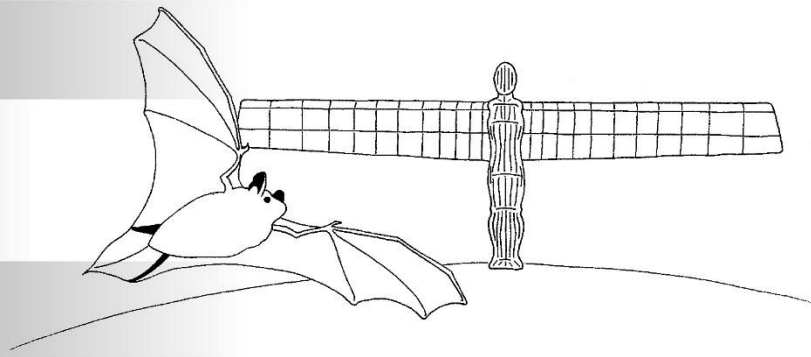


Northern Bats



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South Yorkshire Bat Status.

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Introduction

Identifying the status of bats is difficult. Bat roosts are not always easy to locate, bats are active at unsociable times and at times when light levels make observing them harder. The final compounding factor is that bats are not easy to definitively identify to species level even with specialist bat detecting equipment. The following document seeks to identify the relative status of South Yorkshire's bat populations on the basis of the information that is known at the time. As our knowledge increases and our interpretation improves, revision of the category that each species has been assigned is anticipated and welcomed.

Methodology

The principal source of information that this assessment is drawn from is the database of records held by South Yorkshire Bat Group (as of February 2017). Particular attention has been given to the records of hibernation and maternity roosts and to any studies that allow comparison of the bats recorded through a standardised methodology (such as the preliminary results of the habitat suitability modelling surveys that the bat group undertook in 2014 and 2015).

Using the information available the bats of South Yorkshire have then been classified in terms of their relative abundance within the county. The categories used in this classification have been drawn from similar attempts to identify the relative status such as Natural England TIN051 (Mitchell-Jones and Carlin, 2014). These are given in Table 1.

Table 1: Relative status categories assigned to South Yorkshire bat populations.

Most abundant ↑ ↓ Least abundant	Common
	Fairly common
	Locally distributed
	Uncommon
	Scarce
	Rare
	Very rare
	Not known to be present

Limitations, assumptions and changes to the database

In order to make sense of the vast amount of varied information held by South Yorkshire Bat Group, some of the data needed to be simplified. Therefore, the following pertinent changes were made to the records listed in the database, prior to any analysis being undertaken:

- All negative records were removed;
- All records with zero counts (for the number of bats) were removed;
- All records with a species but without a count value were assumed to be one bat;

- For all counts identified as ranges in the database, the upper value was taken;
- Where possible all records were refined to a species or genus based on known ranges. For example, a *Plecotus* record would be defined as a brown long-eared bat *Plecotus auritus*, a big bat record would be defined as a *Nyctalus*);
- All multiple species records were split to give one separate record for each species.

It is noted that some of the records held by the database appear to be located beyond the county boundaries. Given that the vast majority of the records appear from within the boundaries and that most of the remaining records are from within close proximity, the out of county records are considered unlikely to substantially skew the assessment of the relative population status of the bats present.

Some of the records held by the database are multiple counts of the same roost on different dates/years. It is likely that the motivation to resurvey a roost is greater if the roost is sizable, or a less common species. This is thought likely to have biased the raw results presented in the Database Results section. Instances where this would be likely to impact the status category assigned to a species have been identified, acknowledged and taken into account as fully as currently possible in the interpretation.

Database Results

Following the changes identified above, the number of records, number of bats, average number of bats per record and maximum number of bats in any one record present in the February 2017 South Yorkshire Bat Group database is given in Table 2.

Table 2: Summarising the breakdown of records held in the South Yorkshire Bat Group Database.

