, noctule and Daubenton’s bat *M. daubentonii* the latter was particularly interesting as it was located in the open dune system well away from water and woodland habitat that would normally be associated with this species. *Nathusius’* pipistrelle, to date, is not a species that is frequently recorded in the North West of England but is interesting to note that the previous coastal recordings have been in autumn, which may suggest the coast forms part of its migratory patterns, particularly in relation to possible migration across the Irish Sea from Ireland where it is more common. Similarly, this study only recorded *Nathusius’* pipistrelle on 14th September 2020. From the Irish coast to the Sefton coast the closest distance, in a straight line, is just over 200km, which, as records show, is well within the flying distance of *Nathusius’* pipistrelle. Potential stop over points within the Irish Sea include oil rigs and ferries. Figures 9-13 show the transect routes, date of surveys and foraging areas. Bat icons represent Bat Logger bat contacts from GPS co-ordinates.



Figure 9: 16/04/2020. Bat locations: Black bat = common pipistrelle. Ainsdale NNR.
<https://www.google.co.uk/maps>.

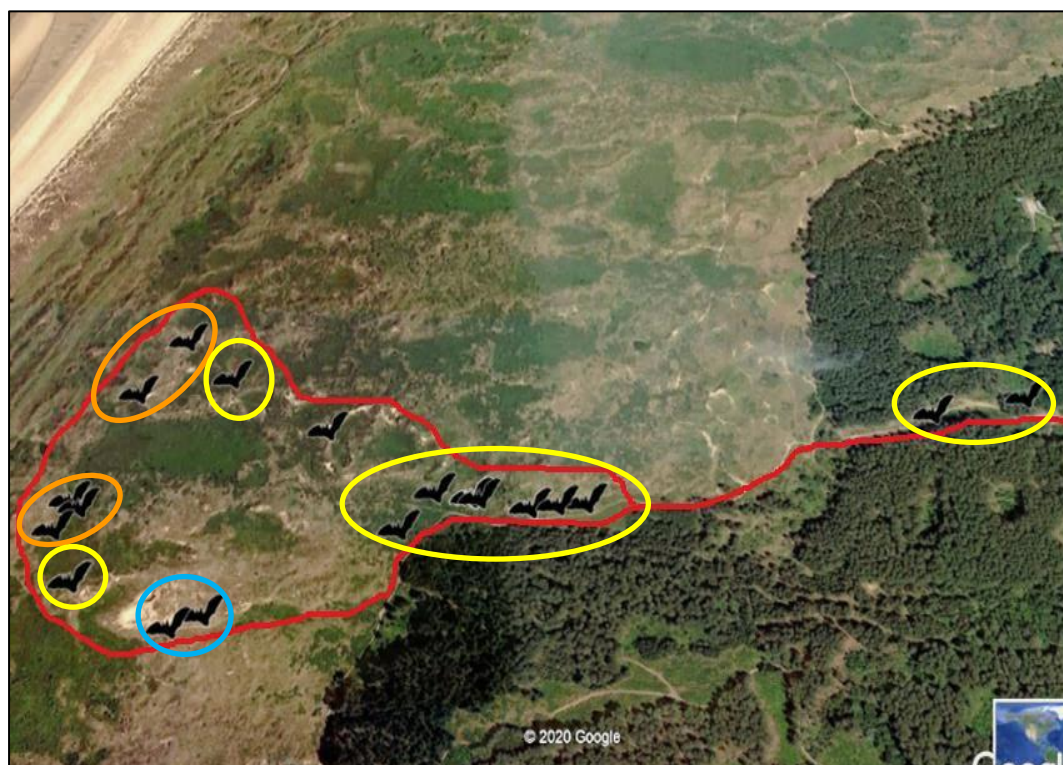


Figure 10: 04/05/2020. Bat locations: Blue circle = Daubenton's bat; Orange circle = noctule; Yellow circle = common pipistrelle (showing bat activity and typical common pipistrelle commuting route to the open dunes along woodland edge). Ainsdale NNR.
<https://www.google.co.uk/maps>.



Figure 11: 03/06/2020. Bat locations: Black bat = common pipistrelle. Ainsdale NNR.
<https://www.google.co.uk/maps>.



Figure 12: 14/09/2020. Bat locations: Black bat = common pipistrelle; Green circle = Nathusius' pipistrelle; Brown circle = brown long-eared bat. Ainsdale and Birkdale LNR.
<https://www.google.co.uk/maps>.



Figure 13: 21/09/2020. Bat locations: Black bat = common pipistrelle. Ravenmeols LNR.
<https://www.google.co.uk/maps>.

Conclusions

1. Five species were recorded notably common and *Nathusius'* pipistrelle, brown long-eared bat, noctule and Daubenton's bat, the latter as noted above was located in the open dune system well away from water and woodland. Coastal recordings of *Nathusius'* pipistrelle recordings have been in autumn, which may suggest the coast forms part of its migratory patterns, particularly in relation to possible migration across the Irish Sea from Ireland where it is more common.
2. Commuting takes place along woodland edge and fire breaks into the open dunes where linear features then become absent.
3. The closest typical roost opportunities for common pipistrelle bats in the form of residential dwellings lie at approximately 2km from the main foraging areas.
4. Common pipistrelle activity along the shoreline and intertidal saltmarsh was frequently encountered including forays over the open seaward sands to approximately 30m away from the frontal dunes.
5. The presence or absence of livestock appears to show no clear differential in relation to bat activity.
6. Activity was more frequent in the open frontal dunes as opposed to the rear fixed dunes where the habitat is more variable in the form of scrub and small pockets of deciduous trees.
7. Deciduous woodland was by-passed in favour of coniferous woodland for foraging.

Future Surveys

Further survey at these sites is recommended; points to consider are:

- Synchronised team surveys over the SSSI coastal zone
- Survey more of the tideline and intertidal marsh
- Compare in more detail use of coniferous and deciduous woodland
- Compare in more detail bat activity during presence/absence of livestock

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Bats with Altitude: Determining the presence of bats in high altitude locations within the British Lake District

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Abstract

Static detectors were used in locations across the Lake District National Park, Cumbria to record bat activity at locations generally above 500m elevation (approximate treeline). Bat activity was detected at over half of all sites surveyed, albeit at relatively low levels (average 6.3 passes per night) and in all months surveyed (April-October 2016 and May-August 2017).

All eight species known to be resident within the county were detected using habitats above 500m; the most common species was common pipistrelle *Pipistrellus pipistrellus*. A low number of bats were detected close to sunset, suggesting summer roosting behaviour at altitude. However, the majority of recordings were notably later, suggesting that bats were commuting to the sites from lower elevations. There were no significant correlations between bat activity and habitat features.

Background

UK bats are some of the best studied in the world; nationwide surveys under the National Bat Monitoring Programme have been carried out since 1996 (Bat Conservation Trust, 2020). Yet, although hibernation behaviour has been studied at some moderate elevations (for example Easegill caves at approximately 300m), little appears to be known about summer bat activity in the higher elevation habitats of the British Isles, areas such as the

Lake and Peak Districts of England, Snowdonia and the Brecon Beacons of Wales and the Highlands of Scotland.

Internationally, studies have been undertaken investigating the altitudes of flying bats; these have demonstrated that many species are present at comparatively high altitudes. Mexican free-tailed bats *Tadarida brasiliensis* can be found at up to 1,118m above sea level (McCracken *et al.*, 2008), while migrating bats, such as the North American hoary bat *Lasius cinereus*, have been documented at up to 3,000m (Peurach, 2003). In Zimbabwe at least six *Molossidae* and one *Emballonuridae* bat species were found feeding at 600m above the ground (Fenton *et al.*, 1997).

Although occasional anecdotal reports of bats observed within mountainous habitat exist, there is little published research on bats foraging above the treeline in high-altitude terrain in the UK (Google Scholar search using keywords: 'bats altitude', 'bats altitude UK', 'bats altitudinal gradient', 'bats elevation'). One of the few studies we could find was undertaken by Dunn and Waters in 2003, which monitored common and soprano pipistrelle *P. pygmaeus* activity across an altitudinal gradient on the Isle of Man; this study sampled activity up to 400m above sea level.

It is generally accepted that Chiroptera, as an order, favours warm habitats; the greatest density of bat species being found within the tropics (Altringham, 1996). Higher altitude habitats, where temperatures are comparatively low, are therefore likely to be less favourable for bats. A comparative study by Erikson and Adams (2003) looking at bat use of high and low elevations in Washington, USA, showed that activity levels were four times greater at low elevations (<150m) than at high elevations (>575m).

Although Britain does not boast any of the highest mountains of Europe, the conditions that can be experienced at the summits of this country's comparatively minor peaks can be disproportionately harsh. Bats seeking to forage within this inclement environment are likely to experience frequent fluctuations in temperatures, strong winds and heavy rain, all within an open and barren habitat with few available roosting locations. In the UK, the treeline is at about 500-600m. Therefore, the above study (Erickson and Adams, 2003) and similar studies, such as those undertaken in British Columbia by Grindal *et al.* (1999) cannot be used as a model because, unlike UK mountains, the habitat surveyed was forested throughout and therefore provided a more suitable location for roosting and foraging bats.

Whilst undertaking a bat habitat modelling study across the southern Lake District in 2013, Chloe Bellamy, of Leeds University, recorded occasional commuting bats above the fells (exact elevation unknown). While, in advance of our study, occasional informal visits were made by the author to relatively high-altitude locations (550m) to determine if bats could be encountered; bats were recorded on all visits.

Aims

It was therefore decided to embark on a study to attempt to establish the following:

- Whether bats use high altitude locations (above 500m)
- Which bat species are encountered on high ground

- Do habitat features have a significant impact on the presence of bats within these locations

Method

Site Selection

The Lake District National Park, in Cumbria, was chosen as a survey area. Cumbria hosts eight resident and two vagrant bat species (which there are currently no county roost records for) (Cumbria Biodiversity Data Centre, 2021).

Table 1: Cumbrian bat species.

Resident	Vagrant
Daubenton's bat <i>Myotis daubentonii</i>	Leisler's bat <i>Nyctalus leisleri</i>
Brandt's bat <i>Myotis brandti</i>	Nathusius' pipistrelle <i>Pipistrellus nathusii</i>
Whiskered bat <i>Myotis mystacinus</i>	
Natterer's bat <i>Myotis nattereri</i>	
Noctule <i>Nyctalus noctula</i>	
Common pipistrelle <i>Pipistrellus pipistrellus</i>	
Soprano pipistrelle <i>Pipistrellus pygmaeus</i>	
Brown long-eared bat <i>Plecotus auritus</i>	

The national park was divided into 3km quadrats (Figure 1). Those that contained land above 500m were numbered from 1 to 80. The aim was to carry out a period of static bat detection within as many of these quadrats as possible.

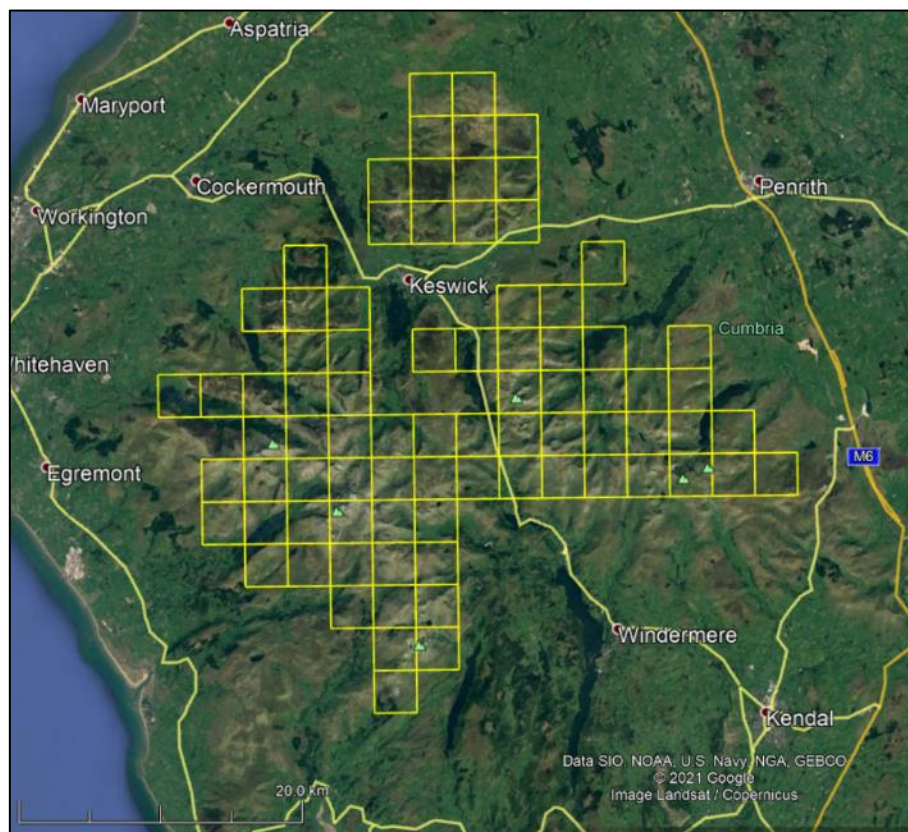


Figure 1: Survey quadrats.

Survey Period

Data was collected between April and October 2016 and between May and August 2017. As activity was expected to be low, it was decided to focus on the months where activity was expected to be highest.

Data Collection

Thanks to funding from the South Cumbria Bat Group (SCBG) and a grant from the Lake District National Park Authority (LDNPA), Anabat Express detectors were procured, bringing the number of available SCBG owned Anabat Expresses up to seven.

The majority of the survey locations were in remote mountainous situations, only accessible on foot. A request was put out on social media and through the bat group and Cumbria Wildlife Trust for volunteers who would be willing and capable of walking to these locations to deploy the detectors. A team of twenty volunteers was established, many of whom had no experience with bat surveying. Volunteers were given an introduction into the operation of the static detectors; the Anabat Express was chosen in particular, due to its ease of use for the inexperienced surveyor.

An online rota was established where volunteers could sign out detectors and see which quadrat squares needed to be surveyed. Volunteers would choose a location within the 3km quadrat that was above 500m elevation. As the detectors are designed to be deployed unmanned, volunteers were required to hide them so that they would not be found by passers-by. Due to the barren nature of the landscape, this would frequently require hiding the detectors beneath piles of rocks or under moss piles (Figures 2 and 3). The Anabat Express is protected by a waterproof housing and can therefore withstand getting wet, as long as the microphone does not get soaked.



Figures 2 and 3: Anabat deployment locations. © Richard McGuinness and Jane Newport.

The Anabat Express units were programmed to 'Night Only' mode, which activates 30 minutes before sunset and turns off 30 minutes after sunrise. This program mode was selected for its ease of operation, the lower demand on batteries (compared to 'Continuous' mode) and the fact that day-flying bats were considered to be relatively unlikely.

Fresh batteries lasted for a maximum period of 20 days, therefore, in general detectors were left *in situ* for at least two weeks in the period between April and October 2016. In

2017, nine additional quadrats were sampled, but the intensity of effort was markedly reduced; all being surveyed by a single volunteer.

Habitat data was collected for each of the sample locations, through the use of aerial imagery and GIS mapping. Distances were measured to landscape features that may have some influence on bat activity:

- Becks (streams)
- Crags or Rocky Outcrops
- Marshy Ground
- Footpaths
- Tarns (standing water)
- Trees
- Buildings

Data Analysis

Anabat Express detectors record to SD cards in ZC file format. Volunteers were required to download the files and email them to the project co-ordinator for analysis. Analysis was undertaken using AnalookW. Calls were identified to species level, where possible, including *Myotis* bats. However, where definitive species identification could not be established (due to the well-known acoustic overlap between species) *Myotis* species files were identified to genus level only. 'Big bats' (*Nyctalus* and *Eptesicus* species) and *Plecotus* species bats were all identified to species level due to the presence of only one resident species of each group (e.g. noctule and brown long-eared bat) in Cumbria.

Simple one-tailed Analysis of Variance (ANOVA) tests were run, using Excel, to determine whether the mean nightly bat passes had any significant dependence on the various habitat proximity values.

In addition, Regression Analysis was undertaken to establish if a significant correlation existed between the mean nightly bat passes and the minimum daily temperature or daily rainfall amounts.

Results

Of the 80 possible quadrats, 38 were surveyed in 2016 and a further nine were surveyed in 2017. In total, 179 individual nights were surveyed in 2016, however, with multiple detectors deployed on the same nights, the total number of survey nights in 2016 was 513 (Figure 4). In 2017, 91 individual nights were surveyed, with a total of 131 survey nights undertaken.

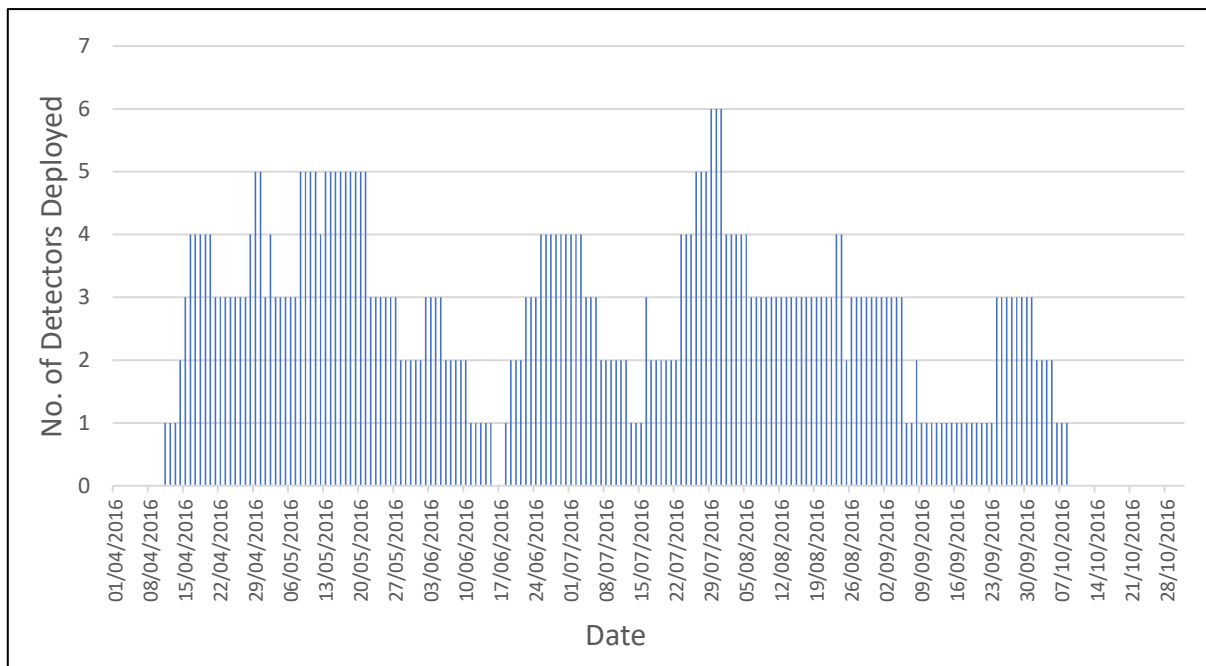


Figure 4: Survey nights in 2016.

The minimum period of deployment was eight consecutive nights and the maximum was 20 (although one detector ran out of battery power after a single night); the average deployment period was 13 nights. Due to the variation in deployment periods, a mean number of bat calls per night was obtained for each location, which could provide a comparative value.

Of the 47 locations surveyed during 2016 and 2017, 27 sites recorded bats. In total 3729 files were identified that contained bat calls. Some files contained multiple species, therefore a total of 4040 individual bat passes were recorded.

Of the eight resident Cumbrian species, all eight were identified (Figure 5), although not always to species level. The dominant species was common pipistrelle with 2593 passes, over five times more than the next most prevalent species group, which was *Myotis* (479) followed by soprano pipistrelle (438). The dominance of common pipistrelle is demonstrated by the fact that it features in 64% of the bat files recorded. Naturally, it was also recorded on the highest number of nights (Table 2). The least numerous species of bat to be encountered were whiskered bat (5) and Brandt's bat (22). However, it can be assumed that a proportion of the *Myotis* species files should be attributed to these species. The most common *Myotis* bat was Daubenton's bat; conversely to whiskered and Brandt's bat identification, this may be because this species of bat can be more readily identified through sound analysis than other *Myotis* species.

Noctule and brown long-eared bat both featured a similar number of times, with just 86 and 85 files respectively; they were also recorded on a similar number of nights (34 and 38), giving them similar mean number of passes per detected night. All *Nyctalus* calls were examined for the possibility of Leisler's bat; however, no files matched the parameter profile of Leisler's bat.

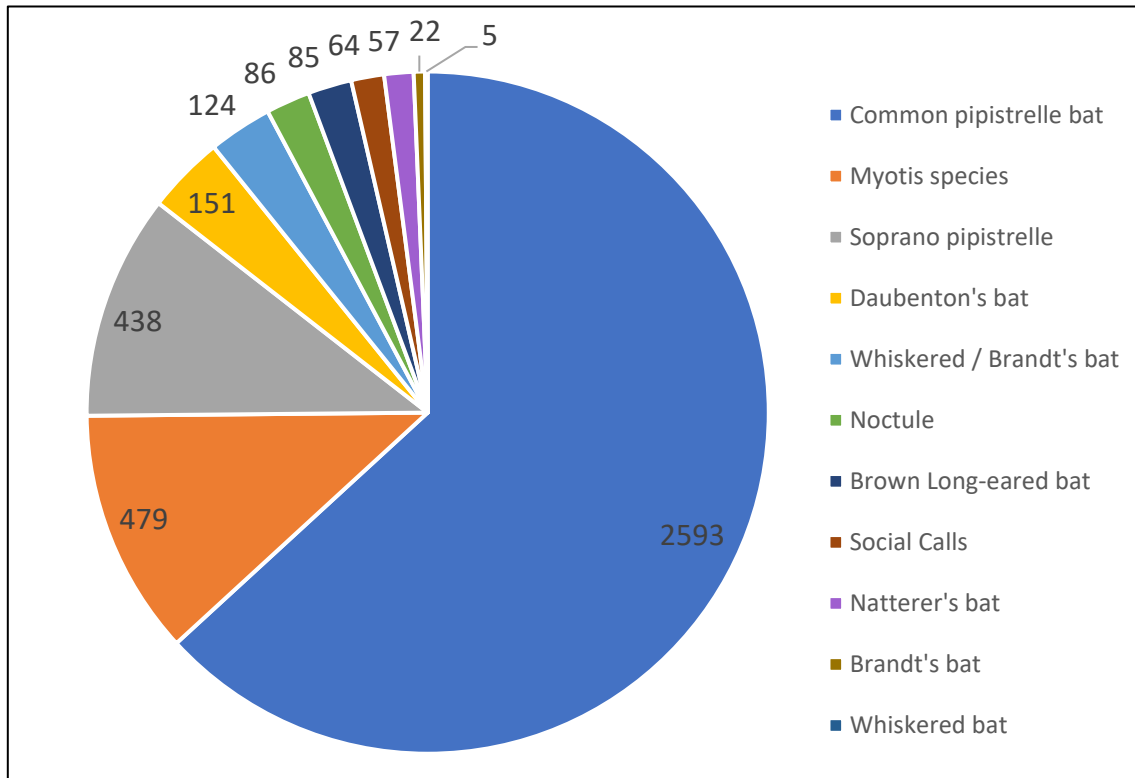


Figure 5: Proportion of recordings by call type.

Table 2: Number of bat calls and nights recorded, by species.

Species	Total Calls Recorded	No. Nights Recorded	Mean No. of Calls Per Recorded Night
Common pipistrelle	2593	80	32.4
<i>Myotis</i> species	479	52	9.2
Soprano pipistrelle	438	55	8.0
Daubenton's bat	151	26	5.8
Whiskered/Brandt's bat	124	18	6.9
Noctule	86	34	2.5
Brown long-eared bat	85	38	2.2
Social Calls	64	23	2.8
Natterer's bat	57	24	2.4
Brandt's bat	22	3	7.3
Whiskered bat	5	3	1.7

64 files were found to contain social calls; these were predominantly *Pipistrellus* type D social calls (Figure 6). Over half of these files (36) were recorded within the period 22/08/16 to 03/09/16 when mating and therefore mate attraction and competitor antagonism is likely to be strong.

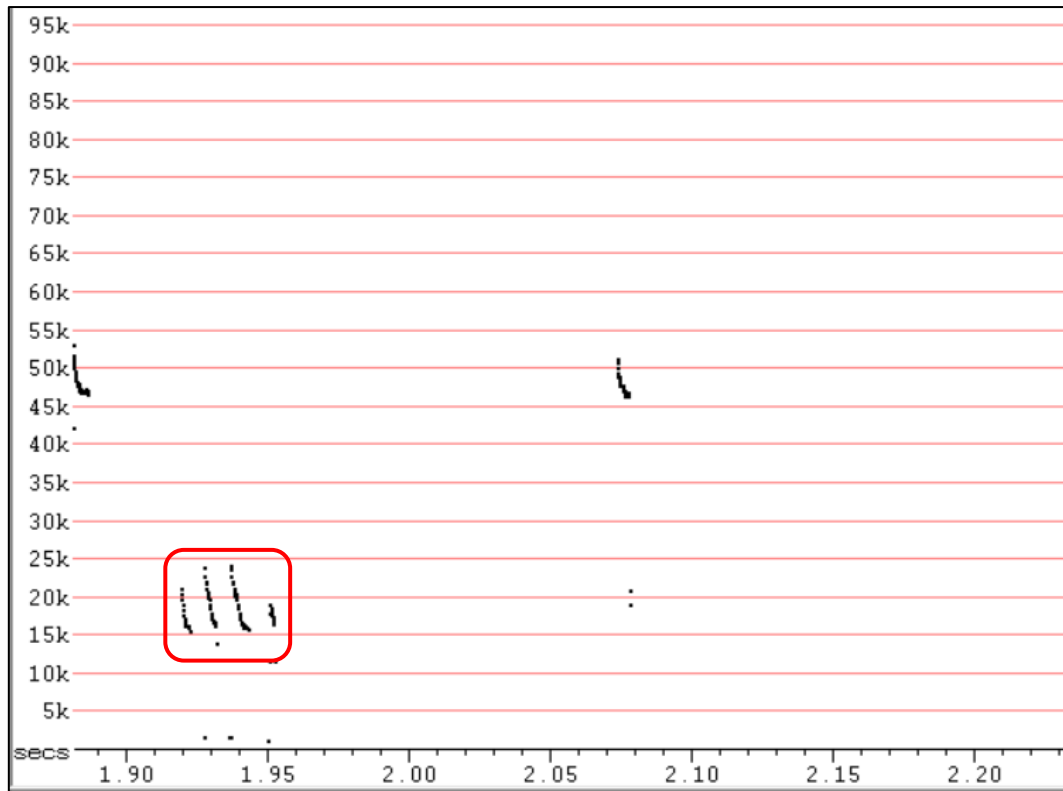


Figure 6: Common pipistrelle type D social call.

Due to a geographic bias of volunteers living on the eastern side of the National Park, a greater proportion of eastern quadrats were sampled (Figure 7). Given this, it would be expected that a greater proportion of east-facing locations would be chosen. However, a variety of aspects were sampled with no significant emphasis towards any aspect (Figure 8).

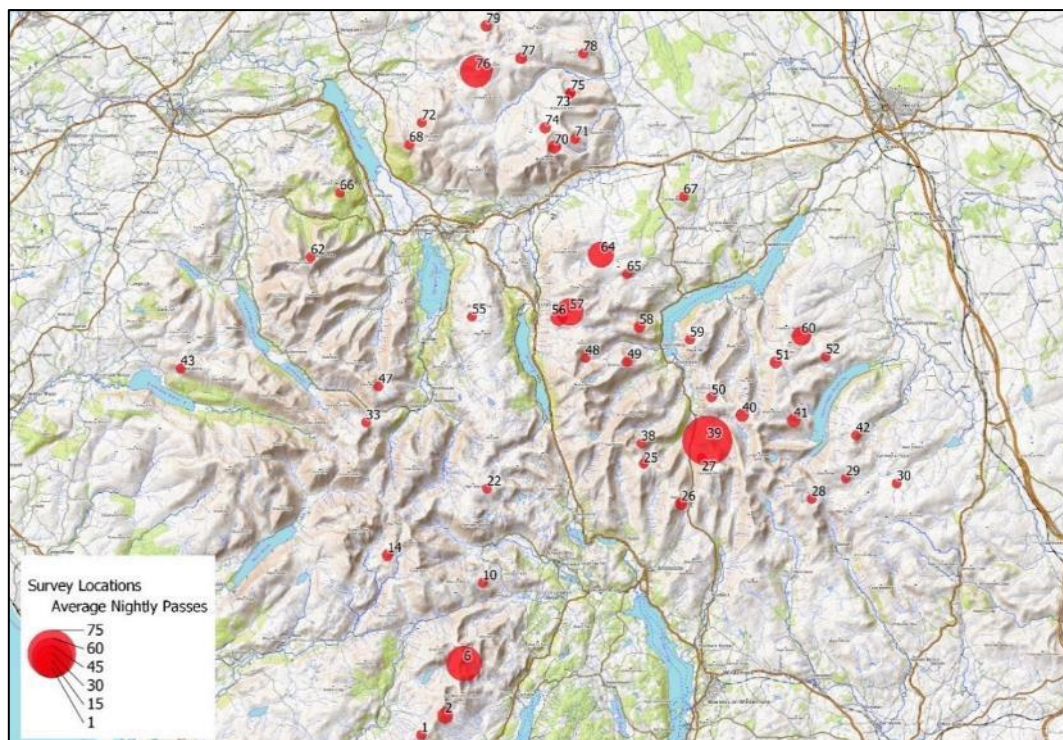


Figure 7: Average nightly passes in surveyed locations.