Species / species group	Number of records	Sum of the number of bats recorded	Mean count per record (2dp)	Maximum count for any one record
Bat (species unknown)	1312	5700	4.34	317
Unknown <i>Pipistrellus</i> species	1227	23401	19.07	550
common pipistrelle <i>Pipistrellus pipistrellus</i>	2034	9123	4.49	337
soprano pipistrelle <i>P. pygmaeus</i>	353	11576	32.79	730
Nathusius' pipistrelle <i>P. nathusii</i>	2	2	1	1
brown long-eared bat	320	1285	4.02	105
Unknown <i>Myotis</i> species	144	230	1.60	15
Daubenton's bat <i>Myotis daubentonii</i>	552	14015	25.39	412
Natterer's bat <i>M. nattereri</i>	284	1238	4.36	39
whiskered bat <i>M. mystacinus</i>	77	107	1.39	30

Brandt's bat <i>M. brandtii</i>				
Alcathoe bat <i>M. alcathoe</i>				
whiskered bat	112	1052	9.39	60
Brandt's bat	2	2	1	1
Unknown <i>Nyctalus</i> species	65	159	2.45	12
Noctule <i>Nyctalus noctula</i>	335	986	2.94	88
Leisler's bat <i>N. leisleri</i>	72	205	2.85	32
All species combined	6891	69081	10.02	730

The high mean count, and high sum of the number of bats recorded, for soprano pipistrelle and Daubenton's bats is likely to be influenced by two large historic colonies of these species. Both colonies have been very well studied. The records from across the years for the soprano pipistrelle colony were responsible for 25 of the top 50 records in the bat group's database when ordered by count size. This included the highest count of all, across all species records (730 bats). Similarly, the records for the Daubenton's bat roost, which recorded a peak count of 412, were responsible for 13 of the top 50 records.

Discussion

Breeding and hibernating bats

Together with the database records used, the monitoring undertaken by South Yorkshire Bat Group at maternity roosts and hibernation roosts allows us to identify whether each species is known or suspected to breed and/or hibernate within South Yorkshire. In total eight species are known or suspected to breed and hibernate regularly in South Yorkshire. These are shown in Table 3.

Table 3: Species known or suspected to breed and/or hibernate in South Yorkshire.

Species	Breeding known or suspected	Hibernation known or suspected
common pipistrelle	Yes	Yes
soprano pipistrelle	Yes	Yes
Nathusius' pipistrelle	No	No
brown long-eared bat	Yes	Yes
Daubenton's bat	Yes	Yes
Natterer's bat	Yes	Yes
whiskered bat	Yes	Yes
Brandt's bat	No	Unknown
Alcathoe bat	No	No
noctule	Yes	Yes
Leisler's bat	Yes	Yes
serotine <i>Eptesicus serotinus</i>	No	No
Barbastelle <i>Barbastella barbastellus</i>	No	No

Following consideration of the information available the relative status of South Yorkshire's bat populations is shown in Table 4.

Table 4: The relative status of South Yorkshire's bat populations.

Species	Relative population status within South Yorkshire
common pipistrelle	Common
soprano pipistrelle	Fairly common
Nathusius' pipistrelle	Very rare
brown long-eared bat	Locally distributed
Daubenton's bat	Fairly common
Natterer's bat	Locally distributed
whiskered bat	Uncommon
Brandt's bat	Very rare
Alcathoe bat	Not known to be present
noctule	Uncommon but widespread
Leisler's bat	Scarce
serotine	Not known to be present*
barbastelle	Not known to be present

*A single record of a serotine was reliably identified within the county in 1977. It was reported in [The naturalist](#).

Common pipistrelle was considered to be the only relatively common species. This was principally based on the large number of records. It is acknowledged that the sum of the number of bats recorded (Table 2) was higher for soprano pipistrelle and Daubenton's bat than for common pipistrelle. As identified in the Database Results section, the presence of one well studied large colony of each is considered likely to be responsible for skewing the data. Therefore, while concentrations of both species (Daubenton's bat and soprano pipistrelle) may be greater than common pipistrelle at a local level, particularly around large roosts, they are considered less abundant at a county level.

Two species, soprano pipistrelle and the Daubenton's bat, were considered to be fairly common. Daubenton's bat was the species with the highest number of bats recorded when summed over all South Yorkshire Bat Group Database records. Apart from the large, well-studied roost mentioned above, this may also be an effect of the fact that they tend to be recorded in locations where they aggregate (i.e. at key foraging sites) and possibly also because they are distinctive enough to identify to species level without the use of a bat detector. Soprano pipistrelle recorded the maximum count for any one species and the highest mean number of bats reported per record. This tallies with the fact that soprano pipistrelle maternity roosts are known to be relatively large (Barlow and Jones, 1999). Even taking into account the factors likely to inflate their perceived abundance, the records suggest that both species are fairly common (relatively speaking) within the county.