England – North West

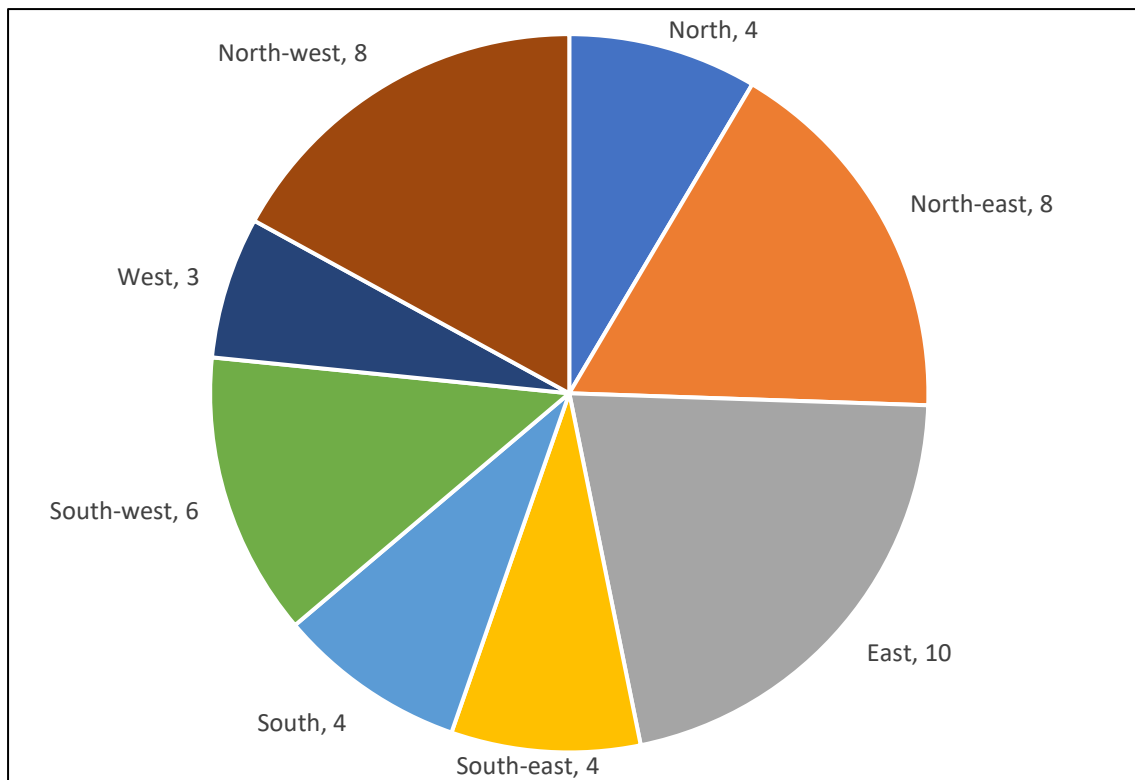


Figure 8: Proportions of aspects surveyed.

Proximity to habitat features were correlated against the mean nightly bat passes, using a one-tailed ANOVA, to establish any connection between habitat and the level of bat activity. Unfortunately, none of the factors returned a p-value of less than 0.05, which would have suggested a significant correlation. The graphs below (Figure 9) show a large variation in the values in all factors, indicating a lack of a trend and therefore a more random distribution. In order to discern whether the weakness of the statistical analysis was due to the small number of values within each category, and therefore a lack of statistical robustness, t-tests were run with the same figures, dividing the results into two categories, 0-500m and >500m. These also did not return a significant figure.

England – North West

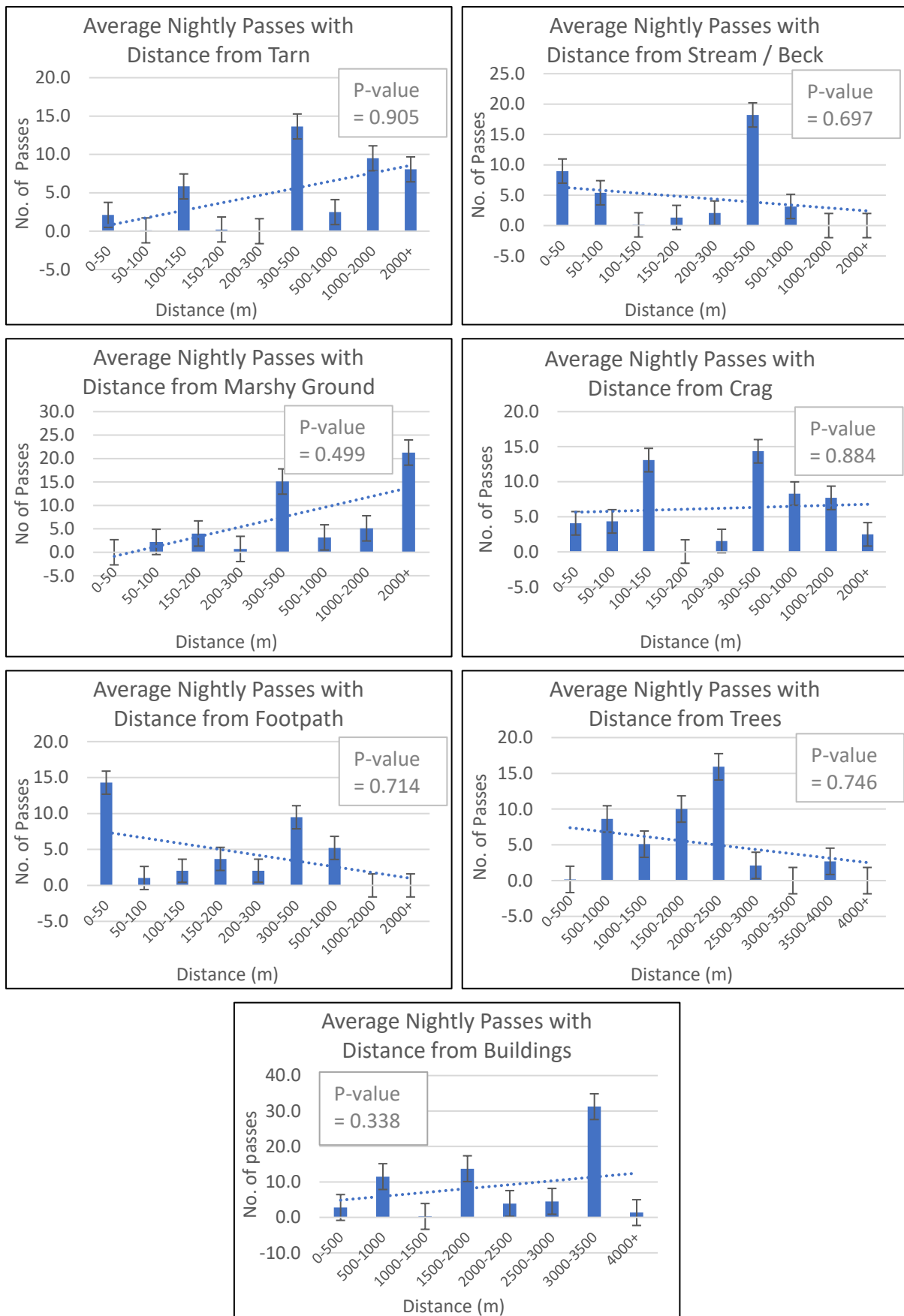


Figure 9: Graphs of average nightly passes against various habitat factors.

In addition, historic rainfall and minimum daily temperatures were correlated against the daily mean number of bat passes using regression analysis. There is a weak to moderate correlation between temperature and bat activity, as can be seen in Figure 10. However, there was no significant correlation between rainfall levels and bat activity, with a figure returned that suggested random distribution (Figure 11).

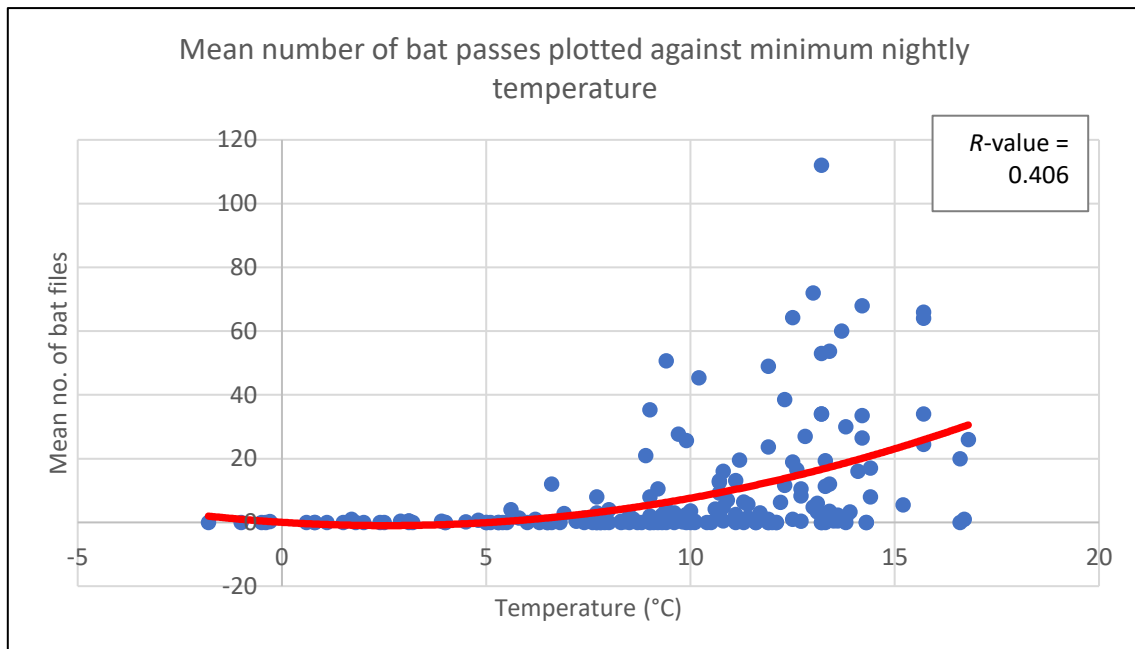


Figure 10: Mean number of bat passes plotted against minimum nightly temperature.

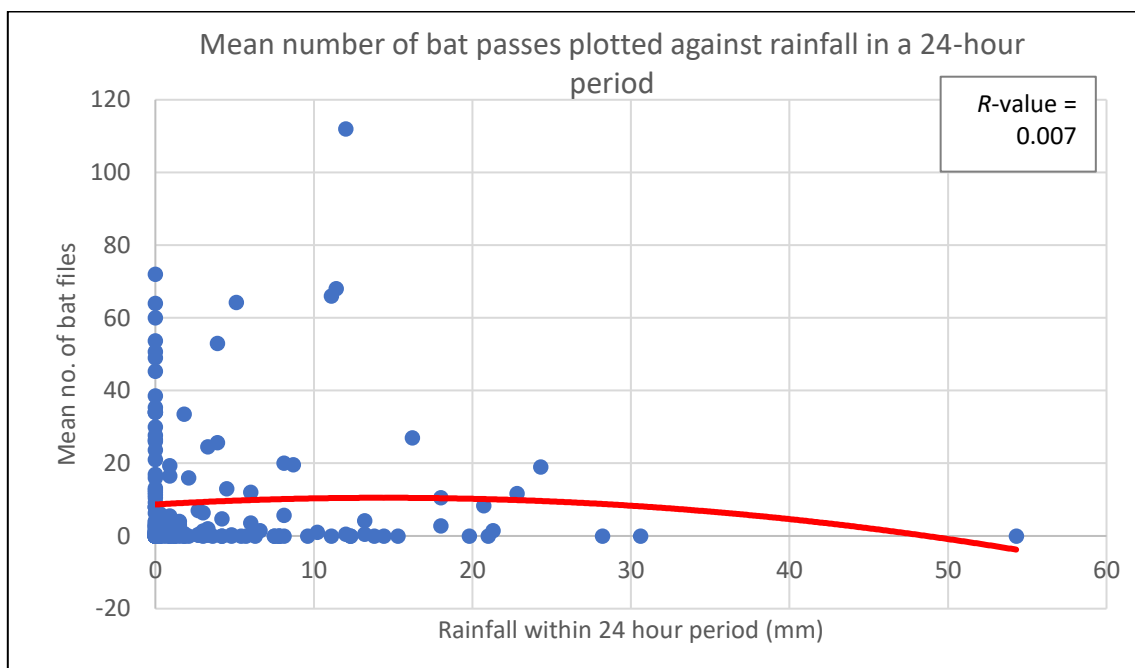


Figure 11: Mean number of bat passes plotted against rainfall in a 24-hour period.

Finally, the time of the first nightly bat recording was examined in relationship to the sunset time. The earliest recording of a bat was a common pipistrelle, recorded at 2 minutes and 54 seconds after sunset, on the 1st August 2016. The table below shows the first recordings

of each species, while the graphs within Figure 12 illustrate the recording times after sunset, including the average species emergence time (where relevant).

Table 3: Time of earliest recording, by species.

Species	Earliest 1st Recording (mins after sunset)	Mean Species Emergence Time (MSET)	1st Recording Variation from MSET
Common pipistrelle	2	25 mins	-23
Soprano pipistrelle	14	31 mins	-17
Brown long-eared bat	36	59 mins	-23
<i>Myotis</i> species	38	N/A	N/A
Whiskered/Brandt's bat	39	29 mins	10
Daubenton's bat	46	45 mins	1
Noctule	54	7 mins	47
Natterer's bat	72	54 mins	18
Whiskered bat	78	33 mins	45
Brandt's bat	170	24 mins	146

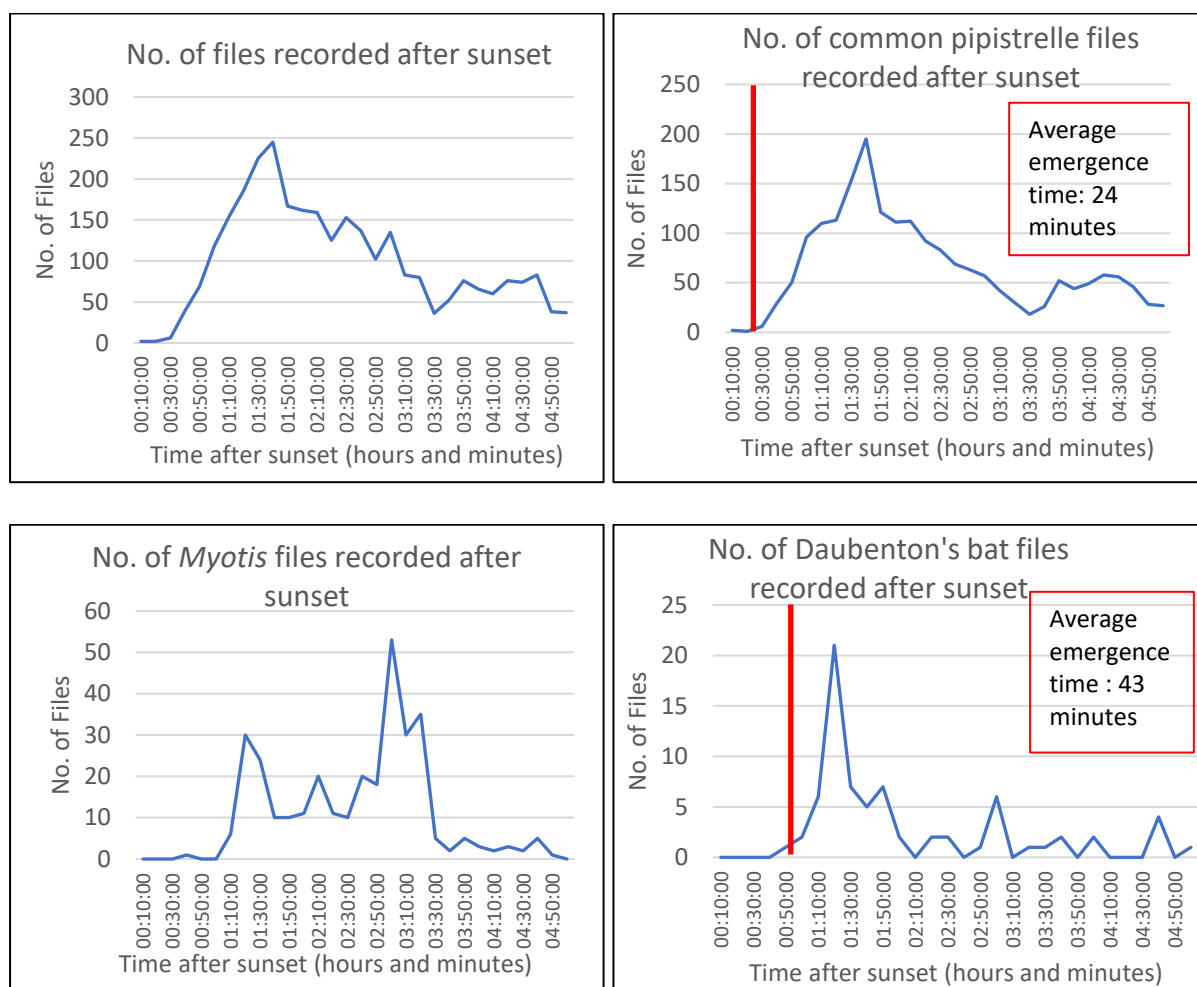


Figure 12: Number of bat passes recorded over time (data pooled over all locations/survey periods). (Continued on next page.)

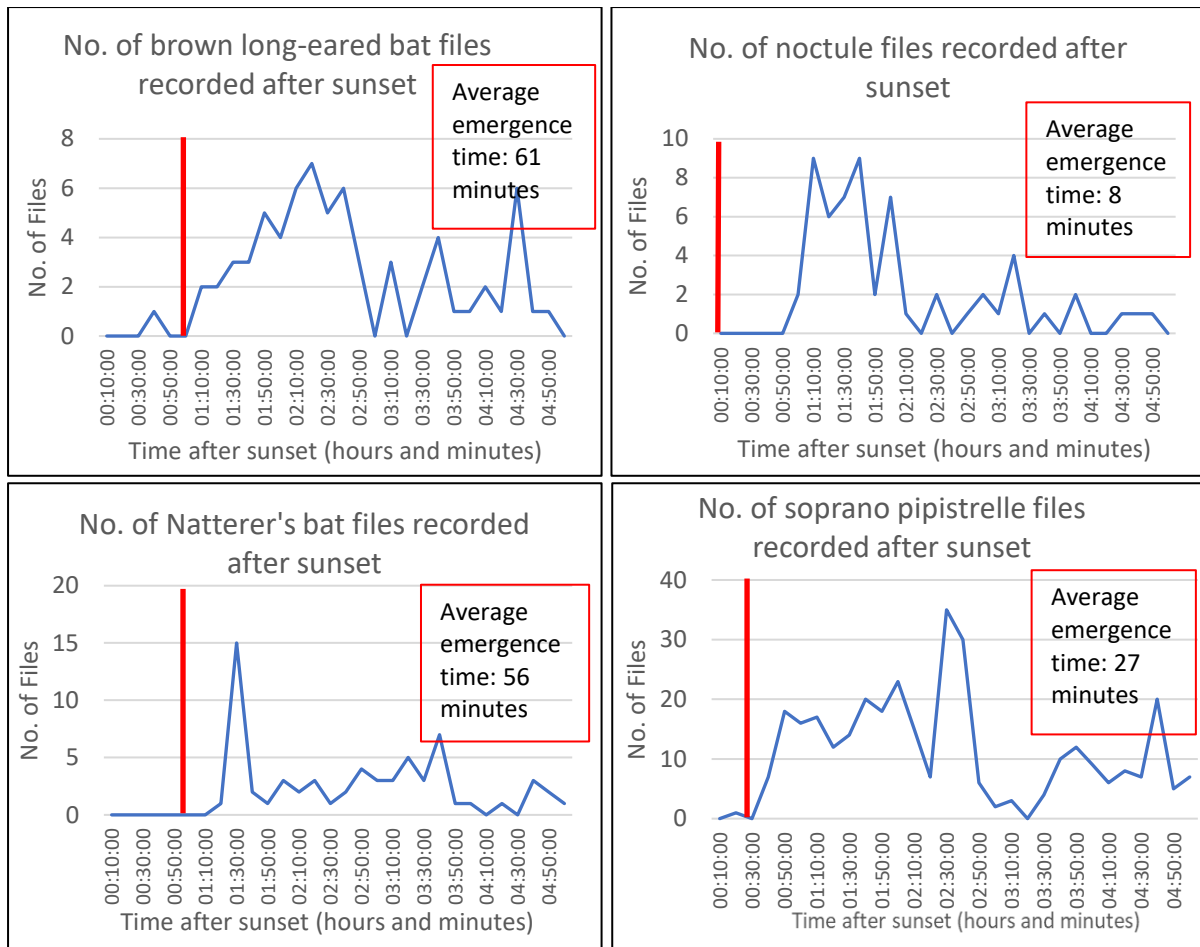


Figure 12 continued: Number of bat passes recorded over time (data pooled over all locations/survey periods).

The majority of the sites, however, did not have significantly early recordings; the graphs below (Figure 13) show the earliest emergence times for four species, in relation to the Mean Species Emergence Time (MSET), at each site where that species was recorded. The majority of the sites display first recording times of well past the MSET.

The time of the latest files recorded for each species, those recorded close to sunrise, were also accounted for (Figure 14). Again, the species that were active closest to sunrise were common pipistrelle and soprano pipistrelle bats, the former recording three files that were actually after calculated sunrise time for the day in question. The latest of these three files was two minutes after sunrise on the 24th May 2016. The latest soprano pipistrelle was recorded at one minute before sunrise.

England – North West

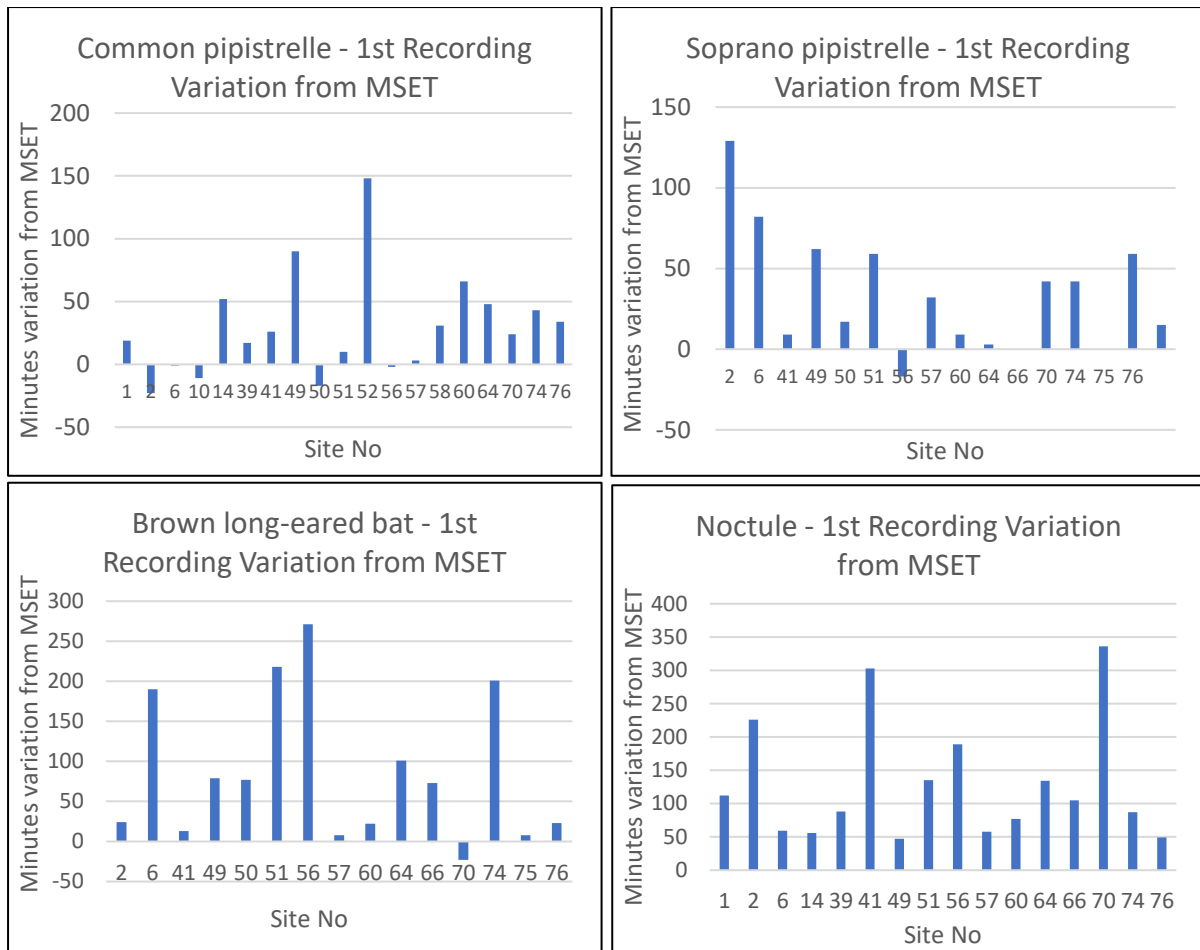


Figure 13: Time of first recording at each site for four species in relation to MSET.

Table 4: Time of last recording, by species.

Species	Last Recording (mins) in Relation to Sunrise
Common pipistrelle	-2
Soprano pipistrelle	1
<i>Myotis</i> species	40
Daubenton's bat	40
Natterer's bat	58
Whiskered/Brandt's bat	89
Brown long-eared bat	95
Noctule	102
Brandt's bat	153
Whiskered bat	176

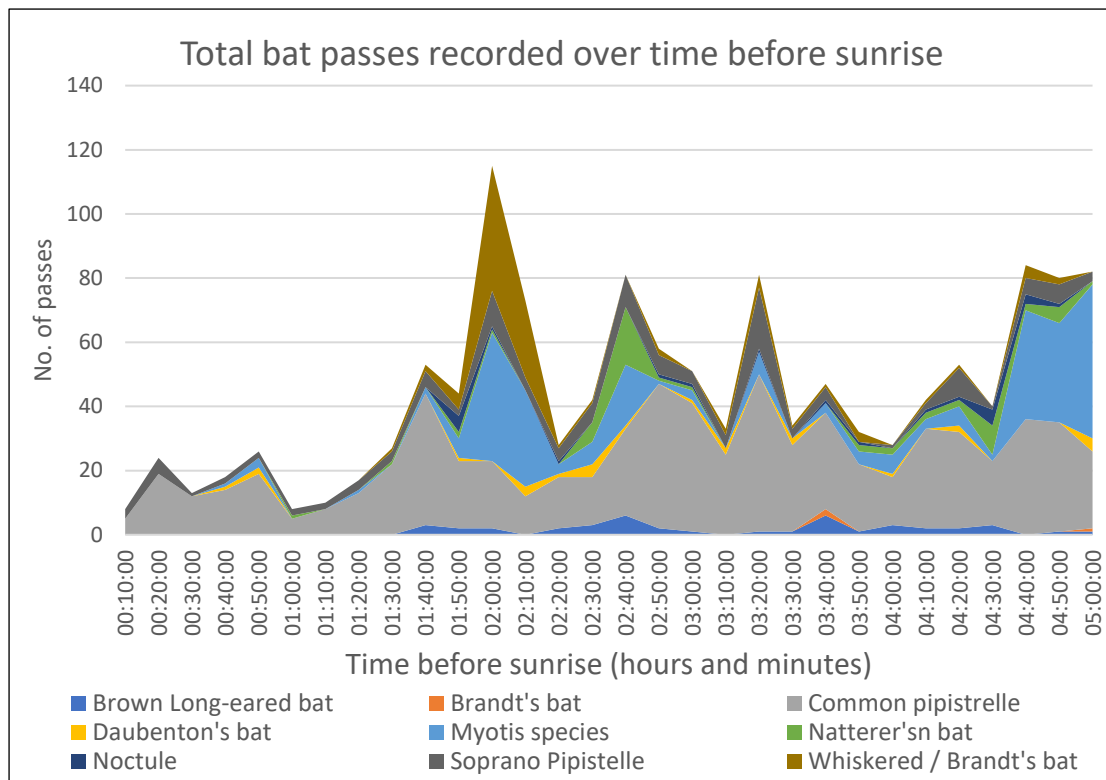


Figure 14: Total bat passes recorded over time before sunrise (Data pooled over total survey period).

Discussion

Presence of Bats

The initial aim of this project was to establish whether British bats could be found foraging and/or commuting within the comparatively harsh environment of the Lake District higher fells. In this respect, the conclusion is resoundingly positive.

With over 4000 individual bat passes recorded on a total of 634 calendar nights, it can be concluded that the presence of bats within the high fells of the Lake District is a feature and not an exception. That said, the presence of bats within the survey data is far from consistent. With an average of just 6.3 passes per night, it is clear that there is not a significant population of bats using the fells. 20 of the 47 sites that were surveyed did not record any bats at all; however, one site recorded 779 bat passes within a ten day period (this site is examined later in the discussion).

Although the Lake District fells reach a maximum height of 978m (Scafell Pike), the majority of the locations that were surveyed were within the 500-600m band, with 34 of the 47 sites falling within this category. As the project relied on the good will of volunteers, and the Lake District fells are a potentially dangerous environment, it was decided to allow volunteers to decide where they were prepared to position the detectors. This may provide some bias of results and does not conclusively prove that bats can be found on or around the peaks of the highest fells. The highest location to record bats was site 39, which was located at 615m above sea level, close to the summit of Hartsop Dodd; this site was actually the location which recorded the maximum number of bat passes, as mentioned above. Three sites were surveyed at elevations above 615m, but none returned any bat files.