Brown long-eared bat, and Natterer's bat were considered to be locally distributed within South Yorkshire. These bats are species which use woodland extensively and have relatively quiet calls in this habitat. Barataud (2015) gives the detection ranges of *Plecotus* species in woodland as 5m, which is the lowest range of all species identified as present within South Yorkshire, and Natterer's bat in woodland as 8m, which is second lowest. They are likely to be under represented in the database as many tree roosts will go undetected, as would most echolocation calls from bats flying within the canopy.

Noctule was considered to be uncommon but widespread. This species was considered likely to be present across most of the county.

Whiskered bat was also identified as uncommon. The records that the group holds shows that they are recorded less frequently than Natterer's bat and Daubenton's bat. Given that this seems to be consistent with the results of comparable surveys such as the hibernation checks and autumn swarming work that the group has completed, it appears to accurately reflect our knowledge of this species at present. Recent harp trapping and mist netting surveys undertaken by the bat group in 2018 indicate that whiskered bat may be relatively widespread in woodland around west Sheffield, but more work is required before enough evidence is available to suggest different status category.

Where Leisler's bats occurred, they were considered to be almost as common as noctule. Overall however they appeared less frequently in the database and the maximum number recorded in any one count was less than half that of noctule. Therefore, Leisler's bat was considered to be scarce.

No bats were identified as rare during the assessment.

Two bat species, Brandt's bat and Nathusius' pipistrelle were identified as very rare, both with just two records in the February 2017 database. Brandt's bat was only known to be present in one small part of the county with both database records located at the same position. Subsequent trapping surveys undertaken by the bat group in 2018 have identified them in three additional locations in woodlands in west Sheffield. Trapping by West Yorkshire Bat Group on the northern boundary of the county in 2018 identified additional Nathusius' pipistrelle records at one further site.

Most likely future status changes

Serotine and barbastelle are considered to have the potential to be present at the southern edge of the county. A single serotine record was identified near Rotherham in the late 1970's but this species has not been recorded in the county since. No records of barbastelle exist within the county, but they have been recorded very close to the southern county boundary (Nottinghamshire Bat Group, 2016). South Yorkshire lies within the known range of Alcahoie bat, but this species has never been recorded in South Yorkshire. These species all have the potential to be recorded within the county in the future.

The relative flurry of whiskered bat, Brandt's bat and Nathusius' pipistrelle records in 2018 that were found through targeted surveys using harp traps, mist nets and an acoustic lure, indicates that the widely available survey techniques that were used previously may not have been sufficiently adept at picking up these species. It is therefore entirely probable that the known South Yorkshire distribution and abundance of these species will expand and increase.

References

Barataud, M. (2015) *Acoustic Ecology of European Bats; Species Identification, Study of their Habitats and Foraging Behaviour*. Biotope Éditions, Publications Scientifiques du Muséum, p. 276.

Barlow, K. E. and Jones, G. (1999) Roosts, echolocation calls and wing morphology of two phonic types of *Pipistrellus pipistrellus*. *Zeitschrift fur Saugetierkunde*, 64(5) pp.257-268.

Mitchell-Jones, T. and Carlin, C. (2014) Natural England Technical Information Note TIN051 Bats and onshore wind turbines Interim guidance. [Online]
<http://publications.naturalengland.org.uk/file/6122941666295808>

Nottinghamshire Bat Group (2016) [Online] <http://nottsbatgroup.org.uk/wp-content/uploads/2016/08/NBG-Barbastelle-project-update-August-2016.pdf>

Sheffield Small *Myotis* Project: 2018 Summary Report.

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Abstract

The Sheffield Small *Myotis* Project commenced in 2018 with 12 trapping sessions undertaken at eight sites between May and October 2018. Sites were distributed across the Sheffield Lakeland Landscape Partnership area in west Sheffield, with surveys undertaken by members of South Yorkshire Bat Group. Trapping sessions were conducted using a minimum of two harp traps and one acoustic lure with mist nets occasionally available to the group. Surveys commenced at sunset and continued for a minimum of four hours.

A total of 44 bats of seven species were captured during the project including 13 whiskered bats *Myotis mystacinus* and three Brandt's bats *M. brandtii*. Whiskered bats were recorded from a higher number of sites than any other species (six sites) with Brandt's bat recorded from three sites. The number of bats caught per survey was highest in late July and August, with fewer bats captured in May and no bats caught during the three surveys undertaken in September or October. The acoustic lure appeared to increase the number of bats caught in the harp traps and it is considered the purchase of a second lure will improve capture rates in future years.