Species

During preliminary visits to the high fells prior to the start of the project, both common and soprano pipistrelle had been encountered, as had Daubenton's bat. As predicted, the two *Pipistrellus* species were the commonest species encountered during the study (ignoring the generic *Myotis* classification). However, common pipistrelle was recorded with a significantly greater frequency than soprano pipistrelle. Within Cumbria, both species are encountered with a relatively similar frequency. Indeed, the largest known roosts in the county belong to soprano pipistrelle and number over 2000 individuals. The dominance of common pipistrelle must therefore be assumed to be due to a habitat or prey preference. As both species feed on small insects, predominately Diptera (Dietz and Keifer, 2016), the latter factor is unlikely to be the dominant force; there is an abundance of small dipterans, including both biting and non-biting midges, within the Lake District fells.

Soprano pipistrelle is known to select riparian habitat over all others (Davidson-Watts *et al.*, 2006), whereas common pipistrelle has been found to be a more generalist forager, utilising a wider variety of habitats and over a wider geographic area (Nicholls and Racey, 2006). Although the high-fell habitat is naturally wet in nature, the watercourses tend to be small and the associated habitats are not typically riparian. It is therefore possible that the more opportunistic foraging strategy of common pipistrelle, combined with their wider foraging ranges, allow them to exploit the mountainous habitat while a greater proportion of soprano pipistrelle remain in the lowland riparian habitats.

Although both *Pipistrellus* species were anticipated, it was not known which of the other eight resident Cumbrian species might be recorded during the project. It seemed unlikely that species such as brown long-eared bat, which favour wooded areas and tend to forage relatively close to their roosts, would be encountered in such open and remote locations. However, the results indicate that all eight of the resident species have been recorded during the project, including brown long-eared bat.

One explanation for the presence of bats outside of their core habitat requirements could be autumn swarming and the reconnaissance of winter hibernation roosts. If this were the case, it would be expected that species like brown long-eared bat and those from the *Myotis* family would be recorded with greater frequency during September and October, when autumn swarming is most active. However, low activity of brown long-eared bat was recorded during every month, from April to September, the most frequently recorded month being April (Figure 15); therefore, swarming and reconnaissance are unlikely to be the case with this species.

Conversely, Figure 15 shows that although there is activity by *Myotis* bats throughout the summer, numbers appear to peak in August. This may indeed indicate an increase in activity associated with autumn swarming. During the initial reconnaissance visits to the fells, two hibernating whiskered/Brandt's bats were found in a slate mine on the slopes of Conistone Old Man, approximately 510m above sea level (Figure 16), thus confirming that hibernation does occur in the high fells where conditions are suitable. Whether conditions would be suitable outside of cave-type locations is debatable. Although crags and rocky outcrops are common in the fells, they often freeze in winter and are exposed to temperatures that drop below -10°C most years.

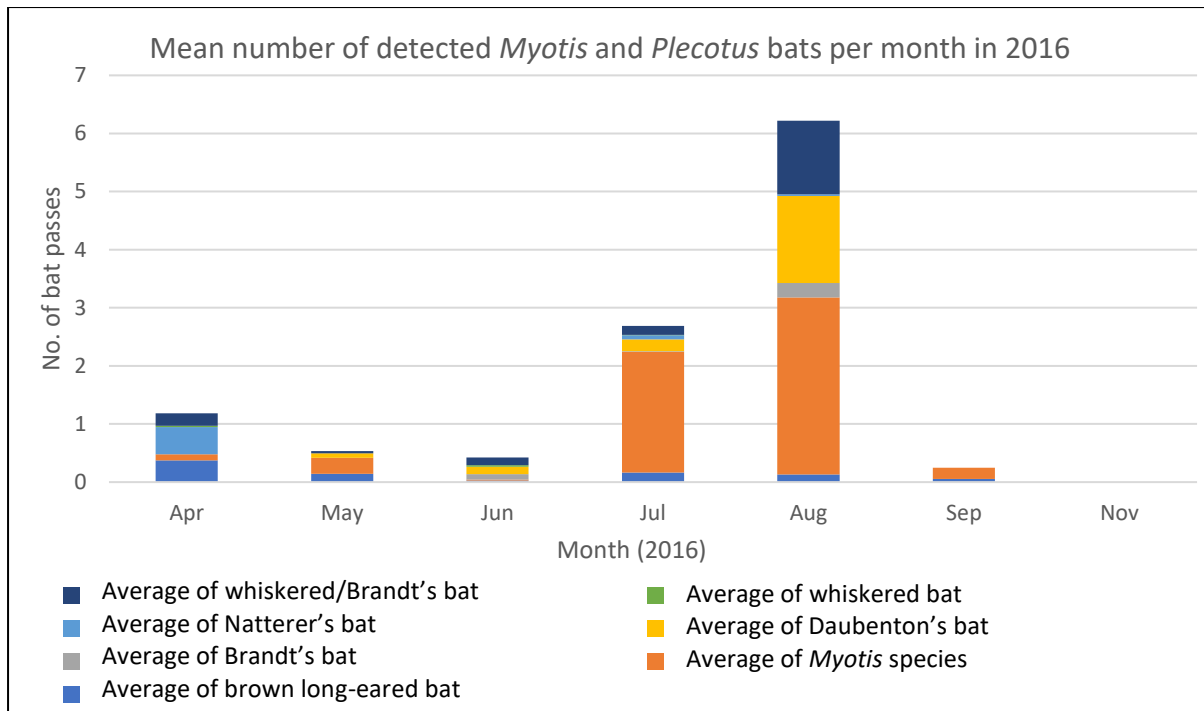


Figure 15: Mean number of detected *Myotis* species and brown long-eared bats per month in 2016.



Figure 16: Hibernating whiskered/Brandt's bat in mine c.510m above sea level. © Rich Flight.

Although the increase in activity is not significant enough to indicate a swarming site itself, the detected bats may have been recorded travelling to swarming sites associated with the high fells, such as caves and mine adits. August is relatively early for *Myotis* swarming, which swarm between mid-August and November, peaking in September and October (Rivers *et*

al., 2005). However, bats are likely to undertake a limited migration to these sites prior the swarming event occurring; this may be what was recorded within this study.

An alternative explanation may be that the recorded bats are male bats that are not associated with a maternity roost in mid-summer. These male bats may be out-competed by females and therefore select the less competitive high-altitude habitats. In a study from 2005, Senior *et al.* established that non-dominant Daubenton's bat males were displaced to sub-optimal higher elevation habitats during the summer by females and dominant males. Although this enabled them to feed without overt competition, it reduced their breeding success in the autumn mating period, as they were not as fit as the lowland males that had had access to higher prey density.

It may therefore be possible that the spike in August is a reflection of juvenile bats, which will naturally assume a subordinate position in the population, joining the displaced male bats in these sub-optimal territories.

The least encountered species were whiskered and Brandt's bat; however, this may be a product of the sound analysis strategy. *Myotis* calls were identified to species level when clear and apparent. However, identification was not automated, all calls were therefore manually identified. Any *Myotis* calls with significant cross-over of species was therefore recorded as *Myotis* species only. It is therefore very likely that a significant proportion of the *Myotis* calls could be attributed to whiskered bat and/or Brandt's bat. This error factor is likely to be exacerbated by an element of call modification brought about by these bats flying in a very open and featureless landscape. Therefore, recorded echolocation pulses are likely to be atypical due to the bat's manipulation of their emitted calls in order to compensate for the open landscape.

A previous paper on bat habitat suitability modelling in the Lake District (Bellamy *et al.*, 2013) found a negative association between each of the bat species and elevation, the strongest being found with noctule, which was said to significantly favour lowland sites. In our study noctule was recorded 86 times at 18 sites. However, this was the third lowest, after whiskered bat and Brandt's bat. Given the discussion above, it is likely that noctule may well have had the lowest actual frequency of passes in the study. This is slightly surprising as noctule is a large, strong flying bat which would be able to access the high fells rapidly, even from lowland locations. Bellamy concludes however, that the negative association may be because it is 'a large bat that feeds in the open, it may be particularly prone to climatic effects' (Bellamy *et al.*, 2013).

Timing

The data obtained was not designed to provide any direct information regarding roost sites. However, the timings of the recorded calls provide some indication of the proximity of the roosts to the survey locations. It can be assumed that if bats were roosting near to the detectors, then the first recordings of each night would be relatively early. As different species emerge from their roosts at different times, relative to sunset, early emergence would be specific to each species.

The data suggests that some species were recorded very close to, or even before their MSET; the most notable were common pipistrelle (23 minutes before the MSET), soprano pipistrelle (17 minutes before MSET), brown long-eared bat (23 minutes before MSET) and Daubenton's bat (one minute after MSET). As these species were recorded comparatively early, an assumption could be made that these individual bats were roosting relatively close to the detector. For the most part, detectors were positioned a considerable distance from what would be classed as typical roosting habitat (woodland and buildings) and therefore it is possible that these bats were instead roosting in rock crevices within the high-altitude fells.

However, despite these early appearances, the majority of recordings were received after the MSET (Figure 12); the peak of common pipistrelle and Daubenton's bat activity occurred 1 hour and 30 minutes after sunset, while the equivalent peak for both soprano pipistrelle and brown long-eared bat occurred 2 hour and 20 minutes after sunset, both well after the MSET.

Although there is some indication that bats are roosting in close proximity to the detectors, and therefore within the high-fell habitat, the data suggests that these occurrences may be exceptional, and not the norm. It seems far more likely that bats are travelling to the detector locations from further afield. This would account for the delay in activity after sunset that is seen in most species and is even seen in the species that have exhibited occasional early emergences.

With a flight speed of approximately seven metres per second (Woodland Trust, 2021), common pipistrelle could potentially cover 1km in 2.3 minutes. Naturally, few bats commute in a straight line and fly at top speed the whole time. In addition, it must be assumed that flying up-hill would be more labour intensive and therefore slower than flying across a flat landscape. Even given these restrictions however, there is potentially enough time at most sites for bats to emerge from lowland roosts and commute to the higher altitude locations within the times observed. It is possible therefore, that bats roosting in lowland areas may have an initial feed near to the roost before expending the energy to fly uphill to the more elevated feeding grounds, where they can then replenish their energy levels with little competition.

Habitat

The reason for bats to either roost within habitat, which is apparently sub-optimal, or to expend additional energy flying up-hill to these higher altitude locations may be explained by the presence of unexploited prey. The high fells are a damp environment which feature tarns and marshy ground; this is an ideal location for insects, such as non-biting midges (the main prey of the *Pipistrellus* species), to breed in. However, insects in these environments have few predators; during the day they are preyed upon by a small number of birds, such as meadow pipits *Anthus pratensis* and wheatear *Oenanthe oenanthe* but during the night there is likely to be a lack of significant predation. The abundance of available prey in these environments, without any viable competition, must therefore warrant the additional energy expenditure, either in metabolic processes to survive in harsh conditions, or the commuting costs.

Habitat factors were analysed as part of the study, but no significant correlations could be found within the data as a whole. This may be more of a reflection of the statistical prowess of the author rather than the lack of correlation of factors. It is also a reflection of the low sample size. When looking at the categories of distance that were used (0-50m, 50-100m, 100-150m, etc.) the sample size was not large enough to provide robust data for each category. Therefore, in each habitat factor, there were categories that had a zero sample size, as well as some categories that were skewed by outlier data.

On a site-by-site basis however, some apparent links can be observed. The site with the earliest emergence of a common pipistrelle was over 2km from the closest building or tree, suggesting that it is unlikely that the bats commuted from these potential roost locations. However, the detector was positioned within 50m of a disused mine shaft, which may well have provided suitable roosting habitat for the recorded bats.

The second earliest recording of this species was eight minutes after sunset (17 minutes before the MSET) at a site that was within 500m of woodland and 950m from buildings. It was also very close to a tarn (freshwater upland pond) which may well have provided a foraging focal point. As previously discussed, a commuting common pipistrelle could hypothetically cover the distance from the nearby trees and buildings in less than two minutes. This was also the site of the earliest soprano pipistrelle recording.

The second earliest soprano pipistrelle recording was from a site within 500m of buildings. Conversely, the earliest brown long-eared bat recordings were from a site that was over 1.5km from any trees or buildings. However, it was within 300m of a crag or rocky outcrop and the second earliest recording was from a site that was within 50m of a crag (but over 1km from trees or buildings).

Without rigorous experimentation (potentially involving trapping and tracking) the connection between these habitat factors is anecdotal at best. However, they provide some explanation for the results received and a possible insight into the habitat usage.

Conclusion

This study was a fact-finding mission; it was not designed to be a comprehensive study into the habitat preferences of high-altitude bats. And as such, the outcome was always likely to involve more questions than answers. However, some definite conclusions can be drawn from the work that was undertaken:

- Bats use high elevation habitats in the UK
- Bats can be found at elevations of up to 615 metres, and possibly higher
- At least eight species of bat can be found in these habitats (all the resident Cumbrian species)
- Common pipistrelle are the most common species to be encountered, followed by soprano pipistrelle
- Bats are known to hibernate in locations as high as 510m

In addition, there are also some inferences that can be made based on the data obtained:

- Some bats are likely to use summer roosts in the high fells
- The majority of bats however, are likely to be commuting to these high-altitude locations from lowland roost sites
- The foraging opportunities that the abundant insect prey provide likely outweighs the energy costs of visiting or living in these areas

Clearly more research is needed if we are to understand how bats use these high environments. There are habitat factors that we have looked at briefly here but not been able to establish a significant correlation between. However, the robustness of the data set is relatively weak, due to the small data sets and the inconsistency between sites, in particular the temporal variation. Although factors such as aspect relative to wind direction, proximity to trees and deep vegetation, and temperature and weather conditions are likely to have an impact on bat presence, establishing the scale of the impact is likely to require a more powerful level of statistical analysis than was employed here.

It is recommended that future research is carried out and could include the following:

- Flight routes of bats commuting to these foraging grounds; do they fly along stream-beds or ghylls? In an open environment such as the fells, ghylls are one of the few landscape features available to navigate by
- A comparison of the call types to establish the proportion of commuting to foraging passes, to determine if the bats are truly foraging in the fells or just using them as a 'short-cut' to reach foraging grounds elsewhere
- Gender segregation within the upland and lowland habitats. Are subordinate males displaced to these sub-optimal habitats by dominant males and/or colonial females?

As a bat group, we hope to return to this study in the future and attempt to answer some of these questions. However, for the meantime, confirmation once again that bats are defying what is expected of them and overcoming barriers to exploit valuable resources is justification for our continued fascination with them. Bats certainly do have serious altitude!

Acknowledgements

South Cumbria Bat Group for their support and providing the Anabat Express equipment. Lake District National Park Authority, who provided a grant to purchase some of the detectors. Cumbria Wildlife Trust, who advertised the survey, thus encouraging volunteers to get in touch. Jess Dangerfield and Hal Starkie, for their assistance in editing this article. And most importantly, the volunteers, who braved the weather and terrain to deploy and retrieve the detectors; none more so than Jane Newport, who personally surveyed 23 sites, and therefore without whom we would have a lot less data!

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The Search for Greater Horseshoe Bat in East Kent

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Introduction

Historical records indicate that the greater horseshoe bat *Rhinolophus ferrumequinum* has been extinct in Kent for over one hundred years. The last record was of a single animal at Sevenoaks in 1909 (Heathcote and Heathcote, 1994). The advent of industrial farming, reaching its height in the 1900s is likely to have been a prime driver of this extinction, with consequent loss of large insect prey, particularly chafer and dung beetles. Maternity roost loss due to barn conversion, farm house renovations and the use of timber treatment chemicals were added factors.

In 2019, four independent ecological consultants, working at four separate proposed development sites in East Kent, recorded greater horseshoe bats on sonograms. These records spanned May to September. In the autumn of 2019, Kent Bat Group (KBG) produced a project proposal after consultation with a number of British bat experts. The project aims are to:

- assess the status of greater horseshoe bat in East Kent
- identify summer and winter roosts
- locate foraging areas
- protect and enhance roosts and foraging habitats

Survey Methods

Hibernation Checks

For over 30 years, KBG have been finding and protecting hibernation sites. Many such sites are known in East Kent. There are four Napoleonic forts in the Dover area alone plus Dover Castle and numerous World War Two defences. In addition, there are chalk extraction sites including deneholes (vertical chalk mines with chambers). The hibernation potential is vast and too great to survey in one winter. Surveying underground sites for greater horseshoe bats is certainly like searching for a needle in a haystack.

Potential Foraging habitats

We were very fortunate to partner with Dan Tuson, Natural England Land Management Adviser. For almost two decades Dan has been using Environmental Stewardship Grants to work at a landscape scale with farmers, restoring botanically diverse grassland across the North Downs of East Kent (Tuson, 2019). More of this work can be viewed at:

https://youtu.be/OVRzUFfp_iE (Accessed: 19th February 2021).

We decided to target five chalk valleys running into the Lydden valley near Dover (Figure 1) for placement of five Wildlife Acoustics Minibat static detectors. These were placed in mature hedges and tree lines adjacent to the herb rich grasslands. COVID-19 restrictions meant a delay in starting, with all five detectors in position by June. Teething problems with these new detectors also meant a failure to record files for the whole of September. October saw very heavy rains and the seals failed meaning removal and curtailment of recording.

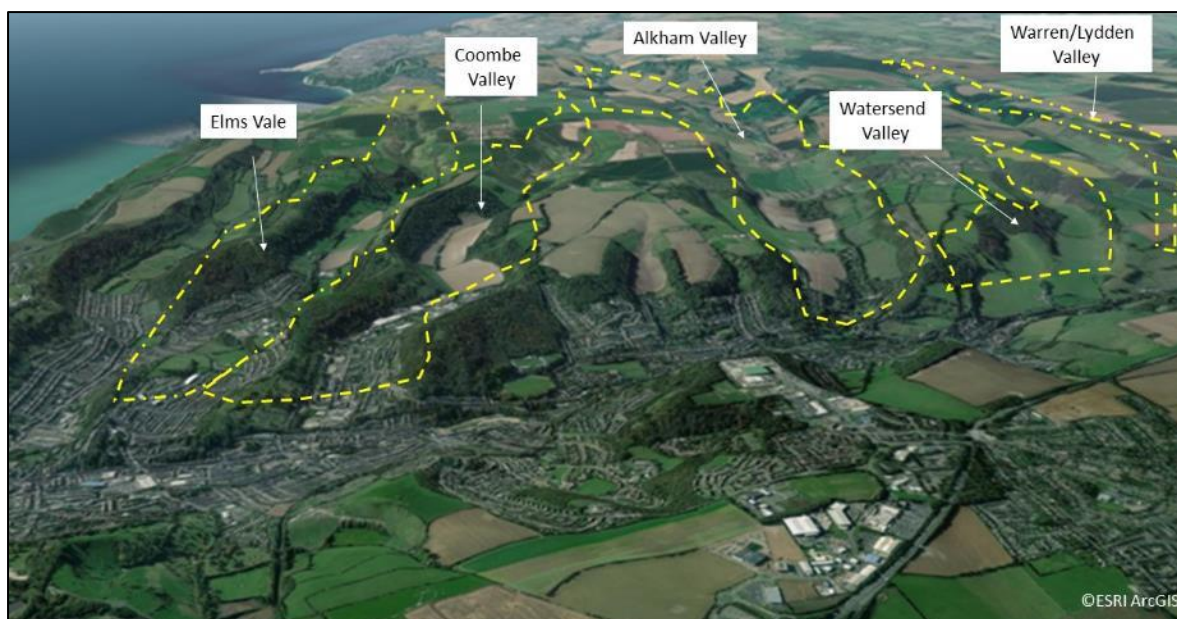


Figure 1: The five valleys where the static detectors are positioned.

The Results

The first download of the detector in Elms Vale produced our only recorded greater horseshoe bat pass of the season. The detectors were set to trigger recording above 60kHz in order to make manual checks of all the sonogram files more manageable. This will have precluded many records of *Pipistrellus* and the larger bat species. Nevertheless, the records of serotine *Eptesicus serotinus* are impressive, given that it is a Kent Biodiversity Action Plan species. An advisory leaflet for landowners on habitat management for serotines was produced in 1999 (Kent Bat Group, 1999). The number of *Myotis* species records was also notable. There is obviously scope for future projects looking at the value of landscape scale grassland restoration in protecting and enhancing the populations of many bat species. A summary of the number of bat passes recorded at each site is shown in Table 1.

Table 1: Static detector bat passes by species and site, recorded between 05/06/2020 and 30/10/2020. (Continued on next page.)

Bat Species	Site					Total all sites
	Elms Vale	Coombe Valley	Alkham Valley	Watersend Valley	Warren/Lydden Valley	
Serotine <i>Eptesicus serotinus</i>	94	4	17	253	50	418
<i>Myotis</i> species	84	85	190	832	222	1413
Noctule <i>Nyctalus noctula</i>	0	0	1	14	2	17
Common pipistrelle <i>Pipistrellus pipistrellus</i>	1324	118	646	4087	5152	11327
Soprano pipistrelle <i>Pipistrellus pygmaeus</i>	310	19	577	1442	1571	3919
Brown long-eared bat <i>Plecotus auritus</i>	28	1	0	18	1	48

Bat Species	Site					
	Elms Vale	Coombe Valley	Alkham Valley	Watersend Valley	Warren/Lydden Valley	Total all sites
Greater horseshoe bat <i>Rhinolophus ferrumequinum</i>	1	0	0	0	0	1
Other noise	1	9	0	2	0	12
Site total	<u>1842</u>	<u>236</u>	<u>1431</u>	<u>6648</u>	<u>6998</u>	<u>17155</u>
Number of species	6	5	5	6	6	7
Number of nights	147	126	147	147	126	



Figure 2: Hibernating lesser horseshoe bat at Dover Castle in December 2020. © Claire Munn.

Late December 2020 saw the discovery of a hibernating *Rhinolophus* bat by a KBG member and ecological consultant, working on the bat ecology at Dover Castle. This is the first visual

confirmation of a *Rhinolophus* species bat in Kent this century (Figure 2). Intriguingly, this bat proved to be a lesser horseshoe bat, *R. hipposideros*. Sonogram confirmation of greater horseshoe bat was obtained from a static detector in a parallel underground passage some 20yds from this animal in September 2019.

The Future

We are intending to record a full season in 2021 by placing the static recorders back in the five valleys. We have also acquired a further four detectors which we intend to place on the opposite coombe of four of these valleys. We also hope to implement car transect detector surveys along some of the quieter valley bottom roads. We may also walk detector transects at some public access chalk grassland sites owned and managed by various wildlife bodies. A further possibility is to search farm outbuildings for roosts thanks to Dan Tuson's farmer contacts throughout East Kent. All is subject to Covid restriction this year.

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Back from the Brink: Reconnecting the landscape for the grey long-eared bat

Plecotus austriacus

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Introduction and background

Since 2017, the Bat Conservation Trust (BCT) has been working alongside the rest of the Rethink Nature partnership and Natural England on Back from the Brink.¹ Funded by the National Lottery Heritage Fund, Back from the Brink is an ambitious species recovery programme, aiming to save 20 species from extinction and benefit over 200 more. The delivery for this has been through 19 separate but cohesive projects running the length and breadth of England, from the tip of Cornwall to Northumberland National Park. Some of these projects have been focused on single species and some have been integrated projects focused on habitats and landscapes. BCT have been involved with several of these projects and are leading on the species recovery project for the grey long-eared bat *Plecotus austriacus*.²

Grey long-eared bat

One of two *Plecotus* species found in England, the grey long-eared bat is considered to be one of the rarest mammals in the country and is possibly our rarest breeding bat species. Only found in the southern part of England (and the Channel Islands), the latest Mammal Review (Mathews *et al.*, 2018) suggests that the mainland population estimates are around 1000 individuals (with intervals of 400-3000), with a decline of at least 10% over the last three generations likely. This makes the species of conservation concern, listed as Near Threatened on the Global IUCN Red List (Gazaryan and Godlevska, 2020) and Endangered on the British IUCN Red List (Mathews and Harrower, 2020).

Grey or brown?

The *Plecotus* genus contains at least 19 distinct cryptic species (Spitzenberger *et al.*, 2006) spread throughout Eurasia and North Africa. In Britain, the two *Plecotus* species (the other being brown long-eared bat *P. auritus*) pose challenges in identification to many ecologists, particularly when found at the edge of or outside their natural range. It was with this in mind that BCT developed, in collaboration with several of the country's leading grey long-eared bat experts, a guide to aid identification.³ This guide does not offer definitive identification but aims to build a picture of the species with a range of identification features. Due to the cryptic nature of the species, DNA analysis is deemed to be the only 'definitive' means of identification.

Resource partitioning

Cryptic species seem to be common in bat genera (for example *Pipistrellus*, *Myotis*, *Plecotus*) and despite the morphological similarities there are some distinct differences in the ways that individual species use available resources. For example, soprano pipistrelles

¹ <https://naturebftb.co.uk/>

² <https://naturebftb.co.uk/the-projects/grey-long-eared-bat/>

³ <https://cdn.bats.org.uk/pdf/Our%20Work/v.4-Long-eared-bats-guide.pdf?mtime=20200907151026&focal=none>

Pipistrellus pygmaeus are more closely associated with riparian habitats for foraging than common pipistrelles *P. pipistrellus*.

This is also apparent in our *Plecotus* species. Despite the similarities of wing morphology and likely similarities in flight characteristics (both considered to be slow flying and manoeuvrable (Swift, 1998)), and both having a generalist diet of primarily *Noctuidae*, grey long-eared bats favour foraging in open habitats, primarily semi-natural grassland, whilst brown long-eared bats favour woodlands for foraging. This mechanism of resource partitioning between the two species offers a likely explanation for their ability to successfully coexist (Razgour, 2011).

Grassland restoration

The interrelationship between species rich grassland and grey long-eared bats has been more widely understood since Orly Razgour's work. This habitat has therefore been a key priority since the inception of the project. The loss of semi-natural grassland (otherwise known as species rich grassland, wildflower meadows, unimproved grassland) has been well publicised and has had a significant impact on a range of specialised species associated with this habitat - bats included. Therefore, identifying areas where diverse, insect-rich grasslands can be restored, enhanced or created has been our focus.

Legacy

One of the key ambitions of the Back from the Brink program was for there to be legacy in place, for work to continue on our most threatened species, beyond the lifespan of the project. With this ambition in mind, I am very pleased to be working on a new project focused on grey long-eared bats, funded through the Green Recovery Challenge Fund. This time the project focuses on the populations in East Devon and West Dorset - securing more foraging habitat for grey long-eared bats present and future.

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Inside a greater horseshoe bat *Rhinolophus ferrumequinum* summer roost

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Figure 1: A male greater horseshoe bat displaying as described below. © John J. Kaczanow.

Just over ten years ago I had one of the most amazing experiences with a British bat.

After photographing my first greater horseshoe bats *Rhinolophus ferrumequinum* in the Tamar Valley in 1975 I have had the privilege to live and work alongside this species, and many others. I have enjoyed countless surprises and numerous opportunities to benefit by sharing my experiences with others.

I have always considered that my favourite encounters were with barbastelle *Barbastella barbastellus*; firstly, when I found a pair mating in mid-November (Devon) and looking into a nursery tree roost (Somerset) containing over a dozen pups (3-4 days old), added to this a hibernation site with as many as five specimens at a time in the Tamar valley.

It is rare that one gets the opportunity or the need to enter a large maternity/natal/nursery roost of any bat species. Being an avid photographer I long had an aspiration to obtain photographic records of the activity of a summer roost of the greater horseshoe bat. Luckily, one hot, late July afternoon, I was given permission to access such a roost.

With my time inside severely restricted I really did not have a game plan and felt that it was going to be difficult to get something meaningful. The interior of the roost was surprisingly

well illuminated from the outside, but still quite dim and once I got adjusted to it, I felt more at ease.

There were probably around 90-100 bats in a square cluster hanging from a bitumen felted pitched slate roof. A few bats took an occasional flight into another sector of the building; it truly did appear chaotic to say the least.

Using the camera and lens as a binocular I started to get my act together and partitioned the cluster according to the camera's sensor format, and then managed to get a few pictures.

Screening the shots taken on the camera I could identify males and females; several females had pups attached, pup ages probably 0-7 days. Surprisingly, there appeared to be a 40-50% male - female ratio of the adults.

Concentrating for some reason on the males hanging in rather neat rows, I noticed that they were more active than the females. I soon identified a few dominant specimens!

By this time activity was increasing amongst the males with a lot of jostling close to apparent superior females!

I couldn't see clearly what was happening, but it appeared that the dominant males were twisting from side to side and at the same time puffing their chest whilst lifting their head and shoulders (could I say bellowing?).

At the same time, I noticed one male was flicking its wings, outstretching them many times in a flash of an eyelid; as quickly as it began, it ended.

Not really knowing what had occurred and my time inside drawing to a close, I left the confines of the roost.



Figure 2: Male greater horseshoe bats.
© John J. Kaczanow.

Imagine my surprise and delight when I trolled through the images wondering what had been captured and finding a single, almost perfect image of the 'inverted wing flicking action' (Figure 1), truly an amazing encounter.

However, I do regret not taking my ultrasonic sound recorders into the roost with me, and a single question remains: 'were the males really bellowing' (Figure 2)?

I will leave the analysing of these actions to the more informed mammologist.

Every encounter I have with the natural world is savoured; but, as with other things in life we do have favourites. Enjoy yours.

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Roost selection, activity and dispersal of Leisler's bat, *Nyctalus leisleri* (Kuhl, 1818) during the pre-hibernal and hibernal periods

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Introduction

The majority of a bat's life is spent in roosts, so roost selection is likely an important factor affecting survival. Throughout the year, roost selection depends on the diversity and abundance of roosts, the distribution and abundance of food and an energy economy influenced by body size and the physical environment (Kunz and Lumsden, 2003). During hibernation, however, choosing an optimal roost site is fundamental to maintaining energy balance (McNab, 1982). Hibernacula requirements vary among bat species. For example, little brown bat *Myotis lucifugus* requires stable temperatures above freezing and high humidity (McManus, 1974), but big brown bat *Eptesicus fuscus* can tolerate temperatures below freezing in sites with low humidity (Beer and Richards, 1956). In many temperate bat species, it is common to observe migration, often over large distances, to locate suitable winter hibernation sites (Hutterer *et al.*, 2005).

Leisler's bat *Nyctalus leisleri* (Kuhl, 1818) (Figure 1) has been recorded over much of the Palaearctic but is poorly documented outside Europe (Dietz *et al.*, 2009). Throughout most of its range, it is considered rare except for Ireland where it is common (Stebbings and Griffith, 1986; O'Sullivan, 1994). In continental Europe, Leisler's bats are known to migrate over large distances between hibernation and summer roosting sites (Schober and Grimmberger, 1999). For example, individuals ringed in Russia have been recovered in Turkey (1245km) (Likhachev, 1980; Panyutin, 1980); an individual tagged in Italy was recovered in Poland, a straight-line distance of 960km (Dondini *et al.*, 2012); and one bat ringed in Germany was recaptured in Spain, a distance of 1567km (Ohlendorf *et al.*, 2000). Summer or maternity roost sites have been recorded in woodpecker holes or other tree holes, often in beech and oak, as well as in buildings and bat boxes. Similarly hibernation roosts have been found in tree holes and in buildings (Ruczyński and Bogdanowicz, 2005; Spada *et al.*, 2008). There is currently no evidence that any Irish bat species migrate to hibernation sites either within or outside the island (Hutterer *et al.*, 2005). Furthermore, no hibernation sites comparable to the large cave hibernacula in continental Europe have been identified for any Vespertilionid in Ireland (McAney, 2006). Given its temperate oceanic climate, with mean summer temperatures ranging between 15-20°C, and winter temperatures 4.0-7.6°C (Source: Met Éireann), Ireland may provide suitable year-round conditions for temperate bat species. Summer roost sites in Ireland have been reported primarily in buildings (Shiel and Fairley, 1998; Waters *et al.*, 1999; McAney, 2006), with only a few tree roosts identified (mainly oak and ash; Fairley, 2001). Activity and dispersal of Leisler's bat during the summer months has been examined in previous studies (Shiel and Fairley, 1998; Shiel *et al.*, 1999; Russ *et al.*, 2003). However, little is known about activity patterns of Leisler's bats in Ireland leading up to, and during, hibernation. An understanding of the behaviour and specific climatic and roosting requirements before and during hibernation is essential for effective conservation and management of this species throughout their lifecycle.



Figure 1: Leisler's bat on a tree. © Austin Hopkirk.

We radio-tracked adult male and female Leisler's bats in Northern Ireland to examine activity, roost selection and dispersal during the pre-hibernal and hibernal periods. More specifically we tested the hypotheses that:

1. periods of torpor increase with decreasing temperature;
2. Irish populations do not make long-distance migrations to hibernation sites;
3. and roost selection will change during the pre-hibernal and hibernal periods.

Materials and Methods

Fieldwork was carried out in Northern Ireland from 29th July 2002 to 12th November 2002 and from 23rd August 2003 to 21st January 2004. Bats were captured at two sites throughout the study period. In July and early August, females were captured at a maternity roost (>100 individuals) in the attic of an occupied urban building (NI OS grid reference J3477172068), while from August through to October male and female bats were captured at a mixed, predominantly coniferous woodland site containing occupied bat boxes, some 40.32km south of the initial maternity roost (Tollymore Forest Park; NI OS grid reference J3393831898) (Figure 2).



Figure 2: Leisler's bats in a bat box. © Austin Hopkirk.

Tagging and Tracking

Bats were captured on multiple occasions in both years (Appendix 1). Between five to eight individual bats were tagged at one time. All bats were caught in hand nets at evening emergence. Bat boxes were first inspected by day using an endoscope to minimise disturbance. Individuals were identified to species and sex, and weight (g) and forearm length (mm) were determined (Appendix 1). Transmitters were no more than 5% of the bat's body weight (Aldridge and Brigham, 1988). For tagged individuals, the interscapular fur was trimmed close to the skin and temperature-sensitive transmitters (Holohil Systems Ltd., Ontario) were attached using Skinbond surgical cement (Smith and Nephew, Largo, Florida, USA).

Transmitter signals were received by a pair of Yagi antennae and Mariner 57 receiving sets (Mariner Radar, Lowestoft, UK). Tagged bats were radio-tracked at night using the close follow approach by vehicle with a team of 2-3 people using a Yagi antenna mounted on a 3m long mast through the sunroof. A handheld Yagi antenna was used when on foot. Measurements of signal direction ($^{\circ}$), ambient temperature, and skin temperature were recorded every ten minutes throughout the night, with a break approximately between 01:00 and 03:00. In previous studies, skin temperature has been shown to accurately reflect body temperature (e.g. Willis and Brigham, 2003). Using skin temperature as well as activity (static or moving signal), bat behaviour was classified as either 'roosting' or 'in-flight'. At skin temperatures below 6°C, bats were considered to be in torpor, following modal temperature for hibernation for Vespertilionids (Webb *et al.*, 1996). Throughout July, August and September, no more than four individual bats were tracked simultaneously. As roost excursions diminished in frequency and duration later in the study, it became possible to monitor eight tagged bats simultaneously.

Roost Characteristics

Roosts identified from radio-tracking were visited in the day and were classified as domicile (human-inhabited buildings), non-domicile (uninhabited buildings), bat box and trees. For all tree roosts, distance to the nearest habitat edge, the type of cavity (exfoliating bark, rot hole and split) was recorded as well as the tree girth and species.

Data Analysis

Data were analysed using Minitab v13 statistical software (Ryan and Joiner, 1994) and R (R Core Team, 2012) with the Forecast package (Hyndman *et al.*, 2012). To limit the effects of non-independence of data points collected from the same individual means were taken. Nightly means were taken from measurements per individual taken on average between 22:00 and 07:00. A Wilcoxon test was used to test differences between nightly mean skin and ambient temperature for individual bats across the season in both 2002 and 2003. Mixed effect models controlling for the individual were unsuitable as q-q plots showed residuals to be non-normal. ANOVA was used to test for differences between ambient temperature during periods of flight and roosting. A Wilcoxon test was used to test for differences between skin temperature of bats in flight and roost as q-q plots showed ANOVA residuals to be non-normal.

The mean of the roosting and flight encounters per quarter per bat was calculated as an index of activity (i.e. roosting versus flight).

Time series analysis using ARIMA models (e.g. Jia *et al.*, 2010), so that temporal non-independence of data was accounted for, was used to examine skin temperature across season for roosting bats, pooled by date and modelled separately in 2002 and 2003. In time-series analyses the next value in the time series is dictated by autoregressive terms, moving average terms and deterministic trend terms as well as using unlagged ambient temperature as a further predictor variable. The coefficients for these terms are given with their standard errors. ARIMA models were selected using AICc. The inclusion of a trend term is evidence of a temporal trend that is not explained by an auto-correlated decrease in temperature. The inclusion of an ambient temperature term implies that there is an association between ambient temperature and skin temperature.

Results

In total, 29 adult Leisler's bats were tagged with radio transmitters and 25 tracked on 94 nights in 2002 (29th July to 12th November; five males, nine females) and 101 nights in 2003 (two males, nine females; 23rd August to 31st December) (Appendix 1). The mean forearm lengths for tagged bats, with standard errors, were 43.18 ± 0.27 mm for males and 43.71 ± 0.28 mm for females and the mean masses were 17.0 ± 0.57 g for males and 18.38 ± 0.55 g for females. Over the entire study period, bats were tagged from a total of eight roosts (one maternity site and seven bat boxes) and tracked to a further 68 roosts.

Seasonal activity patterns

Seasonal variation in skin and ambient temperature for individual bats in both 2002 and 2003 were highly correlated (2002: Spearman's Rank Correlation Coefficient = 0.638, $p < 0.001$; 2003: Spearman's Rank Correlation Coefficient = 0.600, $p < 0.001$ (means per bat per day)). Overall, there was a significant difference in skin temperature between bats in flight

($30.39 \pm 1.35^{\circ}\text{C}$) and those in the roost ($18.86 \pm 0.83^{\circ}\text{C}$) (Wilcoxon: $W = 220$, $N = 1070$, $p < 0.001$). Ambient temperature was significantly higher during the time when bats were in flight ($12.92 \pm 0.52^{\circ}\text{C}$) than when they were in the roost ($11.49 \pm 0.37^{\circ}\text{C}$) (ANOVA: $F_{1,43} = 4.58$, $p = 0.038$).

From August to November, time spent in flight decreased while time spent roosting increased (Figure 3). In the second quarter of August, bats were observed roosting about 50% of the time. However, time spent roosting increased from August to October and during mid-November bats were observed roosting 100% of the time. This is in contrast with the ambient temperature which gradually decreased over this period. The best ARIMA model of skin temperature for 2002 included an ambient temperature term (0.58 ± 0.28), a deterministic decline (-0.41 ± 0.10) and a moving average term (-0.87 ± 0.11). For skin temperatures in 2003, the best model includes an ambient temperature term (0.78 ± 0.11), a deterministic decline (-0.17 ± 0.11), an autoregression term (-0.42 ± 0.14) and a moving average term (-0.55 ± 0.14). Over the study period, ambient temperature gradually decreased from about 13.5°C in mid-September to about 6°C in late December (Figure 4). The skin temperature of roosting bats decreased rapidly from about 29.5°C in the second half of September to about 15°C in the second half of October. After this period, from the start of November to the end of December, the pattern of variation in skin temperature matched that of ambient temperature. Mean skin temperatures of roosting bats were similar for both males and females from mid-September to mid-November.

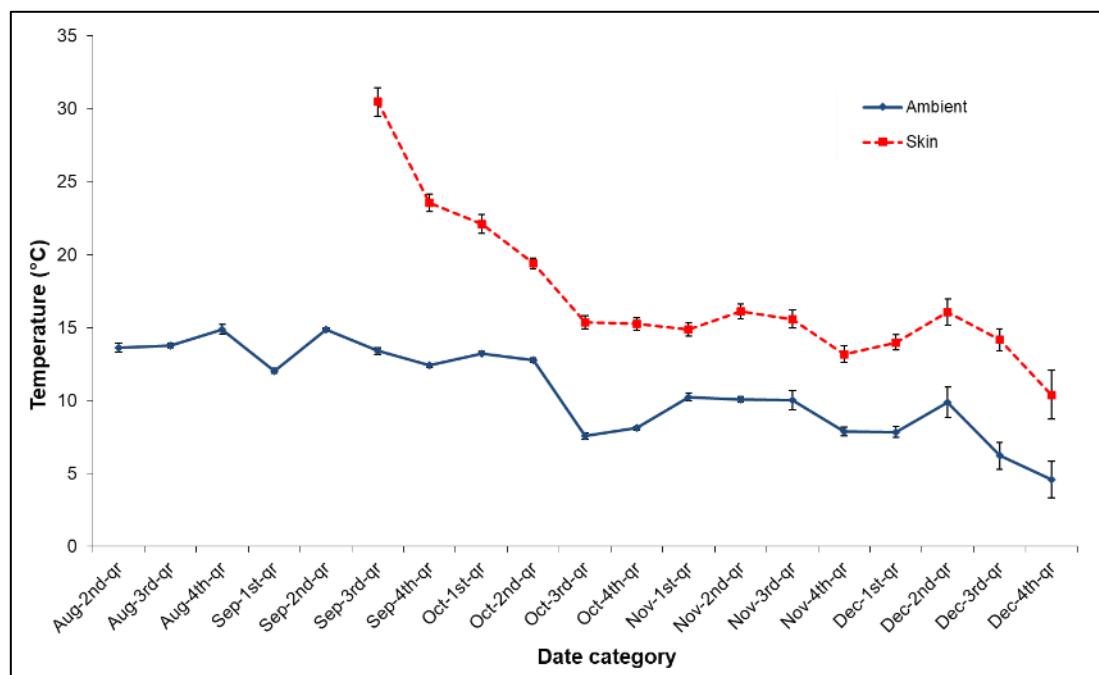


Figure 3: Overall mean skin temperature and mean ambient temperature for radio-tagged bats ($N=29$) for monthly quarters with an Activity Index (0=100% Roosting, 1=100% Flying). Error bars represent standard errors.

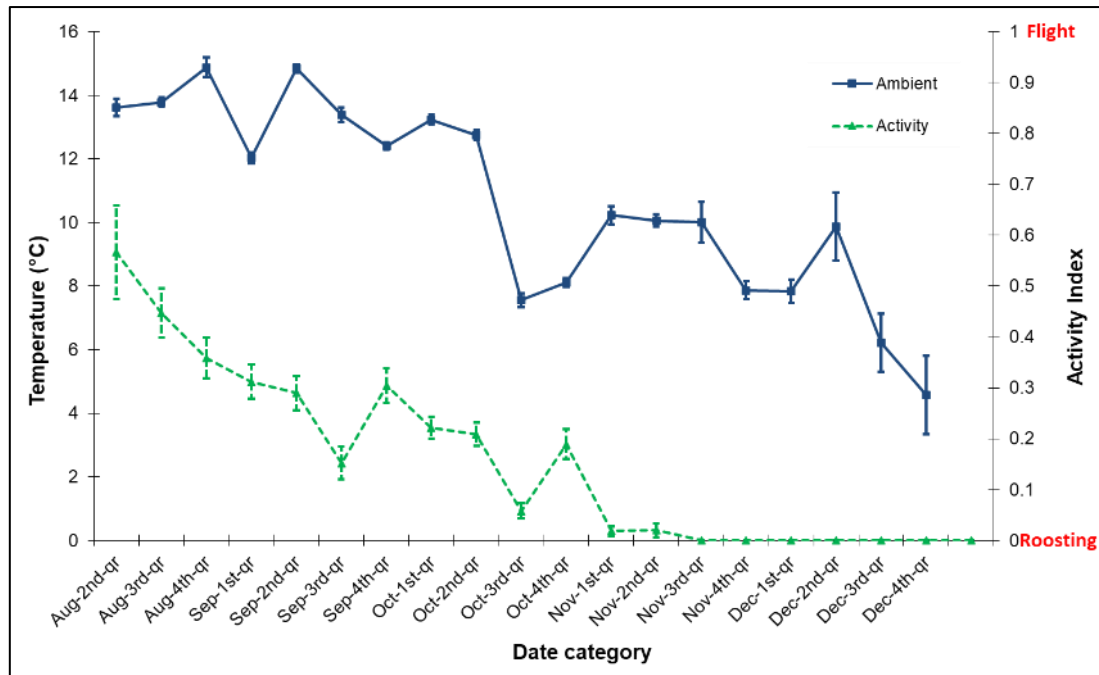


Figure 4: Overall mean skin temperature of roosting bats and mean ambient temperature for radio-tagged bats (N=29) for monthly quarters. Error bars represent standard errors.

During September and October, skin temperatures of roosting bats ranged from about 39°C to 6°C (Figure 5). During November and December, however, skin temperatures very rarely rose above 24°C. Below this threshold there is a positive correlation between ambient temperature and skin temperature for September (Spearman's Rank Correlation Coefficient = 0.178, $p < 0.01$), October (Spearman's Rank Correlation Coefficient = 0.473, $p < 0.001$), November (Spearman's Rank Correlation Coefficient = 0.533, $p < 0.001$) and December (Spearman's Rank Correlation Coefficient = 0.685, $p < 0.001$).

Northern Ireland

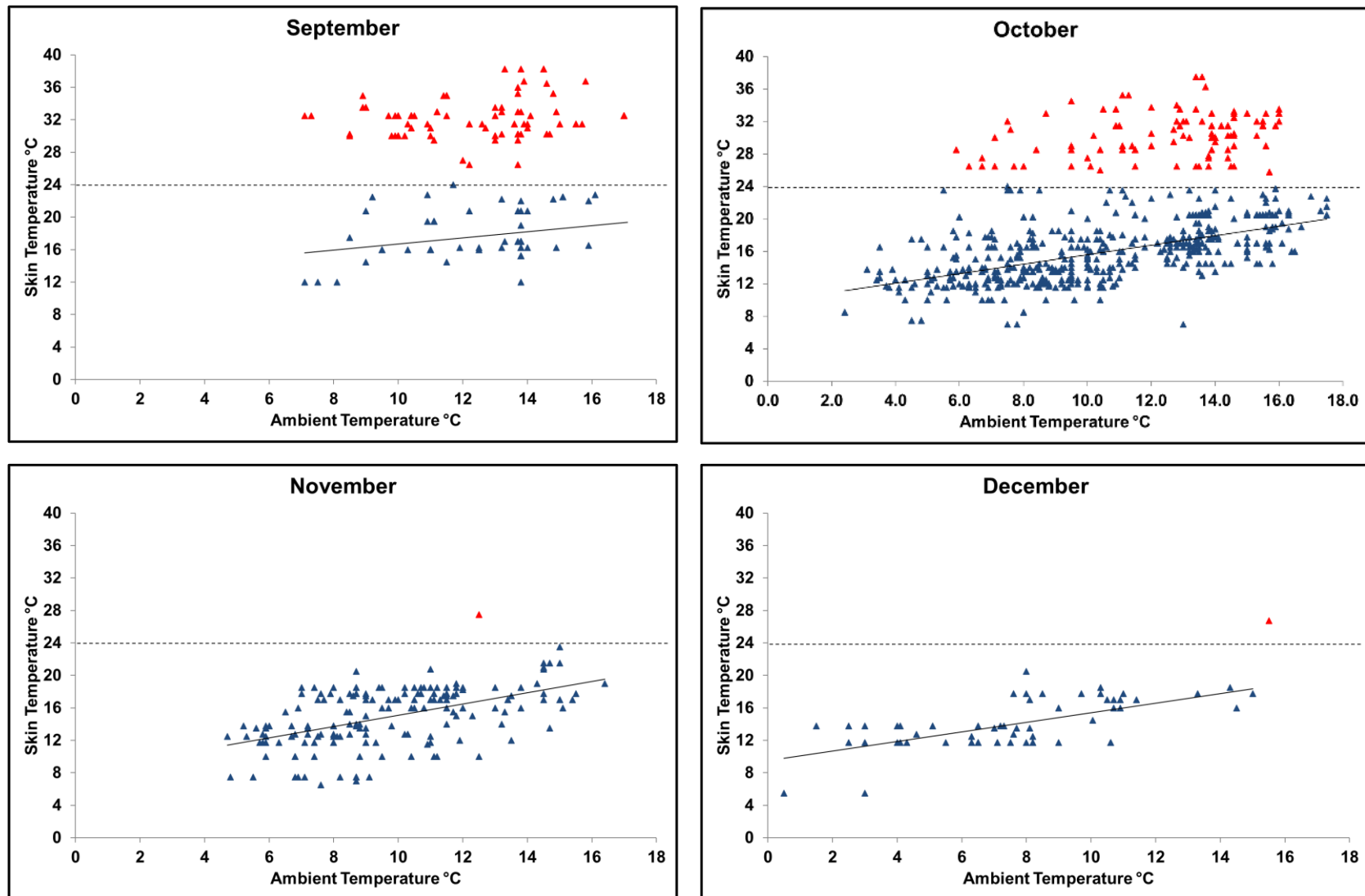


Figure 5: Relationship between ambient temperature and skin temperature of roosting bats for a) September (N=194), b) October (N=587), c) November (N=175) and d) December (N=59). The dotted line represents a maximum roosting skin temperature threshold for November and December with red markers representing temperatures above this threshold and blue markers representing temperatures below). The solid line represents the correlation between ambient and skin temperatures under this threshold.

Dispersal

Across the study period, male Leisler's bats moved a mean distance of 1.41 ± 0.38 km between roosts, while females moved a mean distance of 2.01 ± 0.45 km. The greatest distance travelled was by a female bat that flew 33.81 km at a mean bearing of 184.1° between roosts in a 24-hour period. Distances between successive roosts were greatest during the mid-September to late October period with several movements over 5 km. After mid-October movements between roosts did not exceed 5 km.

Roosts

Bats were recorded using a variety of roost types at the start of the study period. Fifteen roosts were identified in the roof spaces of domiciles; four non-domicile buildings were used, including cracks in walls in barns and an animal byre as well as the roof space of an unoccupied dwelling. Eight bat boxes were used, while 41 tree roosts were identified (Table 1). Generally, bats were recorded in bat boxes and non-domicile buildings from the end of August through to mid-October; trees and, to a lesser extent, domicile buildings from the end of October to mid-November; and just trees after mid-November (Figure 6).

Table 1: Tree species and cavity types used for roosting.

Common name	Latin name	Roost Type				
		Exfoliating bark	Rot hole	Split	Unknown	TOTAL
Ash	<i>Fraxinus excelsior</i>		1			1
Beech	<i>Fagus sylvaticus</i>		6	1	4	11
Birch	<i>Betula pendula</i>		1			1
Elm	<i>Ulmus species</i>		1			1
Larch	<i>Larix decidua</i>			1		1
Oak	<i>Quercus species</i>	3	3	17		23
Spanish chestnut	<i>Castanea sativa</i>	1				1
Sycamore	<i>Acer pseudoplatanus</i>		2			2
TOTAL		4	14	19	4	41

The tree species used most by roosting bats were oak, followed by beech and of the roosts located in trees, the most common type was splits within tree branches (Table 1). Rot holes and exfoliating bark were used to a lesser degree. 81% per cent of roosts in tree splits and 75% of roosts in exfoliating bark roost were located in oaks. In contrast, only 22% of roosts in rot holes were located in oaks with the rest in beech, sycamore, ash and birch. Fifty per cent of identified roosts were on forest edges and paths and 34.5% were within 15m of an edge. The remainder (15.5%) were within 200m.

Examples of roosts are presented in Figures 7-16.

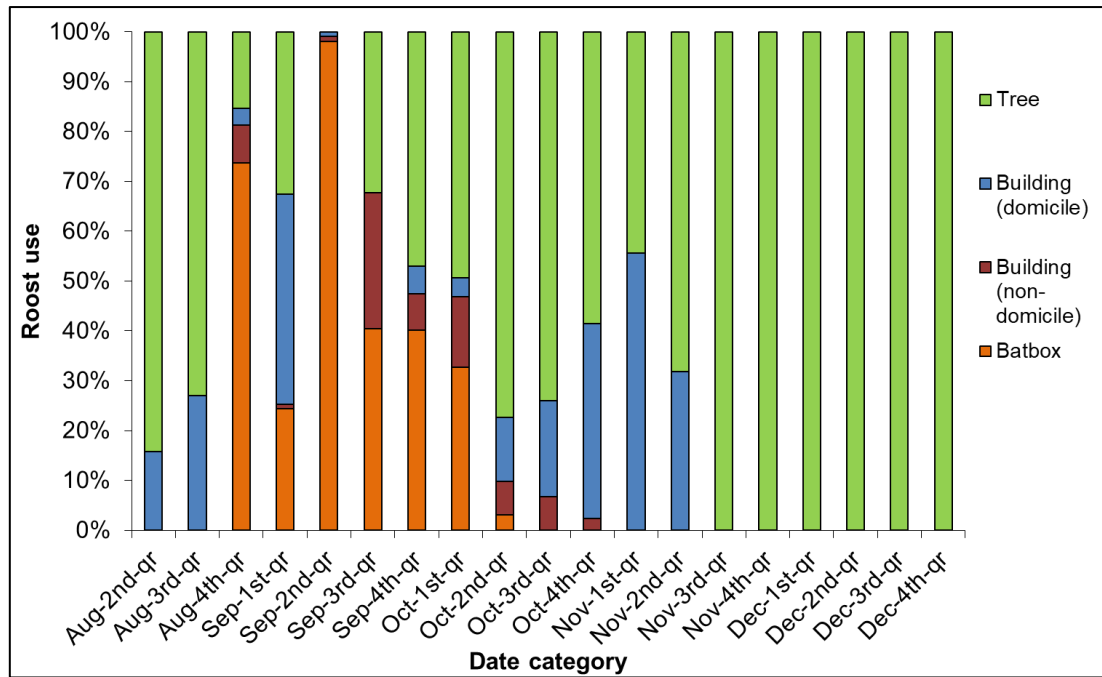


Figure 6: Mean proportion of roost use across month categories.



Figure 7: Maternity roost in an attic in Belfast. © Austin Hopkirk.



Figure 8: Roost in a barn. © Austin Hopkirk.



Figure 9: Roost under a soffit just outside Tollymore Park. © Austin Hopkirk.



Figure 10: Roost in a hole in a brick wall behind render. © Austin Hopkirk.



Figure 11: Roost in a rot hole. © Austin Hopkirk.



Figure 12: Roost in a sycamore. © Austin Hopkirk.



Figure 13: Roost in an oak tree. © Austin Hopkirk.



Figure 14: Leisler's bat droppings in a tree roost. © Austin Hopkirk.



Figure 15: Roost in a split in an oak. © Austin Hopkirk.



Figure 16: Roost in a larch. © Austin Hopkirk.

Discussion

In this study, as predicted, bats were shown to spend longer periods roosting from mid-August onwards until after the first week in November (at which point mean ambient temperatures were around 10°C and mean skin temperatures were around 15°C) when they spent prolonged periods in the roost, and in torpor. Thus the onset of hibernation appears to occur at the start of November. No bats were active when ambient temperatures dropped below 6°C. This is supported by a study by Webb *et al.* (1996) which found that Vespertilionid bats hibernated with a range of temperatures from -10 to 21°C, with a mode of 6°C.

Our data supported the hypothesis that Leisler's bats in Ireland do not undertake long-distance migrations and observed dispersal between summer, mating and winter roost sites was, on average, 2km. The majority of movements occurred between mid-September and late October during the probable mating period (Dietz *et al.*, 2009). Shiel *et al.* (1999) carried out a radio-tracking study of Leisler's bat in the Republic of Ireland and revealed that the mean straight-line distance travelled by juveniles was 19.7km with distances of two individuals exceeding 34km. In this study of the pre-hibernal period, similar movements were observed, with the longest straight-line distance of 33.1km recorded for a single female.

The finding that Leisler's bat in Ireland hibernates within its summer range is in contrast to observations in continental Europe where long migrations have been recorded between summer and winter roost sites, some up to distances of 1,567km (Ohlendorf *et al.*, 2000). Generally, however, this migratory behaviour has been observed in regions where ambient temperature variations are extreme (Likhachev, 1980; Panyutin, 1980; Ohlendorf *et al.*, 2000; Dondini *et al.*, 2012). We suggest that the temperate oceanic climate in Ireland provides environments favourable in both the summer and winter months for Vespertilionids explaining the sedentary behaviour.

Bat boxes appeared to be important for Leisler's bats in this study: the majority of tagged bats were initially located in bat boxes which were in use until the end of October. They seemed to augment the few apparent roosting opportunities offered by the mixed, mostly coniferous forest in the present study. Leisler's bats are known to exhibit a mating system characterized by resource defence polygyny (Bogdanowicz and Ruprecht, 2004), with mating groups of one male and up to ten females (Helvesen and Helvesen, 1994). This seasonal use of bat boxes and the observation of several females to a single male in these bat boxes suggested that these were being used as mating roosts, as seen in other studies (e.g. Dondini and Vergari, 2009).

We found that Leisler's bats in Ireland are dependent on features in buildings and splits or holes in trees throughout the pre-hibernal period, but that trees were used almost exclusively after November, particularly deciduous trees demonstrating the importance of these roost sites for hibernating Leisler's bats. Several bats, however, were observed using domiciles until mid-November when the batteries in their transmitter expired.

Despite the habitat surrounding roosts being predominantly coniferous, tree roosts used by Leisler's bats were located predominantly in oak (*Quercus* species) and beech (*Fagus* species) trees. Similarly, Leisler's bats in Poland used oaks and ash (*Fraxinus* species) (Ruczynski and Bogdanowicz, 2005), while bats in Switzerland selected chestnut *Castanea sativa* trees during the pre-hibernal period (Spada *et al.*, 2008). Although rot holes, exfoliating bark and crevices were utilised by bats, by far the most common tree roost type was splits in the trunk or tree branch and of these, the majority were located in oaks (Ruczynski and Bogdanowicz, 2005). It is not known whether oaks were selected as they are more likely to contain splits or whether there was simply a greater number of oaks in proportion to other deciduous tree types used as roosts within the study sites. The majority of roosts were on, or close to, forest edges and paths, possibly because tree cavities closer to the edge of woodland and trees in less dense woodland may experience increased diurnal temperature through solar exposure (Kurta *et al.*, 1993; Vonhoff and Barclay, 1996; Brigham *et al.*, 1997) or because of increased susceptibility to wind damage. Although Leisler's bats usually forage high above the ground, on emergence from roosts, when light levels are high, they often tend to follow linear landscape elements (Russ *et al.*, 2003). It is possible therefore that roosts that are located close to these linear elements will be selected. In addition, wing loading of Leisler's bats is high and thus the species is not very manoeuvrable in cluttered environments (Dietz *et al.*, 2009) and thus it is likely that roosts located on the edges of clutter will be selected rather than in the centre. This is supported by a study by Spada *et al.* (2008) of roost selection in Leisler's bat, which found roosts were more often in open forest patches with low tree density.

This study additionally revealed that buildings, domiciles and non-domiciles are important for Leisler's bats in Northern Ireland during the pre-hibernal period. Domiciles are particularly important in Ireland during the maternity period (Allen *et al.*, 2000). However, non-domiciles, such as barns, byres and uninhabited houses were also used, particularly from late-August until late-October, while several bats were observed using domiciles until mid-November during the hibernal period.