The proportion of small *Myotis* bats caught during surveys was higher than expected which raises the possibility that either the survey method is more effective than anticipated or that both the whiskered bat and Brandt's bat are more common within the study area than previously thought. Preliminary information on the effectiveness of different social call sequences in attracting bats and the variation in physical characteristics between whiskered bat and Brandt's bat is presented.

Introduction

A group of three cryptic bat species within the *Myotis* genus are small and morphologically similar leading to them becoming known as the 'small *Myotis* bats' (Brown, 2016). Within the UK this grouping includes the whiskered bat, Brandt's bat and the rare Alcahoie bat *M. alcahoie*.

It is widely considered that confident species identification of the small *Myotis* bats on the basis of echolocation calls alone is not possible (Rydell, et al., 2017). Whilst these bats display physical differences which can be recorded during the inspection of captured bats in the hand, even experienced surveyors have been shown to make identification errors (Brown, 2016). Consequently, it is advised that species identifications made in the field are confirmed by DNA analysis of a sample of tissue, fur or excrement taken from the bat (Brown, 2016).

Prior to commencement of this project, South Yorkshire Bat Group's database (SYBG, 2018b) included numerous whiskered bat records but only a single confident Brandt's bat record. The single Brandt's bat record was confirmed through DNA analysis of a dropping collected in 2015 from a site on the boundary of the Wyming Brook nature reserve in west Sheffield. To date, the Alcahoie bat has not been recorded within South Yorkshire and has currently only

been confirmed within various counties in southern England and Ryedale in the Yorkshire Dales (Jan, et al., 2010; Brown, 2016).

The primary objectives of the Sheffield Small *Myotis* Project were to provide information on the distribution and relative abundance of small *Myotis* bats within South Yorkshire through focused capture of bats from sites within the Sheffield Lakeland Landscape Partnership (SLLP) area. The SLLP is funded by the Heritage Lottery Fund as part of its national landscape partnerships programme. It facilitates a range of projects focused on enhancing the natural and cultural assets of an area of land to the northwest of Sheffield.

Methods

Survey site selection for the small *Myotis* study was made taking into account the combined whiskered bat and Brandt's bat Habitat Suitability Model created for the Sheffield area (Blackburn, 2018) and existing confirmed species presence records held by SYBG (SYBG, 2018b) at the onset of the project (Figure 1).