With the knowledge that populations of Leisler's bats in Northern Ireland are sedentary, a priority for the conservation of this species should now be the identification and protection of both pre-hibernal and hibernation roost sites, the nature of which was previously unknown. While this study again highlights the importance of buildings for Irish populations of Leisler's bats, it also suggests that deciduous trees with splits and rot holes are an important resource to bats during the hibernal period. The protection of older trees, particularly oak and beech should be a conservation priority.

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Appendix 1: Details of tagged Leisler's bats.

ID	Date	Location	Roost type	Sex	Forearm length (mm)	Weight (g)	Tag (Holohil Systems Ltd.)	Tag weight (g)	Duration (nights)
75590	29-jul-02	Belfast	Building	F	44	14.0	LB-2	0.56	No data
75536	31-jul-02	Belfast	Building	F	45	16.0	LB-2	0.56	No data
75589	31-jul-02	Belfast	Building	F	43	14.0	LB-2	0.56	No data
75588	1-aug-02	Belfast	Building	M	43	14.0	LB-2T	0.58	6
75587	12-aug-02	Belfast	Building	F	44	17.0	LB-2T	0.58	12
75537	22-aug-02	Belfast	Building	M	44	17.5	LB-2T	0.58	21
72291	29-aug-02	Belfast	Building	F	43	17.0	LB-2T	0.58	11
75538	11-sep-02	Tollymore	Bat box	F	43	18.0	LB-2T	0.58	26
75540	16-sep-02	Tollymore	Bat box	F	45	22.0	LB-2T	0.58	36
75540	16-sep-02	Tollymore	Bat box	M	42.4	18.0	LB-2T	0.58	31
75581	24-sep-02	Tollymore	Bat box	F	43	17.0	LB-2T	0.58	24
75607	24-sep-02	Tollymore	Bat box	M	42	18.0	BD-2AT	0.78	30
75608	10-oct-02	Tollymore	Bat box	F	44	21.5	BD-2AT	0.78	32
75611	10-oct-02	Tollymore	Bat box	F	42	19.0	BD-2AT	0.78	31
75612	10-oct-02	Tollymore	Bat box	F	45	21.0	BD-2AT	0.78	29
75601	10-oct-02	Tollymore	Bat box	F	43	20.0	BD-2AT	0.78	No data
75602	10-oct-02	Tollymore	Bat box	M	44	17.5	BD-2AT	0.78	31
75541	23-aug-03	Belfast	Building	F	46	18.5	LB-2T	0.90	No data
75582	23-aug-03	Belfast	Building	F	43	18.0	LB-2T	0.90	20
75583	19-sep-03	Belfast	Building	F	45	20.0	LB-2T	0.90	28
75584	19-sep-03	Belfast	Building	M	43	18.5	LB-2T	0.90	30
75610	2-oct-03	Tollymore	Bat box	F	42	20.5	LB-2T	0.90	12
75592	2-oct-03	Tollymore	Bat box	M	44	18.5	BD-2A	0.90	25

Northern Ireland

ID	Date	Location	Roost type	Sex	Forearm length (mm)	Weight (g)	Tag (Holoheil Systems Ltd.)	Tag weight (g)	Duration (nights)
85999	6-oct-03	Tollymore	Bat box	F	43	19.2	BD-2A	0.90	86
86000	6-oct-03	Tollymore		F	N/A	19.5	BD-2T	0.92	54
75609	6-oct-03	Tollymore		F	N/A	18.0	BD-2T	0.92	27
85996	7-oct-03	Tollymore		F	N/A	18.5	BD-2T	0.92	77
85997	7-oct-03	Tollymore		F	N/A	20.5	BD-2T	0.92	68
85998	7-oct-03	Tollymore		F	44	22.0	BD-2T	0.92	67

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The impact of different lighting colours on the foraging activity of Daubenton's bat, *Myotis daubentonii*, at a site in Midlothian, Scotland

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Abstract

Light pollution has increased dramatically over the last century, resulting in a wide range of negative impacts on many different taxa, including bats. Light-averse bats such as *Myotis* species are especially sensitive to artificial lighting but few studies have examined whether the impacts on this genus differ with light colour. The foraging activity, during periods of natural darkness, of Daubenton's bats *Myotis daubentonii* was recorded, using a bat detector, at a LED lamp emitting white, amber and red light. Recording periods were 1.5 hours long (comprising six, 15-minute light or dark periods) and were carried out over 21 nights. Foraging activity was significantly reduced in white and amber lighting compared to the dark control, but not in red lighting. The response to different lighting colours in this study is best explained as direct avoidance due to the (real or perceived) risk of predation, rather than a food-induced reaction. The results suggest that white and amber lighting should be avoided in close proximity to waterbodies used by Daubenton's bats for foraging, but red lighting may mitigate the negative impacts of lighting on this species. Further research is required to ascertain the precise wavelength at which negative impacts occur in this species and to determine whether there are any safe lighting colours for other, highly light-averse species.

Keywords

Artificial light at night, ALAN, Foraging efficiency, Light colour, Light-emitting diodes, Daubenton's bat, *Myotis daubentonii*

Introduction

Since the beginning of the 20th century, rapidly increasing urbanisation and industrialisation have led to dramatic increases in the global coverage of artificial light at night (ALAN) (Stone *et al.*, 2015a; Cravens *et al.*, 2018). There is currently a global shift from older lighting types - such as mainly yellow-orange high pressure sodium (HPS) and virtually monochromatic orange low pressure sodium (LPS) lamps - to more modern, broad-spectrum 'white' forms of lighting such as light-emitting diodes (LEDs) (Mathews *et al.*, 2015; Stone *et al.*, 2015a). Compared to older lighting types, LEDs have the advantage of: being brighter and more energy-efficient; having a longer lifespan; having reduced running costs, and can produce light of any colour (Mathews *et al.*, 2015). LEDs are the most widely used form of outdoor lighting, representing around 70% of the British market share and 60% of the global market share in 2020 (Stone *et al.*, 2015a; Russo *et al.*, 2019b). As LEDs become more and more affordable, their extent may increase even further, including non-essential uses such as advertising and architectural lighting (Rowse *et al.*, 2015). Despite this, the ecological impacts of LED lighting - particularly on nocturnal animals (Lewanzik and Voigt, 2017) - are not well understood (Stone *et al.*, 2015b; Voigt *et al.*, 2018b).

ALAN is known to have a wide variety of negative effects on bats, including on emergence, commuting, migration, foraging, drinking, roosting, hibernation and breeding (Russo *et al.*, 2017; Russo *et al.*, 2019a). Many previous studies have shown that the impact of ALAN on

insectivorous bats is highly species-specific. Species can generally be divided into two groups, light-tolerant bats and light-averse bats. Light-tolerant bats, which in the UK include the genera *Eptesicus*, *Nyctalus* and *Pipistrellus* (Mathews *et al.*, 2015; Voigt *et al.*, 2018b), are known to exploit the increased concentrations of insects that artificial lighting attracts for more efficient foraging (Beier, 2006; Mathews *et al.*, 2015). In contrast, light-averse species, which include the genera *Rhinolophus*, *Barbastella*, *Plecotus* and *Myotis* (Voigt *et al.*, 2018a; Russo *et al.*, 2019a), are seldom observed feeding on insects at street lights (Mathews *et al.*, 2015; Rowse *et al.*, 2015).

It has been suggested that light averse bats are intolerant of artificial lighting due to their slow and less agile flight increasing their vulnerability to visually oriented predators such as owls and other birds of prey (Azam *et al.*, 2015; Voigt *et al.*, 2018b). In addition to predation risk, the species-specific response of bats to lighting, and in particular to different colours of lighting, may be explained by two other factors: their ability to detect different lighting colours and the response of their insect prey to light of different wavelengths.

As all of the UK's bat species are insectivores, their response to different lighting colours is likely to depend on how different wavelengths of light affect their prey (Bat Conservation Trust (BCT) and Institution of Lighting Professionals (ILP), 2018). A wide variety of insect taxa are attracted to artificial lights, including many of the insect groups that British bats feed on (Russo *et al.*, 2019a). However, most insects and other invertebrates are most sensitive to shorter (green, blue and UV) wavelengths and are most attracted to UV light (Mathews *et al.*, 2015). Conversely, insects are insensitive to longer wavelengths and are therefore least attracted to red light (Voigt *et al.*, 2018b). Deep orange lighting is thought to be similarly unattractive to insects, while light orange wavelengths attract significant numbers of insects (Mathews *et al.*, 2015; Rowse *et al.*, 2015). White light (which is a mix of all wavelengths) (Waldman, 2002), particularly when it contains UV wavelengths, is also attractive to insects (Spoelstra *et al.*, 2017; Russo *et al.*, 2019a). While LED lights emit little to no UV, and consequently attract fewer insects (Lewanzik and Voigt, 2017), they do still emit some insect-attracting shorter wavelengths (Mathews *et al.*, 2015).

Different colours of artificial lighting may also have direct impacts on bats themselves, depending on which colours the animals can and cannot perceive (Spoelstra *et al.*, 2017). As the retinæ of bats have a high ratio of rods to cone photoreceptors when compared to diurnal mammals (Spoelstra *et al.*, 2017), they can become temporarily blinded by bright light as their rods become saturated and therefore unresponsive— a state which can persist for over ten minutes (Mathews *et al.*, 2015) and result in disorientation (Beier, 2006). The need to avoid this temporary 'flash-blindness' may also partly explain why light-averse species, which are already more vulnerable to predation, avoid ALAN (Azam *et al.*, 2015).

While there is evidence that bats are able to discern a variety of different wavelengths of light (Zeale *et al.*, 2018), shorter wavelengths seem to cause much more disturbance to bats than longer wavelengths (Spoelstra *et al.*, 2017). This could explain why many light-averse species appear to tolerate red light (Spoelstra *et al.*, 2017; Zeale *et al.*, 2018). However, there is evidence that bats may also perceive red light (Simões *et al.*, 2019; Spoelstra *et al.*, 2017). Several studies suggest that many Yangochiropteran bat species, including *Myotis* species, are sensitive to UV light (Simões *et al.*, 2019). Research suggests that

Yangochiropterans are also particularly sensitive to (green) wavelengths of 520-540nm (Mathews *et al.*, 2015; Simões *et al.*, 2019) but incur fewer negative impacts from lighting colours with peak wavelengths greater than 540-550nm (Stone *et al.*, 2015a; BCT and ILP, 2018). The impacts of lighting on bats may therefore be reduced by altering the colour of artificial lighting (Spoelstra *et al.*, 2017).

There have been very few studies into the impacts of different colours of lighting on light-averse bats in particular (Spoelstra *et al.*, 2017) and existing studies have produced mixed findings. In two similar studies, the drinking activity of several light-averse species, including *Myotis* species, was significantly reduced when cattle troughs were illuminated with white LEDs (Russo *et al.*, 2017; Russo *et al.*, 2019b). An experiment in the Netherlands found that *Myotis* species were significantly less active in white and green lighting - implying avoidance of these colours – but were equally active in darkness and red light (Spoelstra *et al.*, 2017). A UK study on commuting bats similarly found that *Myotis* species were less active in white and green light relative to the dark control but were not affected by red lighting. However, the same study found that the activity of lesser horseshoe bats *Rhinolophus hipposideros* was significantly reduced at all lighting colours used – white, orange, green and red – relative to the dark control (Zeale *et al.*, 2018). Zeale *et al.* (2018) also found that *Myotis* species were significantly less active in orange lighting than in the dark control. This finding is surprising as this colour of lighting has a wavelength interval of greater than 550nm, which is thought to have fewer negative impacts on light-averse bats (Waldman, 2002; Stone *et al.*, 2015a).

Conversely, Spoelstra *et al.* (2018) found that none of the lighting colours they used (white, green and red) altered the commuting behaviour of Daubenton's bats through culverts in the Netherlands. The results of this study differ markedly with other studies into the impact of lighting on this species. In a study carried out in Italy, the activity of Daubenton's bats was significantly reduced in response to white LED lighting (Russo *et al.*, 2019a). A second study, into light pollution detected from satellite images, also found that Daubenton's bats responded negatively to illuminance (Laforge *et al.*, 2019). Given the lack of consensus as to the impacts of different lighting colours on *Myotis* species, further research on this genus is merited.

Daubenton's bat forage extensively above waterbodies (Warren *et al.*, 2000), feeding on aquatic flying insects (Rydell *et al.*, 1999), which are thought to be more vulnerable to the impacts of artificial lighting than terrestrial insects (Perkin *et al.*, 2014). Additionally, as Daubenton's bats may habitually forage along the same stretches of waterway, ALAN may fragment this species' habitat by acting as a barrier to commuting and exploiting different foraging areas (Russo *et al.*, 2019a). Daubenton's bats are one of the more light-intolerant bat species (Voigt *et al.*, 2018b; Russo *et al.*, 2019a) and therefore artificial light along waterways has key implications for this species (Russo *et al.*, 2019a).

Aims and Objectives

The aim of this study was to ascertain whether the foraging activity of Daubenton's bats differs with lighting colour. The mean number of bat passes, feeding buzzes and feeding buzz (FB) ratio (the number of feeding buzzes divided by the number of bat passes), a measure of foraging efficiency, were used as measures of activity.

Materials and Methods

Study area

All recording sessions were carried out between 06/08/2019 and 04/10/2019 at a single site on the River North Esk, at Springfield Mill Local Biodiversity Site (LBS), Polton, Lasswade, Midlothian, Scotland (OS grid reference NT285647). A single site was used in order to minimise confounding environmental variables. This site was selected for the study as there are previous records of Daubenton's bats in the area (NBN Atlas Partnership, 2017) and the site has tree cover on both sides of the river, in addition to the calm water surfaces which the species is known to prefer (Rydell *et al.*, 1999).

For the lighting treatments, a long-range LED light (Cluson PLR-500, 1200 lumens) was attached to a tripod, placed as close as possible to the water's edge, and directed towards the opposite bank, therefore covering the full width of the river. The lamp was positioned so that its light shone at the normal flying height of Daubenton's bats, low above the water's surface, for the majority of the river's width. Red and amber filters were used for the red and amber lighting treatments, while the white lighting treatment consisted simply of the LED's white light without any filter attached. During the dark control treatment, the LED lamp was switched off, but left in exactly the same location, in order to control for any attraction to/avoidance of a novel object in the bats' foraging territory. In order to ensure that only lighting could impact on bat activity, it was determined that the LED lamp did not produce any audible or ultrasonic sound.

Recording of echolocation calls began at 45 minutes after sunset. Each recording session was 1.5 hours long, and split into six, 15-minute lighting/dark control periods. The survey timeframe was chosen in order to coincide with the anticipated peak in insect abundance. Only a single lighting colour was used per recording session, interspersed with the dark control, as shown in Table 1. There were 21 recording nights in total. In order to avoid habituation, which may reduce any negative impacts of lighting (Russo *et al.*, 2019b), or learned avoidance of the LED light, field work was not carried out on consecutive nights. Each lighting colour was replicated across seven nights, each in an order to control for confounding environmental variables. A Titley Scientific Anabat Walkabout detector, attached to a tripod, was used to record bat activity for the duration of the recording session. The detector was placed in close proximity (c.3m) of the river.

Table 1: How lighting periods were split up over each 1.5 hour recording session.

Lighting Treatment	Elapsed time, from 45 minutes after sunset, at which point each lighting period began					
	0 minutes	15 minutes	30 minutes	45 minutes	60 minutes	75 minutes
White	Dark control	White light	Dark control	White light	Dark control	White light
Red	Dark control	Red light	Dark control	Red light	Dark control	Red light
Amber	Dark control	Amber light	Dark control	Amber light	Dark control	Amber light

Sunset times for each recording night were obtained from the Time and Date website (Time and Date AS, 2019). To minimise the impact of adverse weather on the study, field work was not carried out on nights with persistent heavy rain, high winds, or when the temperature at the start of the recording period was below 8°C. Surveys were abandoned if adverse weather began during the course of the recording period, or if the river became turbulent due to heavy rain the previous day. Weather conditions including temperature, wind speed and direction, cloud cover and precipitation were recorded at the start and end of each recording session.

Call analysis

Bat call analysis was carried out using Anabat Insight software (Titley Scientific). The 'Batclassify' auto-identification plugin was run on each sound file, with an 'ID Tag certainty threshold' of 50%, to give an indication of which species were present in each file. The audio and spectrogram of each file was then manually analysed and the species classification was either confirmed or changed to reflect the actual species present (i.e. the classifiers output was not relied upon, without a manual check).

Originally, all *Myotis* calls that showed clear 'comb filtering' (calls with 'missing' frequencies characteristic of Daubenton's bats flying close to water) (Middleton, 2020) (Figure 1) were manually classed as Daubenton's bat calls. Those that did not show this feature were classed only to genus level as *Myotis*, and FB ratios were calculated separately for the two groups. However, due to the very small number of feeding buzzes classed purely as *Myotis*, all data was consequently pooled and all calls were treated as Daubenton's bat. Also, given the study area and the fact that all *Myotis* individuals observed during the course of the study showed characteristic Daubenton's bat, low flying foraging behaviour, it seemed reasonable to take this approach.

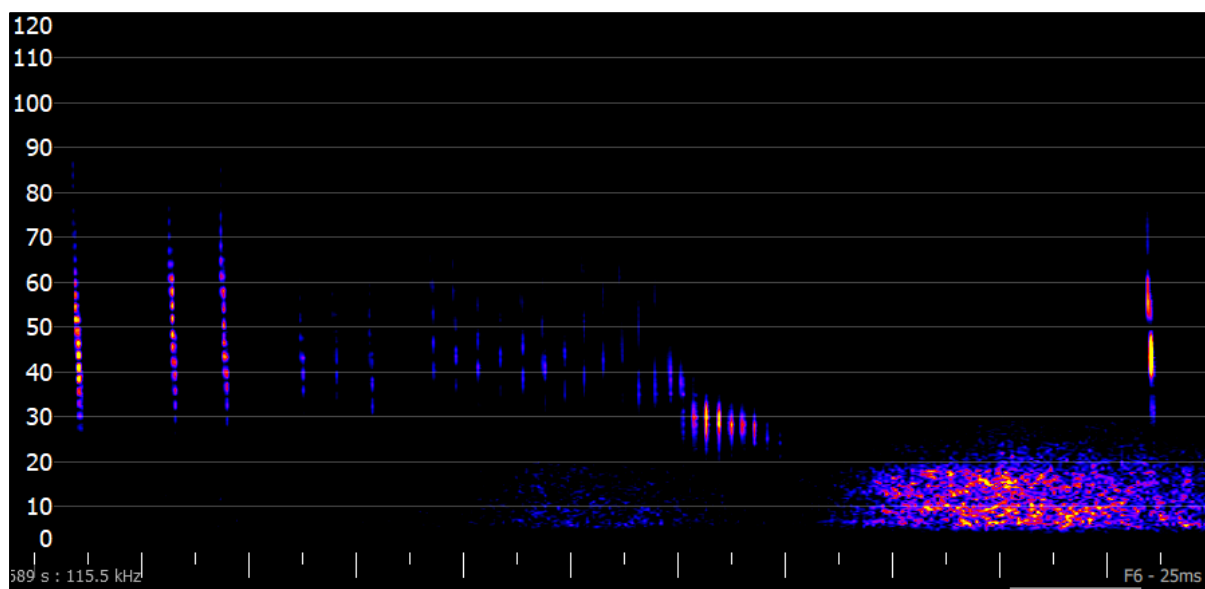


Figure 1: Echolocation calls of a Daubenton's bat, showing characteristic 'comb-filtering', and a feeding buzz (Y-axis denotes echolocation frequency in kHz).

For the purposes of this study, a single bat pass was defined as a file containing *Myotis* echolocation calls, except where there were clearly two or more individuals present, in

which case this was classified as two or more passes. There did not appear to be more than two individuals of the *Myotis* genus present in any sound file analysed and indeed, no more than two Daubenton's bats were seen at any one time during the course of the study.

A Microsoft Excel file of raw species count data was generated for each night's data. The total number of bat passes, feeding buzzes and FB ratio was then calculated for each recording period and this data was entered into a single Excel file.

Statistical Analysis

Statistical analysis was carried out using R Studio statistical software (R Core Team, 2019). As zeroes do not give any meaningful information in ratio data, all zero values were removed from the FB ratio data. The ratio data then met normality assumptions, so a one-way analysis of variance (ANOVA) was carried out on this data. A Tukey-test was then carried out to determine which lighting treatments had significantly different FB ratios from each other. The number of bat passes and number of feeding buzzes data did not meet normality assumptions, so a non-parametric Kruskal-Wallis test was carried out on this data.

Results

A total of 6,828 bat passes and 2,548 feeding buzzes were recorded over 21 recording nights (31.5 hours in total). Of these, 6,076 passes (89%) and 2,502 feeding buzzes (98%) were identified to species level as Daubenton's bats. The remaining 11% of passes and 2% of feeding buzzes were not identified to species level and so were identified to genus level as *Myotis*.

There was a significant difference in FB ratio between the different lighting treatments ($F = 12.97$, $df = 3, 116$, $P < 0.001$) (Figure 2). A Tukey Test revealed that the FB ratio was significantly higher for the dark control than for both white lighting (difference = 0.22 ± 0.05 SE, $P < 0.001$) and for amber lighting (difference = 0.18 ± 0.05 SE, $P < 0.001$). The FB ratio for red lighting was also significantly higher than for white lighting (difference = 0.14 , ± 0.06 SE, $P = 0.030$). FB ratio data can also be read as the median percentage of bat passes containing a feeding buzz – 29%, 45%, 38% and 22% for amber, dark, red and white light respectively.

There was a significant difference in the number of bat passes between different lighting treatments (Kruskal-Wallis $\chi^2 = 9.40$, $df = 3$, $P = 0.024$). The median number of bat passes appears to be significantly lower for white lighting than for any of the other lighting treatments, but there does not appear to be a significant difference between the dark control and the two other lighting colours (Figure 3).

There was a significant difference in the number of feeding buzzes between different lighting treatments (Kruskal-Wallis $\chi^2 = 26.25$, $df = 3$, $P < 0.001$). The number of feeding buzzes during the white light treatment appears to be significantly lower than for both the dark control and red lighting (Figure 4). The amber lighting treatment also had fewer feeding buzzes than the dark control or red lighting.

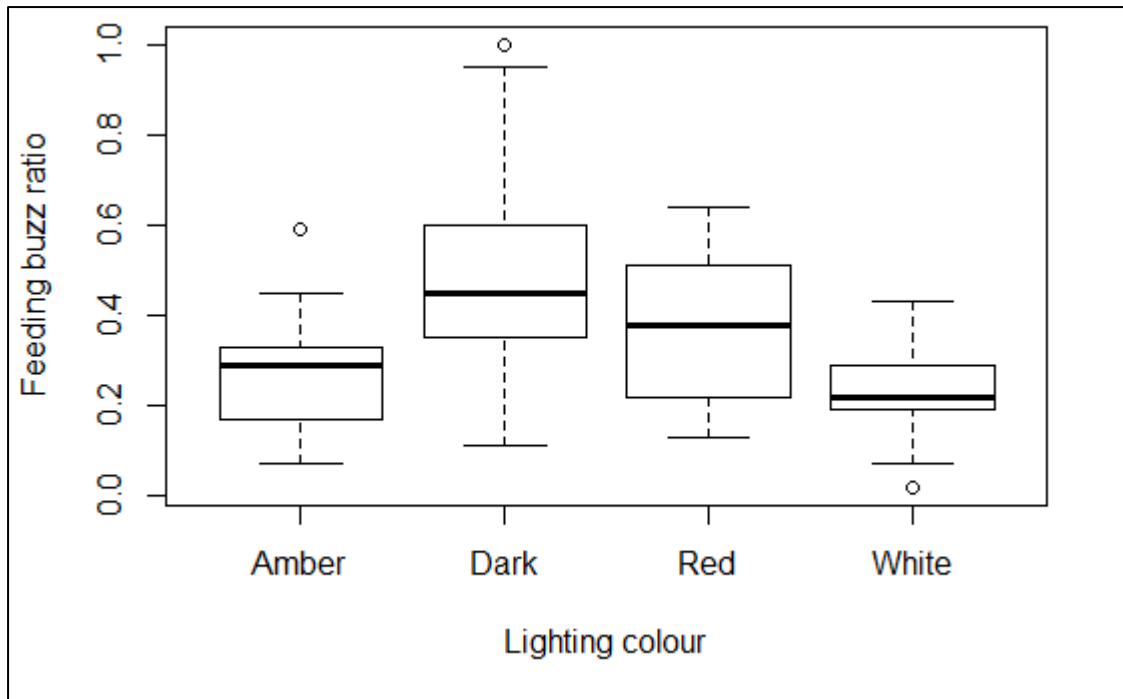


Figure 2: Boxplots of median feeding FB ratio for each lighting treatment, with maximum and minimum. Solid black lines indicate medians, boxes indicate 25 and 75 percentiles (inter-quartile range), and whiskers denote 5 and 95 percentiles (minimum and maximum). Circles indicate outliers.

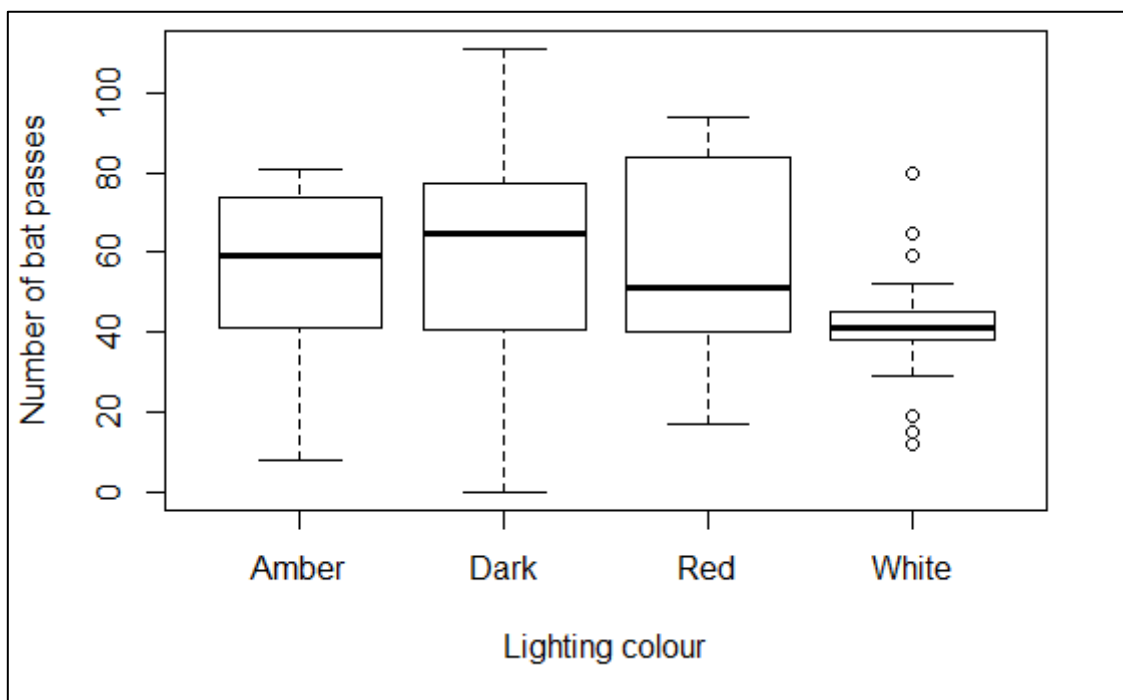


Figure 3: Boxplots of median number of bat passes ($\pm$ IQR) for each lighting treatment, with maximum and minimum. Circles indicate outliers.

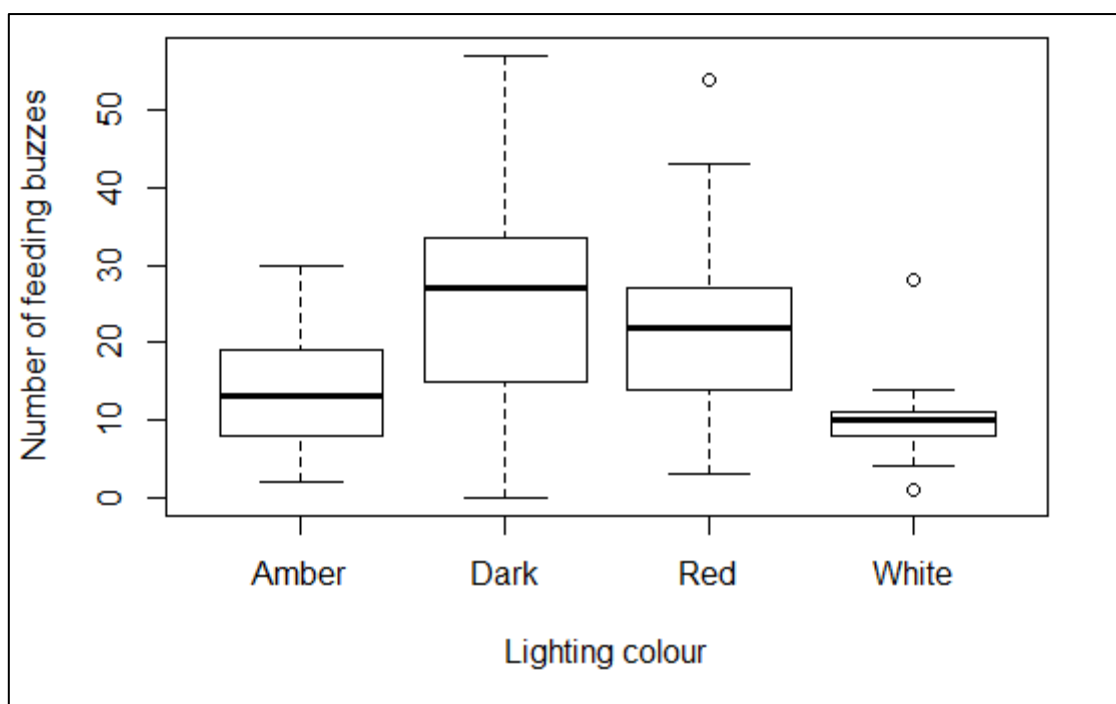


Figure 4: Boxplots of median number of feeding buzzes ($\pm$ IQR) for each lighting treatment, with maximum and minimum. Circles indicate outliers.

Discussion

This study found that both white and amber lighting significantly reduce the foraging activity of Daubenton's bats relative to darkness, while red lighting does not. These findings are consistent with many previous studies on the impact of white lighting on Daubenton's bats and other *Myotis* species (Russo *et al.*, 2017; Spoelstra *et al.*, 2017; Zeale *et al.*, 2018; Russo *et al.*, 2019a; Russo *et al.*, 2019b) but until now, no study has specifically examined the impact of different lighting colours on foraging Daubenton's bats. The finding that the foraging activity of Daubenton's bats was significantly reduced in amber lighting is consistent with the findings of a study by Zeale *et al.* (2018), which found that *Myotis* species were significantly less active at orange HPS lighting than in darkness. The results of both studies contradict other studies in the literature which have suggested that lighting with peak wavelengths above 540-550nm is less impactful on bats (Stone *et al.*, 2015a; Stone *et al.*, 2015b; BCT and ILP, 2018). HPS lamps have a peak wavelength of between 550 and 600nm (Elvidge *et al.*, 2010; Stone *et al.*, 2015b), though they are known to emit some UV and other short wavelengths which light-averse species are especially sensitive to (Stone *et al.*, 2015a), which may explain the results obtained by Zeale *et al.* (2018). In support of this, the activity of *Myotis* species was significantly reduced when their commuting routes were illuminated with HPS lights in previous experiments (Stone *et al.*, 2015a).

One of the greatest limitations of the present study is that it was not possible to determine the precise wavelengths that each lighting colour consisted of. It was not possible to determine whether the LED lamp (particularly during the white lighting treatment) used in this study emitted UV wavelengths which light-averse *Myotis* species are particularly sensitive to and can likely see (Simões *et al.*, 2019), though LEDs generally emit little or no light in the UV range (10-400nm) (Lewanzik and Voigt, 2017; BCT and ILP, 2018). LEDs do, however, emit short wavelengths (Mathews *et al.*, 2015) which are known to have more

negative impacts on light-averse bats than longer wavelengths (Spoelstra *et al.*, 2017). Indeed, Elvidge *et al.* (2010) examined a variety of different LED lamps and found that white LEDs have a peak wavelength of 450-460nm, which is in the blue spectrum (Waldman, 2002; Stone *et al.*, 2015a). This could explain why white light caused the greatest disturbance to the foraging behaviour of light-averse Daubenton's bats.

If the red and amber filters used allowed only a relatively narrow wavelength range of that colour spectra through, both filters would have had a peak wavelength greater than 550nm (Waldman, 2002; Elvidge *et al.*, 2010; Stone *et al.*, 2015a). This narrow wavelength range is characteristic of coloured LEDs (Elvidge *et al.*, 2010; Stone *et al.*, 2015a), but this is usually not how colour filters fitted to white LEDs work. The colour filters, in this study, are unlikely to have been perfect and it is possible that small amounts of other wavelengths (including short wavelengths) may have still been emitted (Olympus Corporation, 2020). The extent to which this took place may have differed between the red and amber filter. If the amber filter allowed through relatively more short wavelengths, than did the red filter, this would explain why amber light also reduced bat foraging activity while red light did not. It is recommended that in future research of this kind, monochromatic coloured LEDs be used instead, so the peak wavelengths can be more readily ascertained.

An alternative explanation for the results obtained with the amber light is that even some lighting colours with a peak wavelength above 550nm are capable of significantly disturbing Daubenton's bats. The response of bats to colour is known to be highly species-specific (Stone *et al.*, 2015a), and very few studies have examined the impact of lighting colours on this particular species (Spoelstra *et al.*, 2018). Previous studies have shown that the impacts of lighting colours on light-averse bats decrease with increasing peak wavelength (Spoelstra *et al.*, 2017; Zeale *et al.*, 2018). This explains why white (which contains the greatest short wavelength spectra of the three colours used) was the most disruptive to foraging behaviour, followed by amber and then red, which was least disruptive. The amber light used in this study likely had a similar peak wavelength (of around or below 600nm) to the HPS light used by Zeale *et al.* (2018) (Elvidge *et al.*, 2010; Stone *et al.*, 2015a). It may be the case that for Daubenton's bats, the peak wavelength above which lighting is no longer significantly disruptive is greater than this figure of 600nm. Further studies are required to conclude whether this is indeed the case, to determine the precise peak wavelength above which significant impacts no longer occur in this species, and whether this wavelength applies only to foraging activity or across all activity types in this species.

The findings of this study - and many others in the literature (Russo *et al.*, 2017; Spoelstra *et al.*, 2017; Zeale *et al.*, 2018; Russo *et al.*, 2019a; Russo *et al.*, 2019b), contrast markedly with results of a study by Spoelstra *et al.* (2018), in which commuting Daubenton's bats showed no reduction in activity in white, green or red light. As the brightness of the LED lamps was similar to that used in a previous study, in which there was a clear reduction in activity under white and green light (Spoelstra *et al.*, 2017), a plausible explanation for this, is the perceived risk of predation. As the clearance height from the water within the culverts in that study was only around 50cm, the bats may not have feared predation in such a narrow space (Spoelstra *et al.*, 2018). In the present study, and the study carried out by Zeale *et al.* (2018), lighting experiments were carried out in more open environments where there was a greater likelihood of predation by visually oriented predators under lit conditions (Stone *et*

al., 2009). In addition, the response of bats to lighting also varies with the type of activity being undertaken by the bats, for example, foraging, commuting or drinking (Russo *et al.*, 2017; Russo *et al.*, 2019b). As Daubenton's bats may forage repeatedly along the same stretch of water (Aughney and Roche, 2006), this presumably puts them at much greater risk of predation under lit conditions than simply passing through an area briefly while commuting. Foraging Daubenton's bats are therefore likely to be more light-averse than commuting bats (Russo *et al.*, 2019a). Light-averse bats may perceive the risk of predation under red light as being lower than for shorter light wavelengths, as they are less sensitive to it (Spoelstra *et al.*, 2017; Zeale *et al.*, 2018).

There were a number of limitations on the present study. August 2019 was unusually wet and surveys often had to be called off due to heavy rain or due to increased turbulence of the river. This study was also time limited, in that it had to be carried out during a specific period. The study may also have suffered from a very small sample size in terms of the number of individual bats recorded. Additionally, only a single LED lamp and a single site were used in this study. Future studies of this kind could overcome some of the limitations of the present study by using multiple lamps and sampling from multiple sites on the same night, which would also give a larger sample size, and could determine whether the impacts of lighting differ with environmental conditions or geographical location. Comparing more open sites with less open ones could also have tested theories about predation driving avoidance of particular lighting colours.

It is recommended that future studies also be carried out over a longer period of time, to overcome the high variability in bat activity data. Longer periods of light/darkness would also have better accounted for any lag in behaviour between light/dark periods. Changing the order of light/dark periods (rather than always starting with a dark period) would have controlled for the confounding variables of time since sunset and insect abundance, while using multiple lighting colours on the same night would have minimised any confounding environmental variables.

Another limitation of this study is that it was not possible to measure insect abundance or activity during the different lighting treatments. It is recommended that future studies do this where possible, as this would allow a comparison between bat activity and insect concentrations at each lighting colour. However, the response of Daubenton's bats to different lighting colours in this study is unlikely to be explained by a food-induced reaction, as insects are known to be attracted to white and light orange lighting, but are least attracted to red light (Voigt *et al.*, 2018b). If Daubenton's bat foraging activity varied according to the attractiveness of different lighting colours to their prey, their response would be the opposite to the results obtained in this study, with reduced activity in red light and increased activity in white and amber light. The response of Daubenton's bats to lighting in this study is therefore better explained as direct avoidance of white and amber light due to a (real or perceived) greater risk of predation (Russo *et al.*, 2019a), or for some other reason yet to be considered.

It was not possible in this study to accurately determine the lux level (brightness) of the LED light used, particularly at the distance of bat activity from the lamp. Previous studies have shown that the brightness level of the lighting used is as important as, or even more

important than, the colour of lighting used (Lewanzik and Voigt, 2017). It is also important to note that lux level is modelled on the perception of brightness by humans, not by bats, and as their visual systems are very different from those of humans, they are likely to perceive brightness levels differently (Kries *et al.*, 2018). For example, Voigt *et al.* (2018a) suggest that *Myotis* species likely perceive lighting emitting UV spectra as brighter than lighting emitting longer wavelength spectra and may also be more likely to experience 'flash-blindness' in these spectra (Beier, 2006; Mathews *et al.*, 2015). The filters placed over the white LED lamp for the red and amber lighting treatments are likely to have decreased the brightness of the light for these colours. However, the fact that foraging activity was significantly reduced at the amber light, but not the red light, shows that even at a potentially lower brightness, the bats still responded differently to different light colours.

It is possible that some of the calls originally labelled as *Myotis* could have been a species other than Daubenton's bat, most likely Natterer's bat *M. nattereri* given the location of the site. However, the individuals observed during every survey showed characteristic Daubenton's bat behaviour and there were no *Myotis* individuals observed visually that did not show this behaviour. Some of the calls picked up by the detector may have been outside of the area covered by the LED light, though in this case, the activity within the area illuminated by the LED lamp would have been even lower than estimated in the white and amber treatments.

The findings of this study suggest that neither white nor amber lighting should be used in proximity to waterways used by Daubenton's bats for foraging. They also support the consensus in the literature that the use of lighting with shorter wavelengths (especially UV, which is particularly disturbing for light-averse bats) should be avoided in light-averse bat habitat. Indeed, in an earlier study, reducing the short (blue) wavelength spectra and increasing the long (red) wavelength spectra present in lighting, reduced the impact of the lighting on light-averse *Myotis* and *Plecotus* species (Spoelstra *et al.*, 2017; Voigt *et al.*, 2018a).

While darkness is always preferable to lighting in terms of impacts on bats, the results of this study suggest that where the use of lighting in close proximity to Daubenton's bat foraging habitat is unavoidable, red light may be preferable to mitigate the impacts of lighting on this species. However, it should be noted that in both the present study and a previous study (Zeale *et al.*, 2018), the activity of *Myotis* bats did still (non-significantly) decrease in red lighting, suggesting that even red lighting is not 100% 'bat friendly'. Red light is therefore unlikely to be a suitable alternative for all light-averse species.

To conclude, this study enhances our understanding of the impact on light-averse bats from different wavelengths of lighting. The results of the FB ratio data confirm that white and amber lighting significantly reduce Daubenton's bat foraging activity, while red lighting does not. This confirms that lighting with shorter wavelengths has more detrimental impacts on light-averse bats, while impacts on this species may be mitigated by attenuating short wavelengths and increasing the amount of red in the spectrum. However, further research is required on a larger scale to determine whether red lighting is suitable for Daubenton's bats in all circumstances, and red light should not be assumed to be safe for all light-averse species as the literature clearly shows this is not the case (Zeale *et al.*, 2018). Further studies

are required on other light-averse species, particularly those shown to be sensitive even to longer wavelengths, to determine whether there are any 'bat friendly' lighting spectra for these species.

The precise peak wavelength at which significant impacts no longer occur in Daubenton's bats is still not known. The response of this species to lighting in this study is best explained as direct avoidance due to the (real or perceived) risk of predation, rather than a food induced response. Further studies are required to ascertain whether predation is indeed the main factor explaining the response of light-averse bats to lighting. While protecting dark refugia (Cravens *et al.*, 2018) and implementing lighting management methods (Azam *et al.*, 2015) should be a priority, altering the colour of LEDs may be necessary to reduce impacts on light-averse bats as increasing urbanisation brings a proliferation of this lighting type.

Acknowledgements

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Brown long-eared bats foraging over dune grassland

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Brown long-eared bats *Plecotus auritus* were recorded foraging over an extensive sand dune peninsula at Dornoch, Highland in 2016 (OS grid reference NH8088). As this species is generally identified as a woodland specialist, we were surprised to find it using this extensive coastal dune grassland habitat, far from mature trees.

This survey work was initially instigated to gauge whether this site supported any bats which may have been indicative of coastal bat movement/migration. However, none were noted. Eleven one-night sampling sessions were conducted between 17th April to 21st October 2016 (Table 1). As this site was very public, the (ye old) SD1 Anabat detector had to be deployed in late evening and collected early the next morning. As a result, this survey involved a considerable voluntary time commitment. This issue was a limiting factor on the amount of available data that could be collected. A Tinytag logger was used alongside the Anabat to establish temperature.

Table 1: Number of brown long-eared bat passes recorded over Dornoch sand dunes, Highland.

Dates	No. of all bat passes (Hundt, 2012)	Brown long-eared bat passes
17/18 April*	0	0
21/22 May	189	17
29/30 May*	49	1
8/9 June*	6	0
22/23 June	63	0
14/15 July	60	0
15/16 August*	39	1
24/25 August*	3	0
3/4 September	158	2
24/25 September	173	3
21/22 October	6	0

*Below average weather conditions for foraging bats.

The sand dune habitat sampled was a 40m width of *Ammophila arenaria* – *Festuca rubra* semi-fixed dune grassland (SD7), with a 20m wide strip of *Leymus arenarius* mobile dune community (SD5/6), before reaching the open beach system (Dargie, 2001; Rodwell, 2000).

The Anabat was hidden within a slightly raised dune ridge (Figure 1) which provided the detector with an elevated position to record bat calls over the dune grassland. The detector was deployed to face east, which gave optimal placement for recording any north-south movement along the coastal dune peninsular. Bat recordings were assessed using Russ (2012).



Figure 1: The dune grassland peninsular at Dornoch, Highland (looking south). Image taken at the Anabat detector sampling site. © David Patterson.

The sand dune system was used by three species of bats, including common pipistrelle *Pipistrellus pipistrellus*, soprano pipistrelle *P. pygmaeus* and brown long-eared bat. Common pipistrelle was the most frequently recorded, followed by soprano pipistrelle and then brown long-eared bat. Bat foraging presence over the dune grassland was generally considered to be low use.

The brown long-eared bat finds its northern UK breeding limit within North Highland (Scott, 2007; Crawley *et al.*, 2020). Although this species is considered very sedentary (Dietz *et al.*, 2009), it has been known to occur much further north than its *known* breeding range, often in fragmented habitats and exposed open locations (Patterson and Wells, 2014).

Brown long-eared bats were recorded on five separate visits, but the highest number of passes were recorded over the night of 21/22 May (Table 1). As this species is normally only recorded when in very close proximity to an SD1 Anabat detector, it is possible that this species may use this dune grassland habitat on a higher frequency than the results show.

Although grassland/ground feeding is known to occur by the brown long-eared bat (Altringham, 2003; Swift, 1998; Dietz *et al.*, 2009), there appears to be little information to indicate at what distance from mature trees/woodland this species is prepared to forage over grassland habitats. This survey recorded brown long-eared bats at approximately 1.5km from trees, which could be notable for what is normally considered a typical species of the forest (Dietz *et al.*, 2009). However, Walsh and Harris (1996) show some coastal habitats (including beaches and dunes) to be significantly selected as bat foraging sites. Indeed, Hawkes-Southern and Lintott (2020) recorded bat passes by *Plecotus* flying over beach habitats in Devon, albeit a minor component of the bats recorded there.

The 21/22 May peak usage over Dornoch dunes could relate to the scant leaf canopy within many mature broad-leaved trees in Dornoch at that time. At this very northern UK latitude, even in early to mid-May, many broad-leaved trees growing locally, including Sycamore *Acer pseudoplatanus*, have still to develop full leaf. Therefore, it is possible that dune grassland (and possibly other grasslands) may well provide a valuable foraging habitat in spring for brown long-eared bats willing to adapt and subsist at the northern edge of their range. We recognise that randomising the location of the bat detector throughout the dune system could have resulted in providing a more representative basis for results (Collins, 2016) and may have recorded brown long-eared bats at an even greater distance from tree/woodland habitat. However, available time was a limiting factor on this voluntary survey when balanced with other commitments.

Acknowledgements

The Bat Conservation Trust (BCT) helped to fund a temperature logger for this project (which is still in use) through the Bat Group Partnership Fund; our thanks to Lisa Worledge and Anne Youngman. John Haddow kindly provided verification of bat calls. Aileen Salway kindly provided data of bats using sand dunes in Grampian.

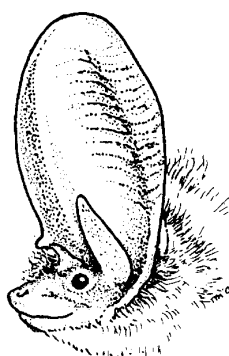
We would like to dedicate this short note to the memory of Marina Swanson who had much enthusiasm for bats in North Highland, especially in Caithness.

First drafted in March 2017, updated January 2021.

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Brown long-eared bat. © BCT

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Lunar Phobia in British Swarming Bats

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Abstract

Swarming bats have been observed to vary their activity levels depending on the phase of the moon resulting in two peaks of activity, and a trough in-between. The part of the moon's phase involved with different activity levels varies between species. Illumination itself does not appear to be the causative factor.

Introduction

The activity of individual species of *Myotis* bats at two sites in Wales during their swarming period has frequently been seen to be bimodal (Thomas and Davison, 2020). The reason for the two peaks of activity over several years of study was unknown, however, Whitby (2020, pers. comm.) suggested that the reduction in activity between the two peaks could be due to lunar phobia of the bats. The current study assesses the possibility that *Myotis* species at swarming time are lunar phobic.

Autumn swarming of some species of bats is a well-known phenomenon thought to be associated with mating and/or checking of potential hibernation sites (e.g. Glover and Altringham, 2008; Fenton, 1969; Parsons *et al.*, 2003a and b; Rivers *et al.*, 2006; Dekeukeleire *et al.*, 2016.). In many of these cases in Britain, swarming was observed in well-developed caves, whereas, in this study the caves are poorly developed, with bats exhibiting their associated lekking behaviour under cover of woodland rather than in the caves themselves.

The effect of lunar illumination on the activity of bats is poorly known, with the limited knowledge available showing apparently conflicting effects. In the tropics over a 53-day sampling period only one out of five species studied responded negatively to moonlight (Appel *et al.*, 2017). In a separate study by Hecker and Brigham (1999), there was no evidence that activity of bats varied directly with intensity of moonlight. However, activity changed depending on height within the forest, and there was a significant interaction between moonlight and height, postulating that the most likely explanation for interaction between height and moonlight is that bats adjust use of microhabitats to match distribution of prey (Hecker and Brigham, 1999). In a similar vein, Roeleke *et al.* (2018) found that noctules *Nyctalus noctula* frequently foraged above the canopy of coniferous forest at low moonlight intensities, but switched to using open grasslands and arable fields in nights with high moonlight intensities. Contradictory behaviour has also been noted when no change in activity at a swarming site due to lunar illumination was observed (Karlsson *et al.*, 2006).

A change in bat activity over the lunar cycle is hardly surprising if one considers its effect on bat prey species. As far back as the 1950s Williams and Singh (1951) reported that entomologists had known for many years that if a bright light is used for attracting insects at night, the catches are considerably higher near the period of new moon than near the full moon. In three successive years, between May and October, the catches in a light trap, both of Lepidoptera alone and of all insects together (chiefly Diptera), reached a peak at, or

shortly after, the new moon, when the geometric mean catches were three to four times as great as those at full moon.

In a meta-analysis of lunar phobia in bats, Sadlana-Vazquez and Munguia-Rosas (2013) reported an overall relationship between moonlight intensity and bat activity that is significant and negative ($r = -0.22$). They found that species foraging on the surface of the water (piscivores and insectivores; $r = -0.83$) exhibited the largest effect, whereas, forest canopy species (i.e. big frugivores; $r = -0.30$) were less affected by moonlight. Bats with different foraging habitats (understory, subcanopy, open air) exhibited the lowest effect. Latitude was positively correlated with lunar phobia ($r = 0.023$).

In Chile, all bat species studied modified their activity based on the moonlight intensity; however, the effects were species-specific. The activity of cinnamon red bat *Lasiurus varius*, hoary bat *L. villosissimus*, Chilean myotis *Myotis chiloensis* and small big-eared brown bat *Histiotus montanus* were lower during bright nights, while the Brazilian free-tailed bat *Tadarida brasiliensis* was the only species whose activity was higher during bright nights (Vásquez *et al.*, 2020).

In the south of England, it was found that the impact of moon illumination on bat activity varied between taxa. Overall bat activity was significantly lower in instances of full illumination than in partial or no illumination. The effect of moonlight on activity of both common pipistrelle *Pipistrellus pipistrellus* and soprano pipistrelle *P. pygmaeus* was more gradual but remained negative. The effect of moonlight on *Nyctalus* and *Myotis* species was less clear: Partial illumination being associated with peak activity of *Nyctalus* and lowest activity of *Myotis* (Perks and Goodenough, 2020).

These apparently contradictory observations may, in part, be due to different behaviour of different species within the genera studied, or even differential behaviours of species over the year. The current study looks only at activity within the swarming period and considers individual species within the *Myotis* genus rather than bats as a whole.

In our study area, swarming bats exhibit two distinct activities. They visit cliff faces and caves in a manner previously described for swarming bats (Glover and Altringham, 2008), but additionally, exhibit lekking behaviour in nearby woodland which is characterised by aggregations of flying bats often exhibiting chase sequences under cover of the woodland canopy.

Materials and Methods

Study area

The study area was the Welsh (west) side of the Wye Valley between Tintern and Chepstow. As shown in Figure 1, the cliffs involved face between east and south-east.

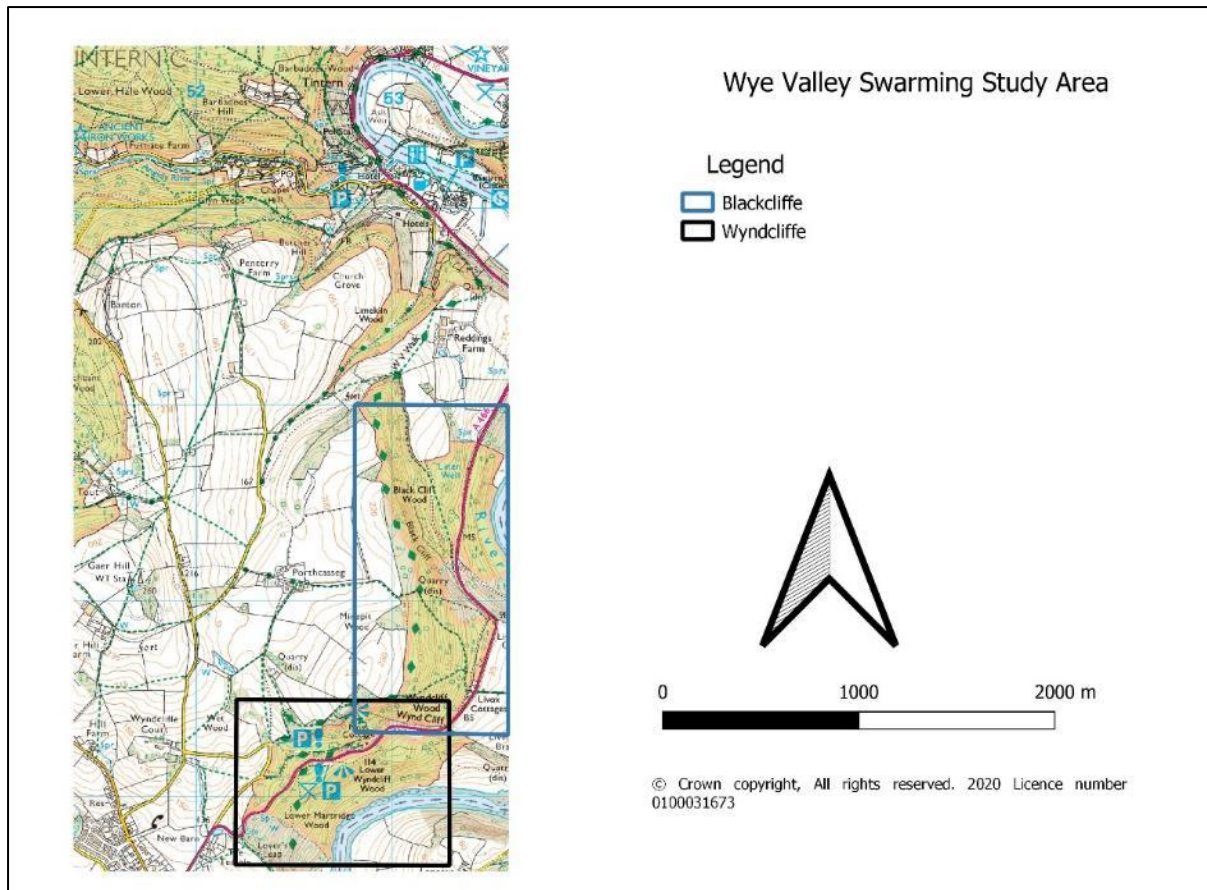


Figure 1: Wye Valley Swarming Study Area.

Measurement of bat activity

Measurement of bat activity in 2015, 2016, and 2017 was undertaken at a small cave as per Davison and Thomas (2017), recording zero crossing files and manually classifying bats as *Myotis*. No attempt was made to differentiate into species. In 2018 activity was measured using an Anabat Swift bat detector (<https://www.titley-scientific.com/uk>), recording full spectrum calls at a different cave where the bats were known to swarm. In this case, analysis of calls was undertaken automatically using Bat Classify software. Whereas in 2020, a Wildlife Acoustic SM4Bat bat detector (<https://www.wildlifeacoustics.com>) was deployed in the broadleaved wood at Blackcliffe. As with the Anabat Swift detector, it switched on automatically at 15 minutes before sunset, turned off 15 minutes after sunrise, and recorded at a sampling frequency of 500kHz. Automated analysis of the SM4's calls was undertaken by Sonobat Version 4.5.0 (<https://www.sonobat.co.uk>). This software was used because of the extensive call library used in the classification metrics, notably that the classification of Bechstein's bat *Myotis bechsteinii* involves substantially more reference calls than that used in the Bat Classify software used in 2018. Sonobat also has the advantage that it sets out to separate Brandt's bat *Myotis brandti* and whiskered bat *M. mystacinus*, which further differentiates it from Bat Classify. The 2020 Blackcliffe site was chosen as it is a lekking site for *Myotis* bats during the swarming period. No swarming or lekking activity has been recorded in the area between Wyndcliffe and Blackcliffe, which suggests that the two areas are distinct from one another.

Analysis of data was carried out using the R statistical software version 4.03, (R Development Core Team, 2020) using the MASS (Venables and Ripley, 2002) and the mgcv (Wood, 2011) packages. A negative binomial Generalised Additive model (GAM) of activity with a log link function, of activity (as measured by number of sound files) against date, controlling for the effects of rainfall, cloud cover and temperature was undertaken. The degree of smoothing (k) and theta were adjusted to achieve the minimum AIC according to the method specified in Thomas *et al.* (2017).

The illumination from the moon was obtained from the Time and Date website (<https://www.timeanddate.com/moon/phases/>) with data regarding cloud cover, temperature and rainfall downloaded from World Weather Online (<https://www.Worldweatheronline.com/Chepstow-weather-history>).

Results

It is of important note that the results from automatic analysis of echolocation calls shows similar species composition and relative abundance as catch records – although inevitably, catch records are only available on a limited number of occurrences in any one season.

In 2018 the model shows that in the case of Natterer's bat *M. nattereri*, the effects of rainfall and temperature were not significant whilst, surprisingly, cloud cover had a marginal significance ($P = 0.03$), but the overall effect thereof is negative, which suggests that the greater the cloud cover, the lower the activity. However, in GAMs, P values may not be very accurate and even levels between 0.001 and 0.1 should be regarded as ambiguous (Zuur *et al.*, 2009).

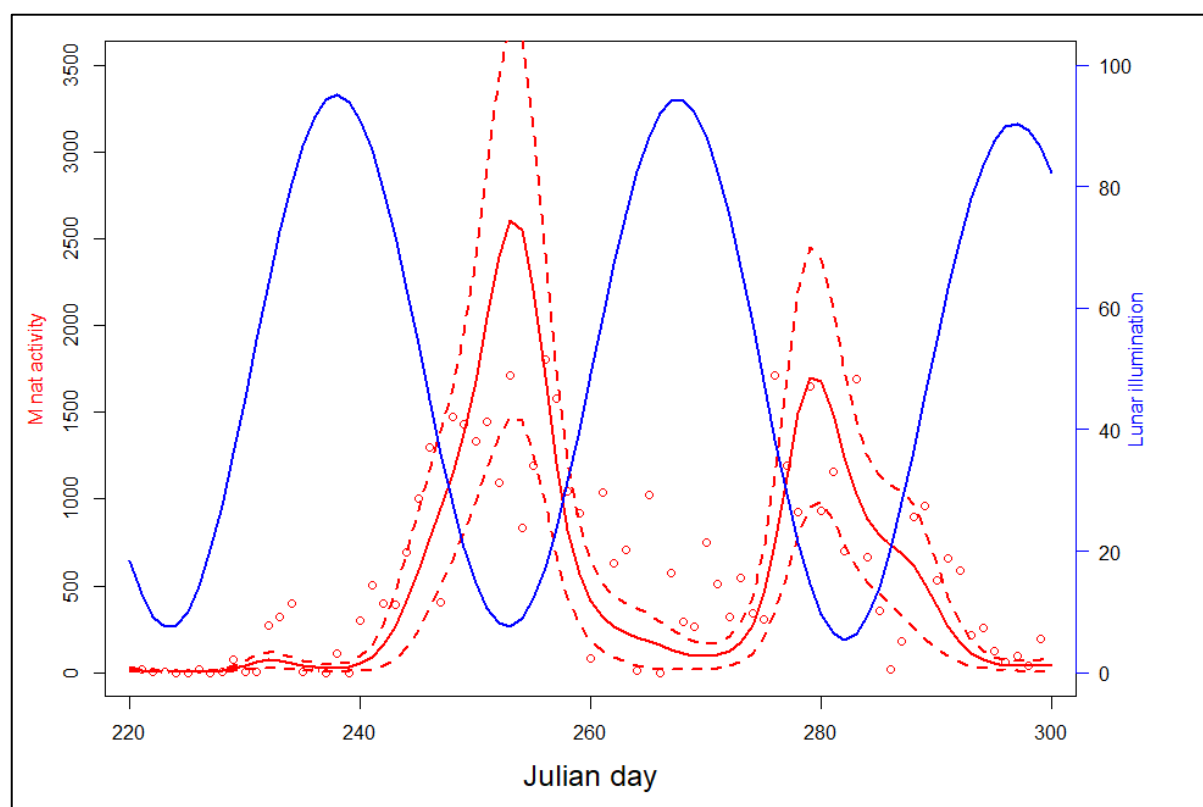


Figure 2: Wyndcliffe 2018 Natterer's bat (M nat) activity at swarming and lunar illumination against time.

In this case, Figure 2 clearly reveals that for Natterer's bat, activity during swarming occurs bimodally with the trough of activity coinciding with maximum lunar illumination.

In contrast, however, the case of Daubenton's bat *M. daubentonii* is a little different. Here, the effect of cloud cover is highly significant, but again negative ($P < 0.001$). The effect of temperature is also highly significant ($P = 0.001$), with rainfall being not significant over the period under consideration. The effect of moonlight illumination is however substantially different, with considerable activity at peak illumination (Figure 3). There is a hint of a second peak of activity at Julian day = 280.

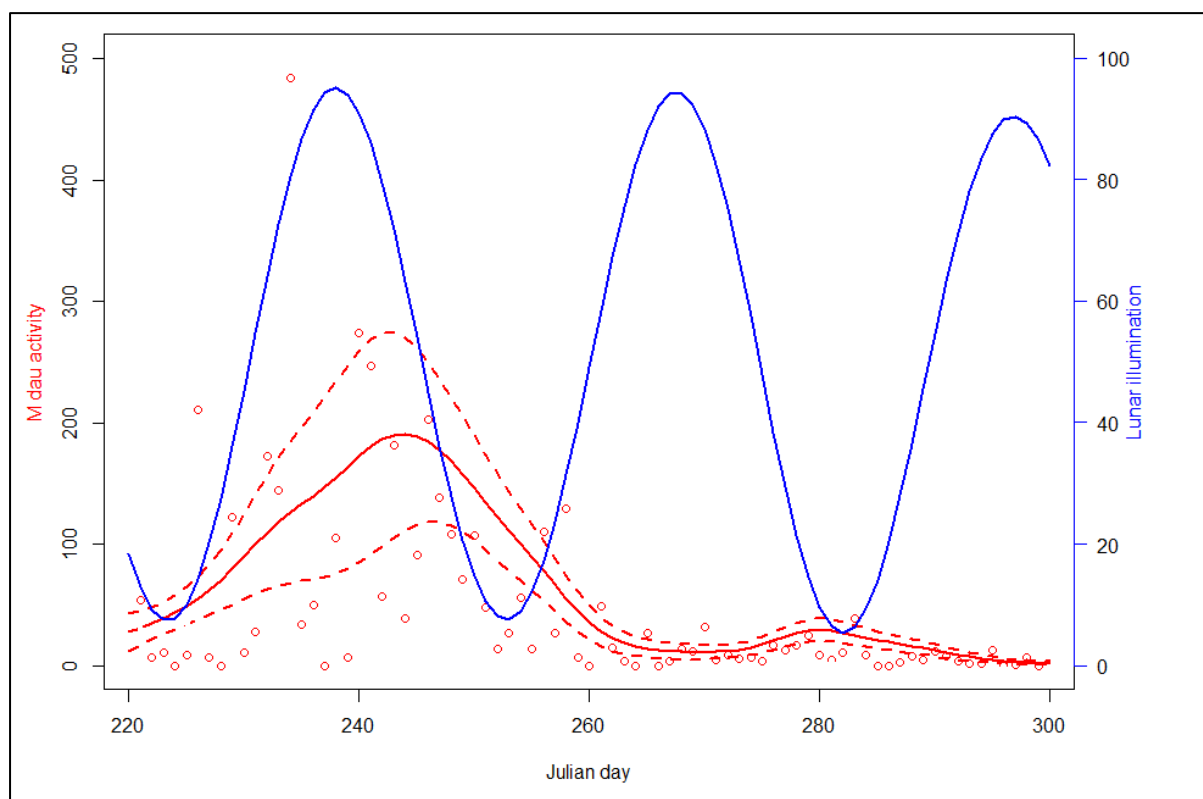


Figure 3: Wyndcliffe 2018 Daubenton's bat (M dau) activity at swarming and lunar illumination against time.

In the case of Bechstein's bat (Figure 4), the only factor of possible significance was temperature ($P < 0.01$). The low numbers and more diffuse nature of activity throughout the swarming period makes clarity difficult, but there is the definite suggestion of peak activity occurring around minimum lunar illumination.

Bat Classify does not try to differentiate between Brandt's bat and whiskered bat, which are thus not being considered here.

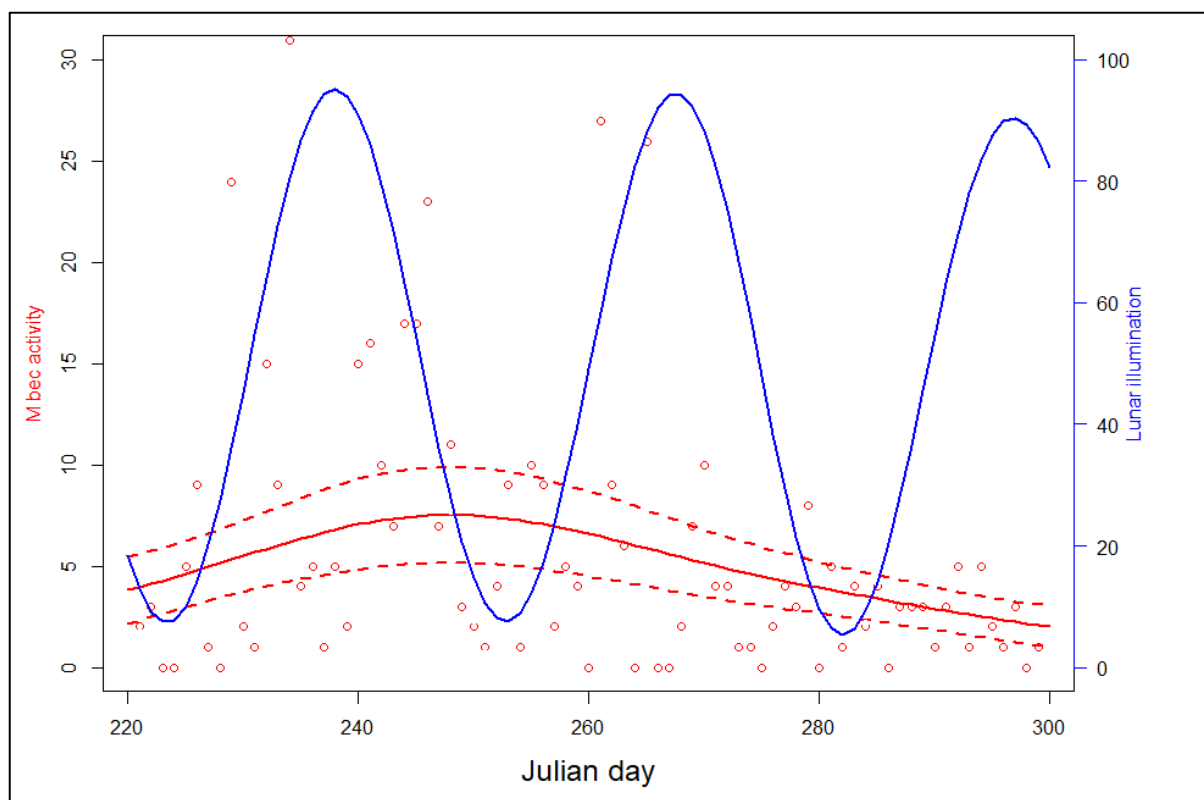


Figure 4: Wyndcliffe 2018 Bechstein's bat (M bec) activity at swarming and lunar illumination against time.

In 2020, the results were obtained from a lekking site within the woodland. Activity was lower than at the cave site in 2018, and there was far more rainfall over the analysis period.

For Natterer's bat (Figure 5), there is some indication of a first peak of activity that has been reduced due to the negative effect of rain in this period on activity (as shown by the graph). However, over the period of study, neither rain nor any of the other environmental factors exert a significant effect on activity. It is likely though that on any individual night, rainfall depresses activity. Indeed, where there is rainfall, activity levels are lower than on nights without rain.

Similarly, none of the environmental variables exert a significant effect on the activity of Daubenton's bat in 2020 (Figure 6) over the period under consideration. However, the activity chart shows the first peak of activity coinciding with rainfall. Even so, there are two peaks of activity, neither of which is at the minimum lunar illumination. Bechstein's bat activity shows bimodality with peaks around minimum lunar illumination (Figure 7).

Brandt's bat does not appear to be constrained by moonlight (Figure 8), and whilst the first peak of whiskered bat activity is coincident with minimum lunar illumination, the second is not (Figure 9).

Wales

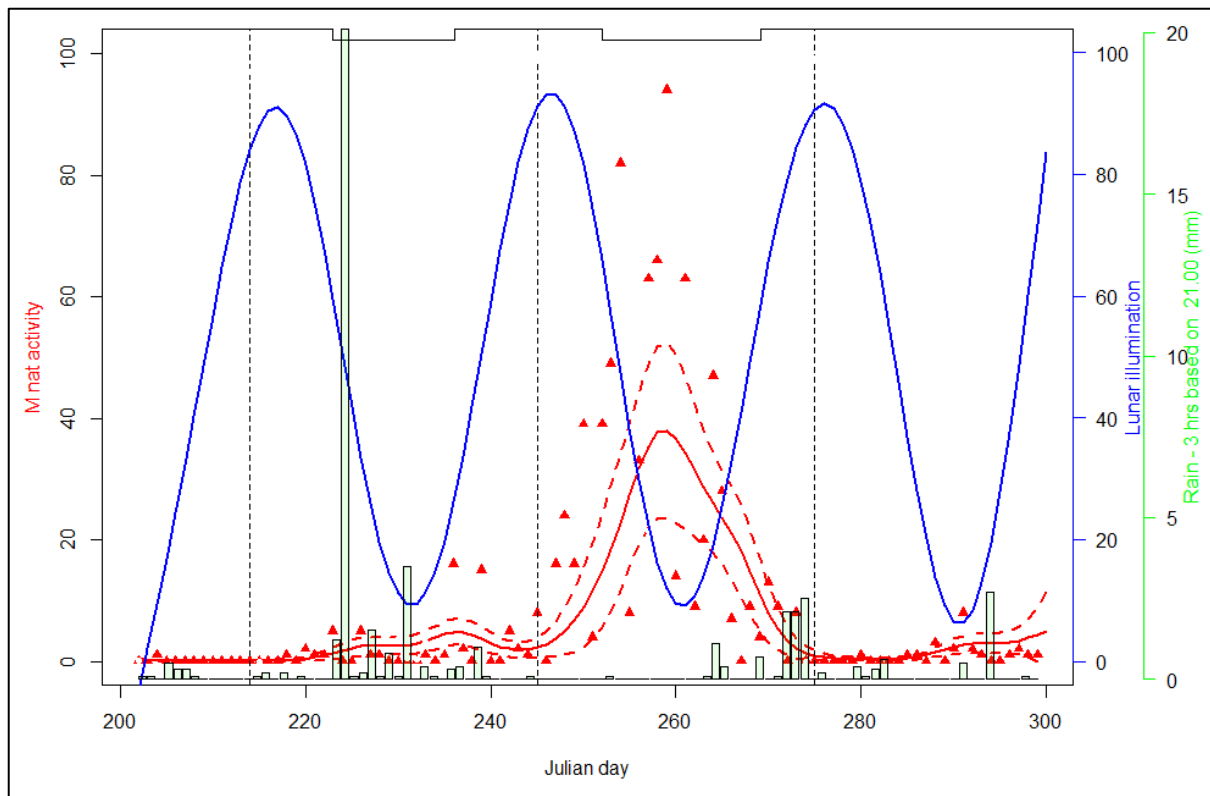


Figure 5: Blackcliffe 2020 Natterer's bat (M nat) activity at swarming, lunar illumination and rainfall against time.

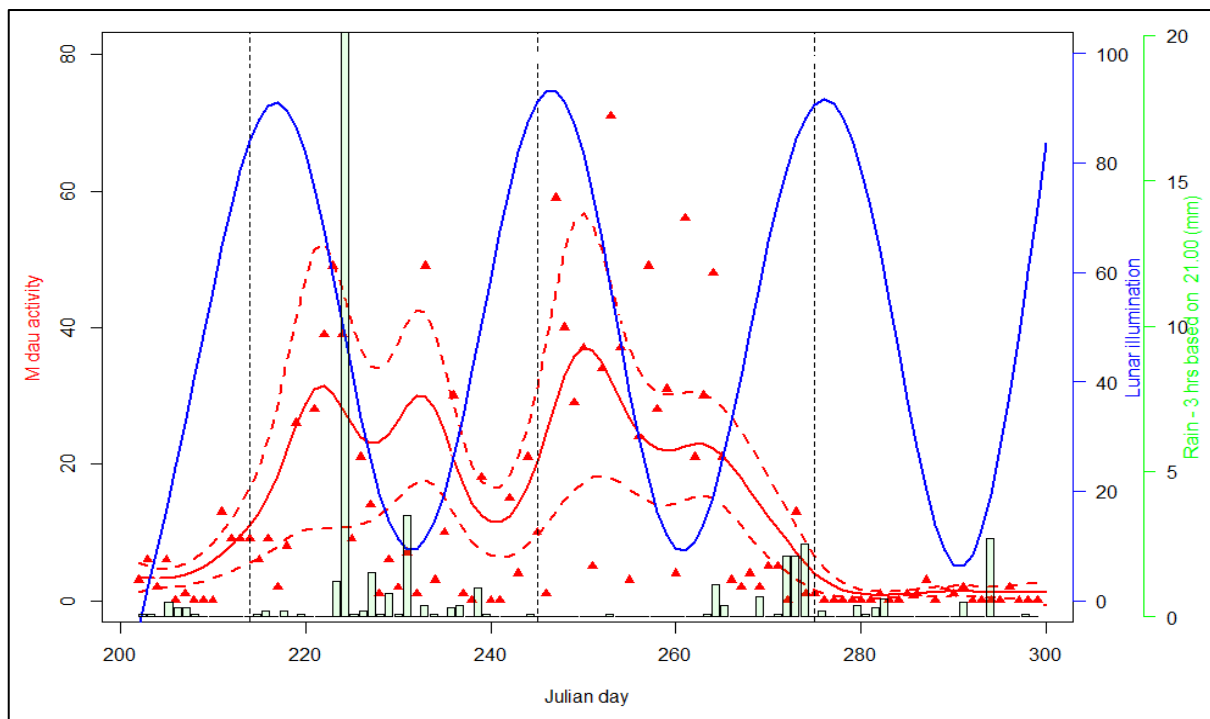


Figure 6: Blackcliffe 2020 Daubenton's bat (M dau) activity at swarming, lunar illumination and rainfall against time.

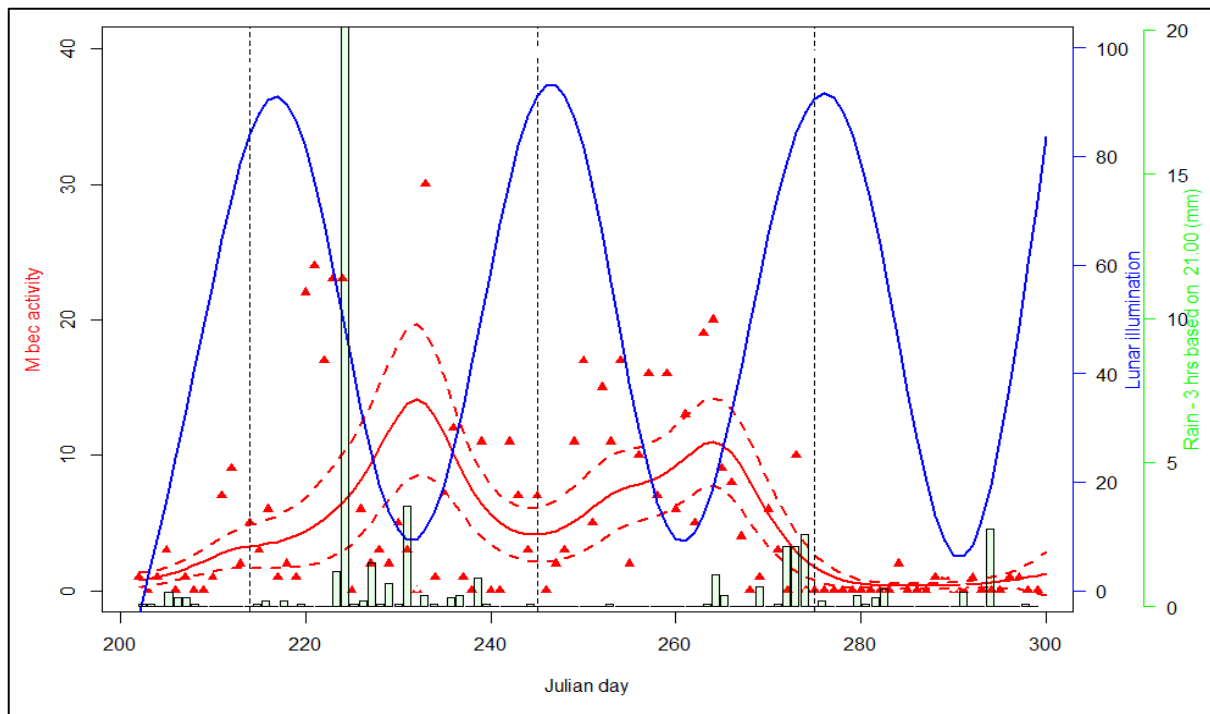


Figure 7: Blackcliffe 2020 Bechstein's bat (M bec) activity at swarming, lunar illumination and rainfall against time.

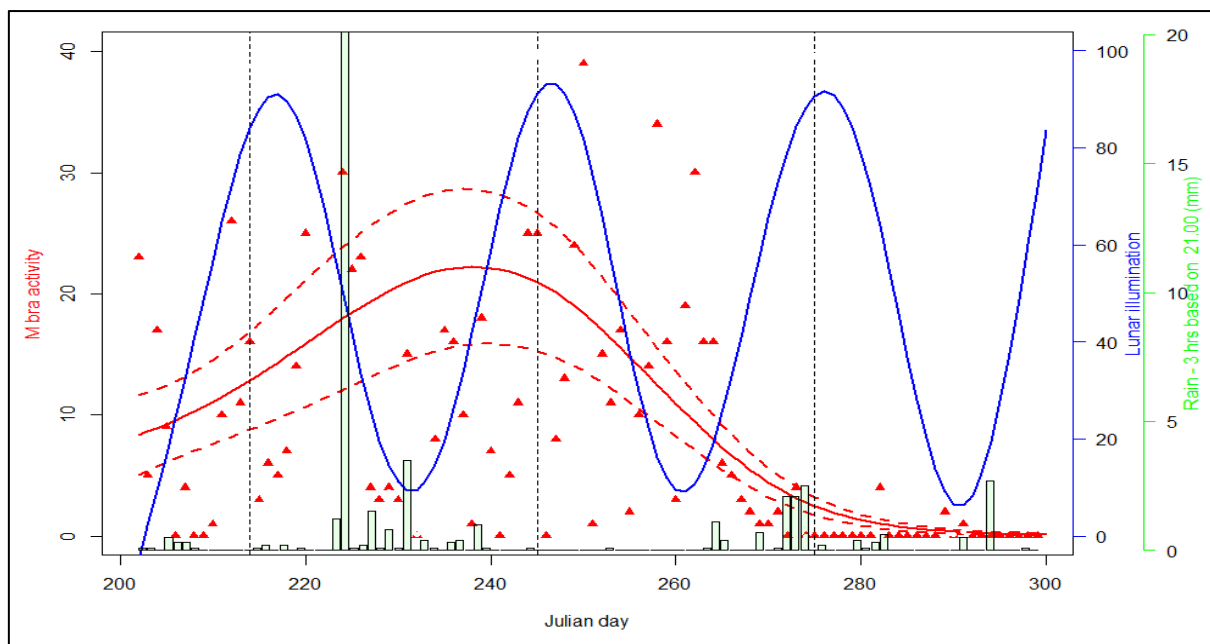


Figure 8: Blackcliffe 2020 Brandt's bat (M bra) activity at swarming, lunar illumination and rainfall against time.

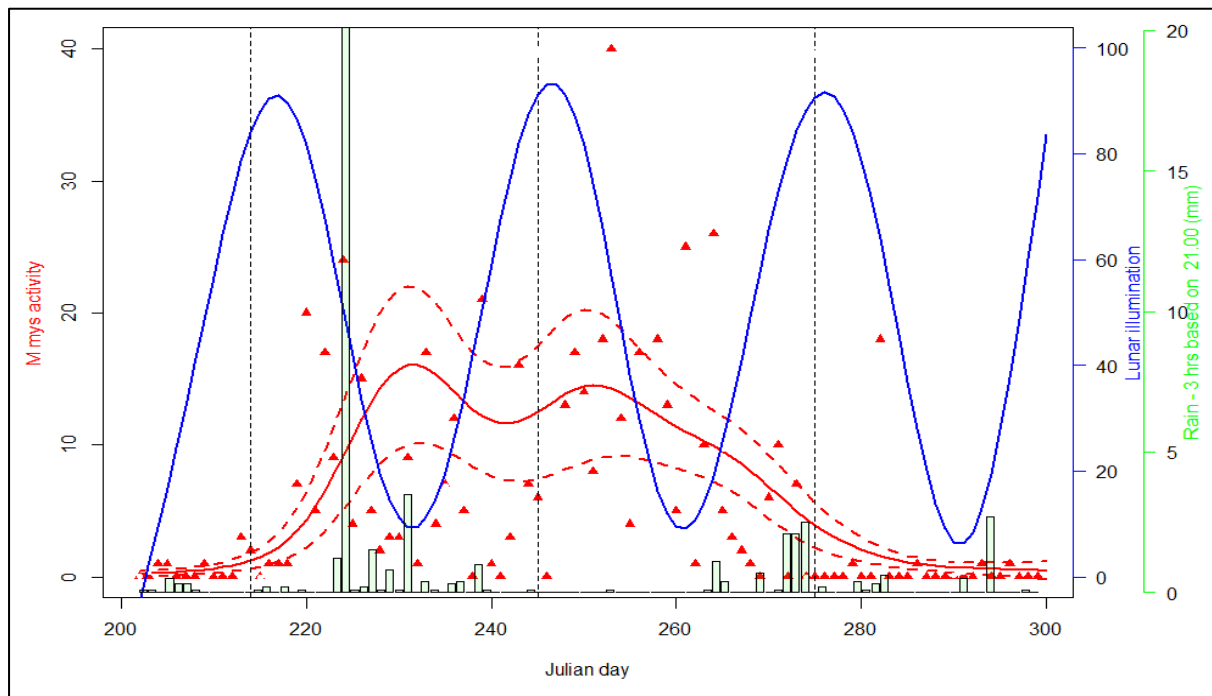


Figure 9: Blackcliffe 2020 whiskered bat (*M. myotis*) activity at swarming, lunar illumination and rainfall against time.

Whilst no attempt was made in 2015-2017 to differentiate the *Myotis* bats by species, subsequent work has shown that Natterer's bat activity at the measurement site is an order of magnitude greater than that of the other *Myotis* species. As such the results are predominantly that species and it is possible to construct a table looking at Natterer's bat activity over five seasons (Table 1).

Table 1: Annual relationship between Peak activity and Peak illumination for Natterer's bat.

Year	Peak Illumination	1st Activity Peak	2nd Activity Peak	Activity difference	Peak Illum to 2nd Peak activity
2015	243	248	259	11	16
2016	232	241	260	19	28
2017	251	237	265	28	14
2018	268	252	280	28	12
2020	247	231	259	28	12

Discussion

There is substantial discussion as to the reliability of auto analysis of bat calls, and indeed even the ability of experts to correctly identify bat calls to species. Nowhere is this situation more complex than for *Myotis* bats where there is considerable overlap between calls of different species in different environments. This exercise shows that for bulk analysis, not every call sequence has to be correctly recorded. Indeed, in this study, many were not ascribed to species. The analysis produces relative activity levels, and that is sufficient for the current study. It is pleasing to note, however, that catch records do tally with activity measurement by acoustic means.

Whilst the relationship between activity and potential moonlight clearly varies between species, it appears to be the same for the individual species over the two years in question. The actual moonlight reaching the bats' environment will be affected by the density and coverage of the clouds. The greater the cloud cover, the lower the amount of light reaching the earth should be, and, if lunar illumination increases do reduce activity (as they appear to do in the case, for example, of Natterer's bat), then increased cloud cover should present some mitigation. However, in the analysis, the effect of cloud cover is negative, the greater the cover, the lower the bat activity. This situation may be explained if the affect is that of phase of moon rather than illumination. It would be interesting in future, to see the actual illumination reaching the ground, and measure the bat activity associated therewith. Of course, illumination may affect bat activity at a swarming site by preventing animals traveling to the site across open ground from the normal roost site, as opposed to an effect at the swarming site itself. As such, a model including actual illumination should include illumination over open land as well as in the woodland.

Although the usual situation for Natterer's bat is for peak activity to occur at or around minimum illumination, that was not the case in 2016. Additionally, other species do not show maximum activity at minimum illumination (e.g. Daubenton's bat). This suggests that factors other than illumination may be at play. In general, the timing of swarming by Julian day is significantly affected by the phase of the moon and thus varies in time slightly from year to year.

The mechanism for the change in activity is unknown but would appear to not be a direct response to the illumination itself, as it occurs in all species to a greater or lesser extent but not always coinciding with maximum lunar illumination and is negatively affected by cloud cover. It could of course be an indirect response to the effect of the light on prey species, but that presumably would require that the bats were using swarming as a feeding opportunity. In which case, the effect measured at one site may be one of movement of bat activity vertically away from the microphone into the canopy as postulated by Hecker and Brigham (1999).

This type of activity measurement confirms trapping data with respect to phasing of swarming between species and could be used to compare swarming times from east to west and north to south. It can also be utilized to monitor peak times of swarming within a night and to track how that might change with progress through the season.

Whilst acoustic methods give a reliable indication of activity here, they did require some trapping to both 'ground truth' the information, and gain information on sex and reproductive condition of the bats involved.

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Evidence of rock exposure roosting bat species in the UK from recreational rock climbers and potentially important landscape habitat characteristics

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Abstract

Evidence for the use of vertical rock face habitat by roosting bats in the UK is limited. Anecdotal accounts from individuals and from literature are known (e.g. Altringham, 2003) but there is little in the way of published evidence on this topic. In this study, we used an online questionnaire approach to target recreational UK climbers for records of roosting bats. Our aims were to provide an initial indication of the frequency of encounter of roosting bats in such habitats and secondly to explore the potential local landscape habitat and topographic factors that may influence vertical rock face roost site selection by crevice dwelling bat species as a functional group.

Introduction

There are over 1,400 described species of bat making them the second-largest order (Chiroptera) of mammals, many of which have declining populations largely due to human impacts on ecosystems (Frick *et al.*, 2019). Bats are also unique in being the only mammals capable of powered flight, allowing them to exploit novel ecosystems and they are known to exploit and roost in various habitats as a result. Some species use man-made structures such as houses, bridges and barns for which the foraging ecology and roosting behaviours are, in many cases, well documented (Kunz and Lumsden, 2003; Patterson *et al.*, 2003; Collins, 2016). However, bats are also known to roost in crevices associated with the vertical rock faces (Fenton, 1970; Altringham, 2003), a terrestrial ecosystem that has received limited study especially in the UK. To the authors knowledge there are no published studies detailing vertical rock face crevice roosting records from the UK. As such, there is an evidence gap associated with the use of these habitats by UK bat species and the factors that may drive this.

Bat species from a number of genera have been recorded roosting in vertical rock face crevice habitat across the globe, with members of the *Barbastella*, *Myotis*, *Pipistrellus*, *Eptesicus*, *Perimyotis*, *Plecotus* and *Chalinolobus* genera recorded from vertical rock face crevice habitat (Hirschfield *et al.*, 1977; Cryan *et al.*, 2001; Neubaum *et al.*, 2006; Michaelsen *et al.*, 2013; Alberdi *et al.*, 2015; Ancillotto *et al.*, 2015; Lemen *et al.*, 2016; Moosman *et al.*, 2017; Williams and Thomson, 2019; White *et al.*, 2020). Published peer reviewed literature detailing such records is however largely dominated by data from North America, although there is evidence of *Plecotus*, *Barbastella*, *Eptesicus*, *Tadarida* and *Myotis* from similar habitats in Europe (Konig, 1973; Michaelsen *et al.*, 2013; Alberdi *et al.*, 2015; Ancillotto *et al.*, 2015).

The use of vertical rock face crevice habitat by roosting bats has been recorded in all seasons with records of summer (Hirschfield *et al.*, 1977; Cryan *et al.*, 2001; Alberdi *et al.*, 2015), transitional or spring/autumn roosts (Michaelsen *et al.*, 2013; Lemen *et al.*, 2016) and hibernation period roosts (Michaelsen *et al.*, 2013; Lemen *et al.*, 2016; Moosman *et al.*, 2017). Acoustic surveys in North America by Lemen *et al.* (2016) identified records of northern long-eared bat *Myotis septentrionalis*, tricolored bat *Perimyotis subflavus* and big

brown bat *Eptesicus fuscus* in December near vertical rock face habitat suggesting that individuals of these species were hibernating in rock crevices in winter. This study also suggested that rock type and micro/meso topography (distribution of crevice features on the vertical rock face) may be significant with records dominated by limestone and shale vertical rock faces with large, deep cracks. This is supported by the work undertaken by Moosman *et al.* (2017) which noted that big brown bat and eastern small-footed bat *M. leibii* favoured crevices that were smaller than nearby randomly selected crevices.

The effects of landscape structure and habitat availability have also been implicated in the selection of vertical rock face habitat by roosting bats with distance to water, woodland cover, aspect and elevation implicated (Neubaum *et al.*, 2006; Ancillotto *et al.*, 2015; Williams and Thomson, 2019). There is also some evidence that the use of such habitat may depend on the availability of alternative roosting habitat and species considered primarily tree roosting may show significant phenotypic plasticity in roost site selection in novel situations (Ancillotto *et al.*, 2015).

The sparsity of detailed research on the use of vertical rock face crevice habitat by roosting bats is perhaps understandable given the logistical constraints associated with the surveying in such habitats due to bat species life history traits: nocturnal, cryptic in crevice habitat, tricky species identification. This coupled with the practical and safety constraints associated with the survey of vertical rock faces and the deployment of automated bat detectors in such habitats, has likely impeded progress.

Vertical rock faces can also be important recreational sites. For example, technical rock climbing (i.e. use of a rope and either fixed or removable anchors for protection from falls) and bouldering (i.e. unroped climbing within a few metres of the ground) are rapidly growing sports in the UK. The latest Active People Survey (APS) results from Sport England (BMRB, 2013) suggests that around 211,000 people go climbing or hill walking at least once a month and 84,000 take part at least once a week. This can place a recreational disturbance pressure on such habitats and has been implicated in negative effects on some species and habitats (e.g. Vogler and Reisch, 2011).

This recreational activity does however also provide the opportunity for the widespread collation of ad-hoc records of vertical rock face crevice roosting bats from chance encounters whilst climbing. It is clear that such records are likely to be heavily biased in nature with on average a greater probability of encounter where levels of activity are high, this is analogous to observer bias in species distribution modelling (e.g. Warton *et al.*, 2013). Additionally, accurate species identification is also likely to be compromised, or impossible, meaning any evidence of species-specific roost selection characteristics will be severely compromised. However, given the functional requirements and thus similarities between many crevice dwelling bat species such data may still be of use in determining landscape characteristics that make some vertical rock faces more attractive for roosting than others.

This study uses such data derived from a questionnaire survey of recreational rock climbers undertaken in winter 2015/16. It aims to compare this with the vertical rock face habitat resource available in the UK in an attempt to quantify any apparent habitat selection at the crevice dwelling bat species functional group level.

Methods

Data collection/ collation

Bat presence data

A questionnaire made up of eight questions was drafted in late December 2015 using the Survey Monkey website. This survey was then subsequently linked within a post on the UKClimbing climbing interest website discussion forum (<http://www.ukclimbing.com/forums/t.php?t=630866#x8212454>).

The following questions were asked:

1. How long have you been climbing?
2. How many routes have you climbed in your climbing career?
3. Have you ever encountered bats using features on the crag whilst climbing i.e. roosting in a crack/behind a flake?
4. If yes to question 3, where were the bats roosting i.e. behind flake, in cave etc?
5. If yes to question 3, what route and crag were you on and where in the country (county) were you when bats were encountered?
6. If yes to question 3, approximately how many bats were present?
7. If Yes to question 3, what time of year were the bats encountered?
8. If yes to question 3 and known, what species or genus of bat were present?

A total of 78 responses were received to the questionnaire. These responses were reviewed online using the Survey Monkey website review interface and all responses were then collated into a single data set with records spatially filtered to those present within England and Wales only to mirror the availability of crag location information.

Available vertical rock face habitat - crag data

Crag data for England and Wales was obtained from the British Mountaineering Council (BMC) (Jones, 2021, pers. comm.). The BMC provided details of 2794 vertical rock face locations (henceforth referred to as crags) across England and Wales.

Landscape habitat data

In our study, we aimed to analyse the land use surrounding the roost sites. To analyse the information on land use surrounding roost sites and crag locations, we used the 2015 Centre for Ecology and Hydrology (CEH) land-use cover map of the UK (Rowland *et al.*, 2017). This landcover map has a 25m pixel resolution.

Two relevant land-use variables for bats were identified as follows: broadleaved woodland and coniferous woodland cover. The selection of the variables was based on known ecological preferences of crevice dwelling bat species (Bellamy *et al.*, 2013; Ancillotto *et al.*, 2015). The raster package (Hijmans, 2019) and landscape metrics package (Hesselbarth *et al.*, 2018) were used in R 3.1.6 (R Core Team, 2019) to collate and extract the land-use information for a 1km, 500m and 250m buffer around each presence and background point. These scales were chosen as bats have been shown to strongly respond to environmental characteristics at scales between 100m and 500m (Bellamy *et al.*, 2013).

In addition to land use variables, due to the known preferences of crevice dwelling bat species for water features and linear habitats often associated with water features, we also incorporated distance to nearest water feature into our analysis. This variable was generated using the OS Open Rivers data set (OS, 2020) with the distance between points and rivers derived in R 3.1.6 (R Core Team, 2019) using the simple features package (Pebesma, 2018).

Population density data

Population density data was obtained from the online CEH data portal (Reis *et al.*, 2017). This gridded population density dataset is provided at a 1km pixel area, and this was manipulated and the total population within 50km of each crag was extracted as an independent variable of interest using R 3.1.6 (R Core Team, 2019) and the raster package (Hijmans, 2019).

Data analysis

Data analysis adopted a use-availability conceptual framework, whereby environmental covariates (e.g. woodland cover, elevation etc.) at the locations where bats were encountered are contrasted with covariates at locations taken from an area deemed to be available for selection (the availability sample: Manly *et al.*, 2002; Johnson *et al.*, 2008). Such methods are analogous to spatial point process models (PPMs) and these have recently emerged as the most appropriate technique for presence-only data distribution modelling (Renner *et al.*, 2015). This approach does however require a quantification of the available habitat area to allow appropriate weighting of the points to give an encounter rate per unit area, unfortunately accurate data on the spatial area of vertical rock face habitat in the UK is not readily available. As such, we have used a figure of 1% of the area of England and Wales, approximately 1500km², in our analysis. Due to this uncertainty over the area of available vertical rock face habitat percentages between one and ten percent were trialled and were found to have no significant impact on model outputs. Alongside this PPM/Poisson regression modelling approach we also ran a series of binomial logistic regression models using the same dependent and independent variables.

PPMs do not use background points as pseudo-absences (Fithian and Hastie, 2013), but rather as quadrature points for estimating the spatial integral of the likelihood function (Warton and Aarts, 2013). The selection of sufficient quadrature/background points can be undertaken analytically where the available space is easily defined spatially. However, due to the nature of our data sources it has not been possible to extend the available space/background sample points beyond the number present in the BMC crag database and as such interpretation of the modelling outputs should be reviewed in this context and with suitable caution.

The response variable of PPMs is the density of species records per unit area (also called intensity), which should be proportional to the probability of occurrence (Fithian and Hastie, 2013; Renner *et al.*, 2015), whilst in the logistic regression modelling framework it is the binomial presence or absence of the crevice roosting bats.

We used a generalised linear modelling (GLM) framework to implement a down-weighted Poisson regression (DWPR), following Renner *et al.* (2015). This approach uses weights to

make the number of presences a negligible proportion of all data and scales the data to the actual area. As a consequence, DWPR estimates model parameters including the intercept. A small weight (10⁻⁶) was assigned to presence locations, while background points (all crag locations) were given a higher weight equal to the area of the study region divided by the number of points used.

Sampling bias

Given the ad-hoc nature of our data collection inherent bias is considered likely due to the relative probabilities of crag use intensity. Such sampling bias can be addressed by explicitly modelling the distribution of the focal species as a function of covariate(s) describing potential sources of sampling bias (Warton *et al.*, 2013). We accounted for this assumed bias through the incorporation of population density as an independent term.

Multi-collinearity

Multi-collinearity means that several particular explanatory variables have a strong linear correlation with each other, which can cause bias when interpreting the significance and influence of other explanatory variables. To eliminate this phenomenon, we checked each variable for any evidence of collinearity and excluded any variables where correlation exceeded 0.7. This resulted in the inclusion of the final following co-variables of interest: area of broadleaved woodland within 1km (ha), area of coniferous woodland within 1km (ha), area of broadleaved woodland within 500m (ha), area of coniferous woodland within 500m (ha), area of broadleaved woodland within 250m (ha), area of coniferous woodland within 250m (ha), population density within 50km of point, elevation above sea level (m), spatial co-ordinates (x and y in km) and aspect (north, south, east or west).

A single global model including all parameters as linear independent variables with an interaction term between spatial coordinates (to explicitly account for spatial variation) was run using the GLM function in R 3.1.6 (R Core Team, 2019) at each of the three habitat-variable spatial scales (e.g. 250m, 500m, 1km), for each of the modelling approaches (DWPR and logistic regression). The error family and link function were selected based on the lowest AIC value as well as the production of residual distributions that best satisfied the model assumptions (following Thomas *et al.* (2017)).

Results

A total of 78 responses were received to the questionnaire, some of which detailed more than one record of bat encounters, giving a total of 94 separate bat observations. Within these responses a total of 75 positive records of bat encounters were noted (c.80% of respondents). The spatial distribution of bat records and crag distribution are shown in Figures 1 and 2, with an example vertical rock face roosting location shown in Figure 3.

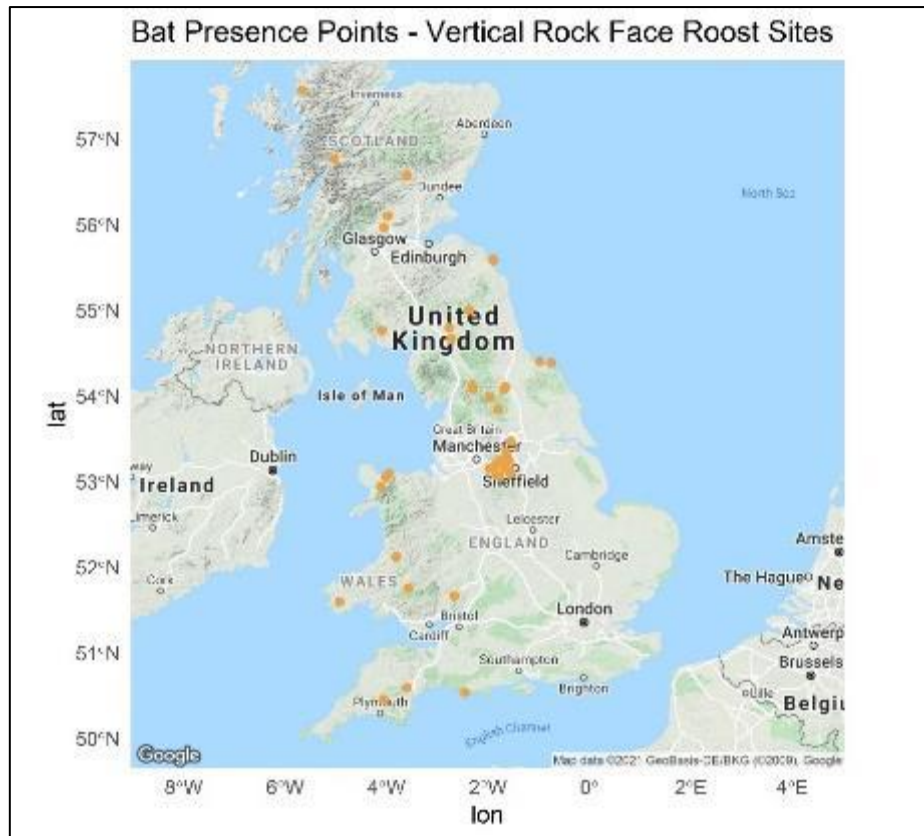


Figure 1: Bat Roost Records from Rock Climber Survey.

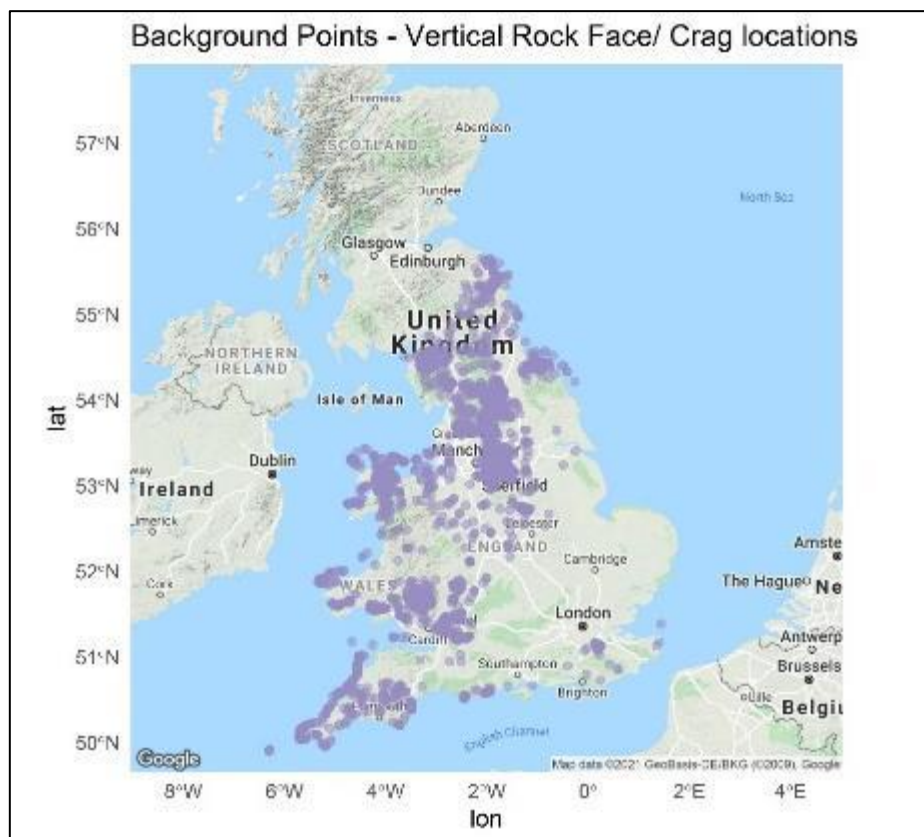


Figure 2: England and Wales Crag Locations from BMC Data.



Figure 3: Example Vertical Rock Face Roost Site. *Plecotus* species bat in-situ. © Nathalie Cossa.

Respondents were asked to provide a broad indication of the time of year they encountered roosting bats but unfortunately <50% of respondents were able to provide a response. However of those that did, 30% of records were from the summer months with 10% from the autumn, 15% from the spring and 1% from the winter. This suggests the maybe some preference for vertical rock face roosting during the active season but as this is likely to be confounded by the seasonal pattern in rock climbing intensity (e.g. more people climb outside in the summer), it is impossible to draw any firm conclusion from this pattern.

Model Outputs

The outputs of both the DWPR and logistic binomial regression analysis approaches delivered consistent results and as such we only present the DWPR model outputs and discuss these below but have provided the logistic regression outputs as supplementary information in Appendix A.

Down Weighted Poisson Regression Model Results

DWPR model analysis of our dataset identified a number of parameters as having a probable significant effect on the rate of bat encounter in vertical rock face habitat at a variety of spatial scales (Table 1).

Wales

Table 1: DWPR Coefficients for Each Model at 1km, 500m and 250m Spatial Scale. Significant parameters highlighted in bold. (Est = estimate, SE = standard error).

	<i>1km Habitat Scale</i>				<i>500m Habitat Scale</i>				<i>250m Habitat Scale</i>			
	Est	SE	z value	P value	Est	SE	z value	P value	Est	SE	z value	P value
<i>Intercept</i>	-4.74	1.40	-3.4	0.0007	-4.99	1.40	-3.559	0.0004	-5.00	1.39	-3.584	0.0003
<i>Distance to Water (km)</i>	-0.36	0.28	-1.29	0.1970	-0.43	0.28	-1.545	0.1223	-0.43	0.28	-1.543	0.1227
<i>Northern Aspect</i>	-0.70	0.63	-1.114	0.2651	-0.68	0.63	-1.086	0.2775	-0.69	0.63	-1.09	0.2757
<i>Southern Aspect</i>	0.86	0.43	1.988	0.0468	0.89	0.43	2.057	0.0396	0.90	0.43	2.091	0.0365
<i>Western Aspect</i>	0.17	0.47	0.374	0.7087	0.19	0.47	0.403	0.6870	0.20	0.47	0.437	0.6619
<i>Broadleaved Woodland Area (ha)</i>	0.01	0.00	2.293	0.0218	0.02	0.01	3.523	0.0004	0.08	0.02	4.169	<0.0001
<i>X Co-ordinates (km)</i>	0.00	0.00	0.644	0.5194	0.00	0.00	0.859	0.3903	0.00	0.00	0.799	0.4242
<i>Y Co-ordinates (km)</i>	0.00	0.00	-0.198	0.8428	0.00	0.00	-0.022	0.9825	0.00	0.00	-0.075	0.9404
<i>Population Density</i>	0.00	0.00	-0.633	0.5270	0.00	0.00	-0.379	0.7046	0.00	0.00	-0.425	0.6705
<i>Coniferous Woodland Area (ha)</i>	0.00	0.00	-0.327	0.7438	0.00	0.01	0.335	0.7379	0.01	0.05	0.187	0.8519
<i>Elevation (m)</i>	0.00	0.00	-0.989	0.3226	0.00	0.00	-1.464	0.1431	0.00	0.00	-1.423	0.1547
<i>X:Y Interaction</i>	0.00	0.00	0.446	0.6555	0.00	0.00	0.252	0.8013	0.00	0.00	0.329	0.7423

Discussion

Despite the limitations placed upon this study due to the ad-hoc and opportunistic nature of the data collection process, the inherent bias through the spatial clustering of rock climbing recreational activity and the resultant relatively low sample size we have been able to confirm the likely regular use of such habitat by roosting bats and the needs to consider crevice dwelling bat species when surveying areas with vertical rock exposure habitat. We have also been able to initially investigate the potential landscape topology and habitat factors that are likely to influence selection by roosting bats and their detection by recreational rock climbers at the local scale.

It is clear from the results of the Poisson regression analysis that the area of semi-natural broadleaved woodland habitat within 1km of the vertical rock face or crag has a statistically significant positive effect on the rate of roosting bat encounter by rock climbers at all three spatial scales (Table 1 and Figures 4-6). This consistency across spatial scales (250m to 1km) gives us some reasonable confidence that roosting bats are more likely to be encountered by recreational rock climbers in local landscapes with more broadleaved woodland. This is likely due to the strong association between many crevice dwelling bat species and woodland habitats for both foraging and roosting (e.g. Boughey *et al.*, 2011; Carr *et al.*, 2020).

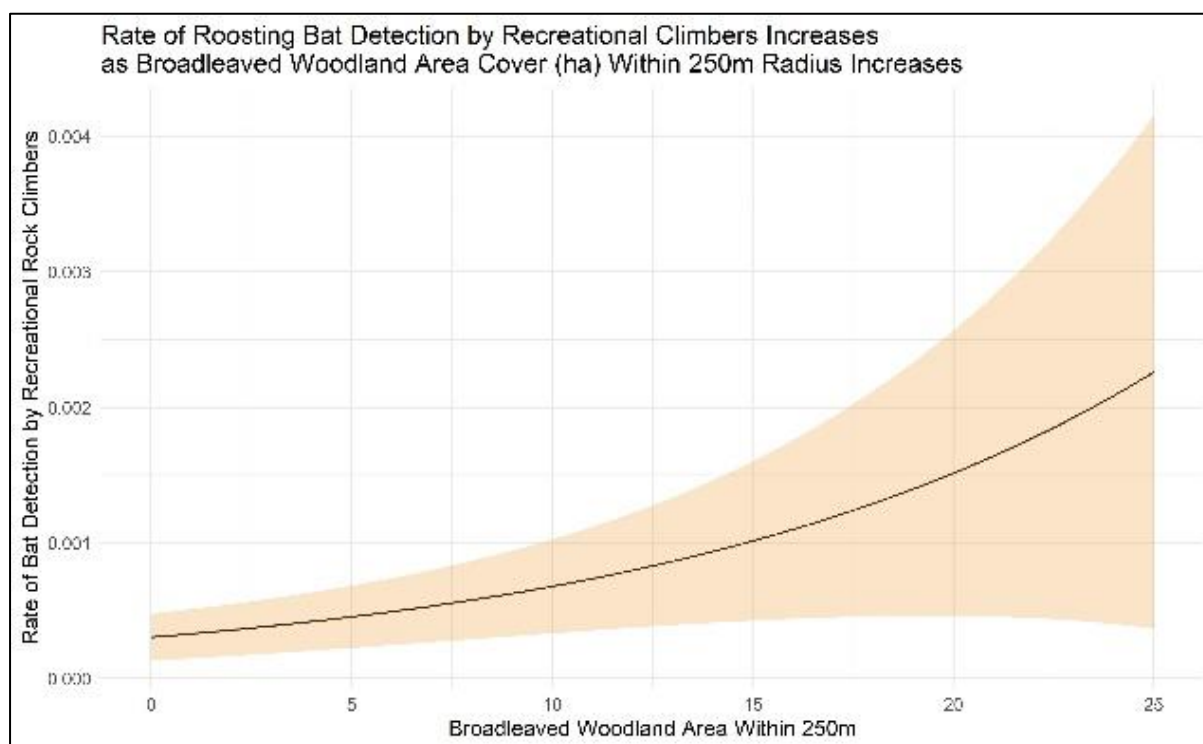


Figure 4: Predicted rate of bat detection against broadleaved woodland area within 250m.

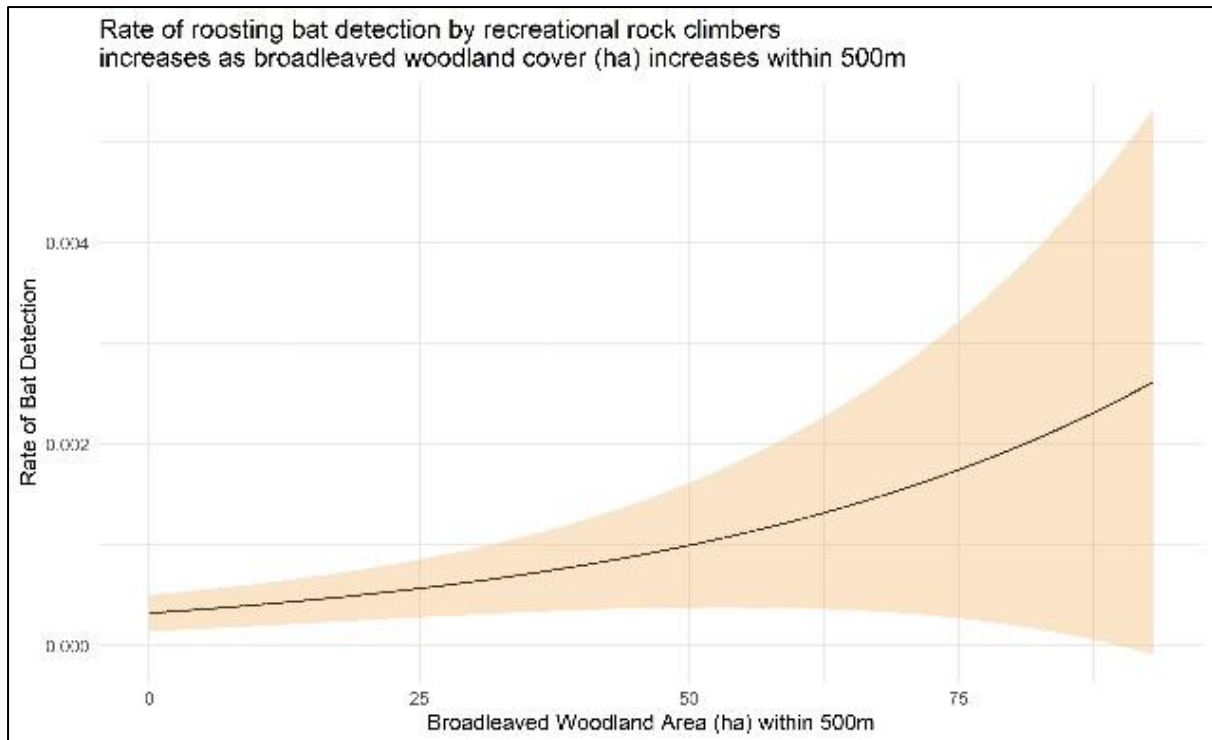


Figure 5: Predicted rate of bat detection against broadleaved woodland area within 500m.

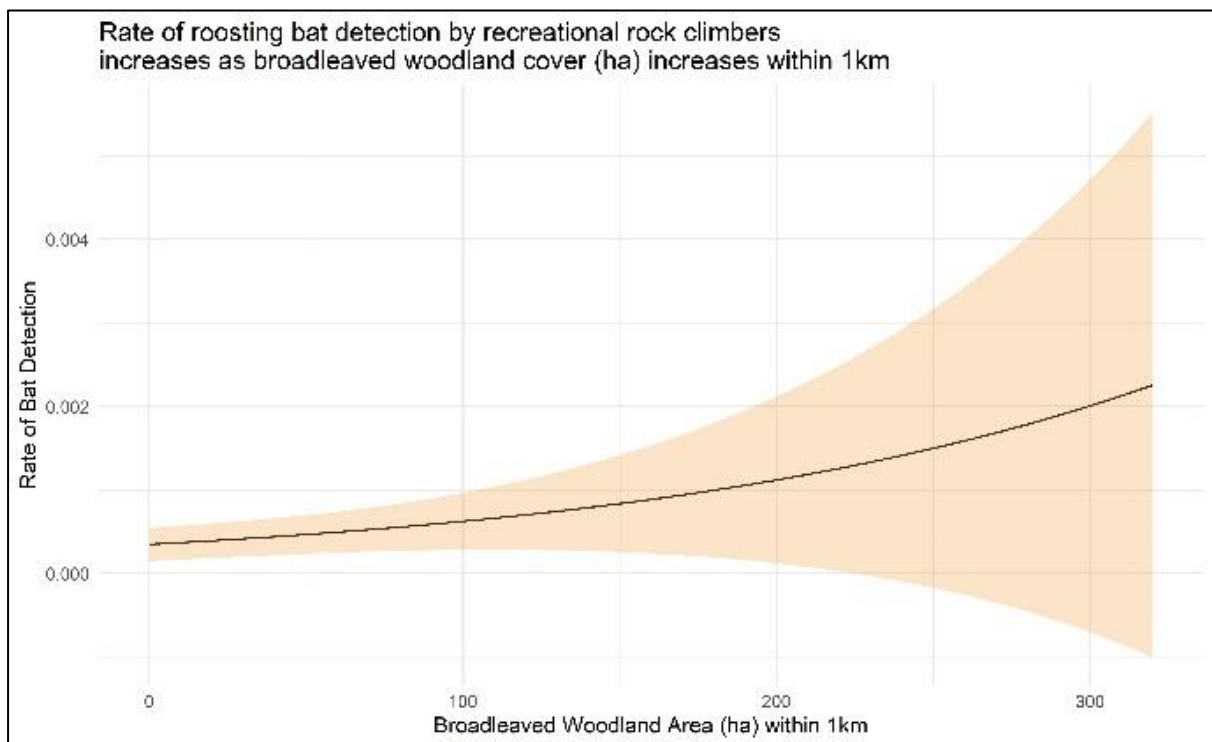


Figure 6: Predicted rate of bat detection against broadleaved woodland area within 1km.

It is also striking from the results of the Poisson regression analysis that crags with a southerly aspect are consistently identified as having a statistically significant positive effect on the rate of roosting bat encounter by rock climbers at all three spatial scales (Table 1). This consistency across spatial scales (250m to 1km) gives us some reasonable confidence that roosting bats are more likely to be encountered by recreational rock climbers in local

landscapes with a southerly aspect and with more broadleaved woodland. The reason for this association with aspect is unclear but could be due to the natural thermal gain these sites receive through increased solar radiation. Alternatively, this could be confounded by a preference for southerly aspect rock faces by recreational climbers, resulting in greater sampling effort at these sites. As such, this statistically significant result should be treated with caution and indeed may not be ecologically significant.

It goes almost without saying that further structured survey of vertical rock face habitat would be beneficial in giving us a greater understanding of the ways in which crevice dwelling bat species use such habitat both spatially and but also temporally. This is being greatly helped in recent years by groups such as Climbers for Bat Conservation in the United States (<https://climbersforbats.colostate.edu/>) and Henry Andrews' great efforts in setting up the bat rock habitat key database (<http://www.batrockhabitatkey.co.uk/cliffs-outcrops-database/>) in the UK. We would encourage readers to submit records to these schemes should they encounter roosting bats in vertical rock face/crag habitats.

We would also encourage further research and engagement with UK climbers to encourage the recording of any roosting bats encountered during recreational climbing activity. Engagement with the BMC to facilitate this and raise awareness would also be recommended.

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