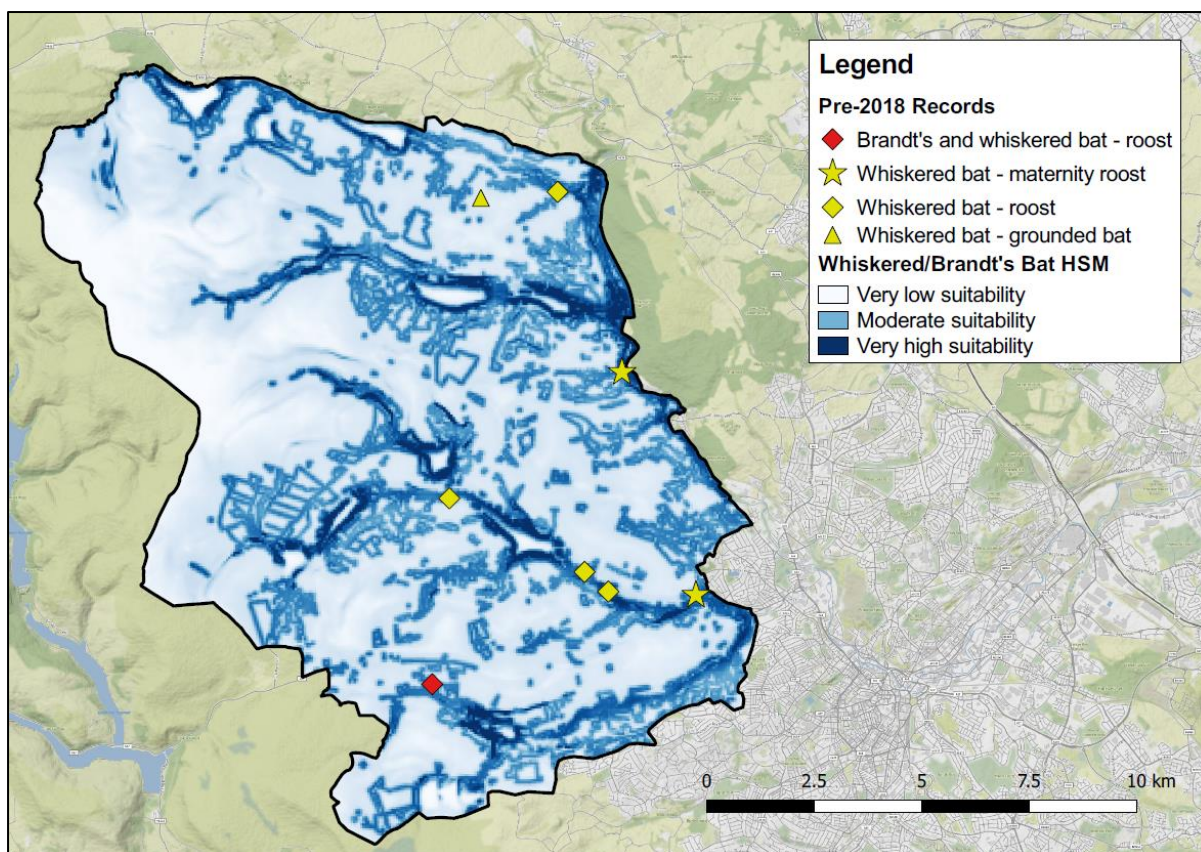


Figure 1: Habitat Suitability and existing small *Myotis* records.

The methodology adopted by the small *Myotis* study was more flexible than similar bat capture surveys undertaken by SYBG (Bell, et al., 2017; Bell, et al., 2017). The decision was made to alter equipment specifications, trap locations and the number of survey visits between sites in order to explore different options, optimise the number of captures per site and develop the skills of the survey team.

Eight locations were surveyed on either one or two occasions between May and October 2018, with 12 survey visits undertaken in total. The first three surveys were undertaken during May,

with surveys suspended from late-May to mid-July due to restrictions associated with the bat maternity period. A further nine survey visits were undertaken between late-July and early-October.

Trapping surveys were carried out using a pair of three bank harp traps and one AT100 acoustic lure on each survey occasion. In addition, one or two mist nets were used during three of the survey visits. Traps were in place from sunset until a minimum of four hours after this time, with trapping nights selected based on recent weather conditions and forecasts for the survey night. Dry survey nights, with little or no wind and temperatures above 8°C at sunset were selected. Trapping teams included a minimum of one surveyor holding a Level 4 bat survey class licence when undertaking harp trapping and a minimum of one surveyor holding Level 3 bat survey class licence when deploying mist nets.

A survey team of at least three people helped ensure both surveyor safety and speed of bat processing. The harp traps were checked every 15 minutes during the survey period, with captured bats transferred to cotton drawstring bags for transfer to a bat processing area. The mist nets were continuously checked and managed by the Class 3 licenced member of the survey team.

In the bat processing area, the species, sex, age and where possible, breeding status were recorded for each bat captured. Before release, bats were checked for injury and providing they were uninjured, released from the hand as soon as possible. Bats were marked by the taking of a fur clipping. A non-toxic water-based liquid chalk pen was used to mark along the forearm running the chalk from the elbow to the wrist. The use of the chalk pen marking established whether recaptures originated from bats caught in the same night or on a different night. Where bats of the small *Myotis* grouping were captured, the fur clippings were retained and sent to Swift Ecology/ Ecotype Genetics Limited for DNA analysis to species level.

In addition to DNA testing of fur samples, all small *Myotis* bats captured were identified on the basis of morphological observations in accordance with the key presented in Bats of Britain and Europe (Dietz and Kiefer, 2016). Morphological parameters linked to successful interspecies identification were recorded, including forearm length, penis shape, tragus length relative to notch on the outer ear, dentition and colour of ear base and tragus. The parameters selected were the same as those previously used by the national small *Myotis* project (D. Whitby, pers. comm., November 2017), which itself was informed by a PhD study which investigated resource partitioning between whiskered bat and Brandt's bat (Berge, 2007).

Once collected the data has been analysed using Microsoft Excel (Microsoft Corporation, 2013) and R: A language and environment for statistical computing (R Core Team, 2012) and mapped using QGIS (QGIS Core Development Team, 2018).

Results

Bat captures by species and sex

A total of 44 bats of seven species were recorded during the project (Figure 2 & Appendix 1). More common pipistrelle bats *Pipistrellus pipistrellus* (34% captures) were recorded than any other single species, with 30% of captures comprising whiskered bat, 16% soprano pipistrelle *P. pygmaeus*, 7% Brandt's bat, 7% Daubenton's bat *M. daubentonii*, 5% brown long-eared bat *Plecotus auritus* and 2% Natterer's bat *M. nattereri*.

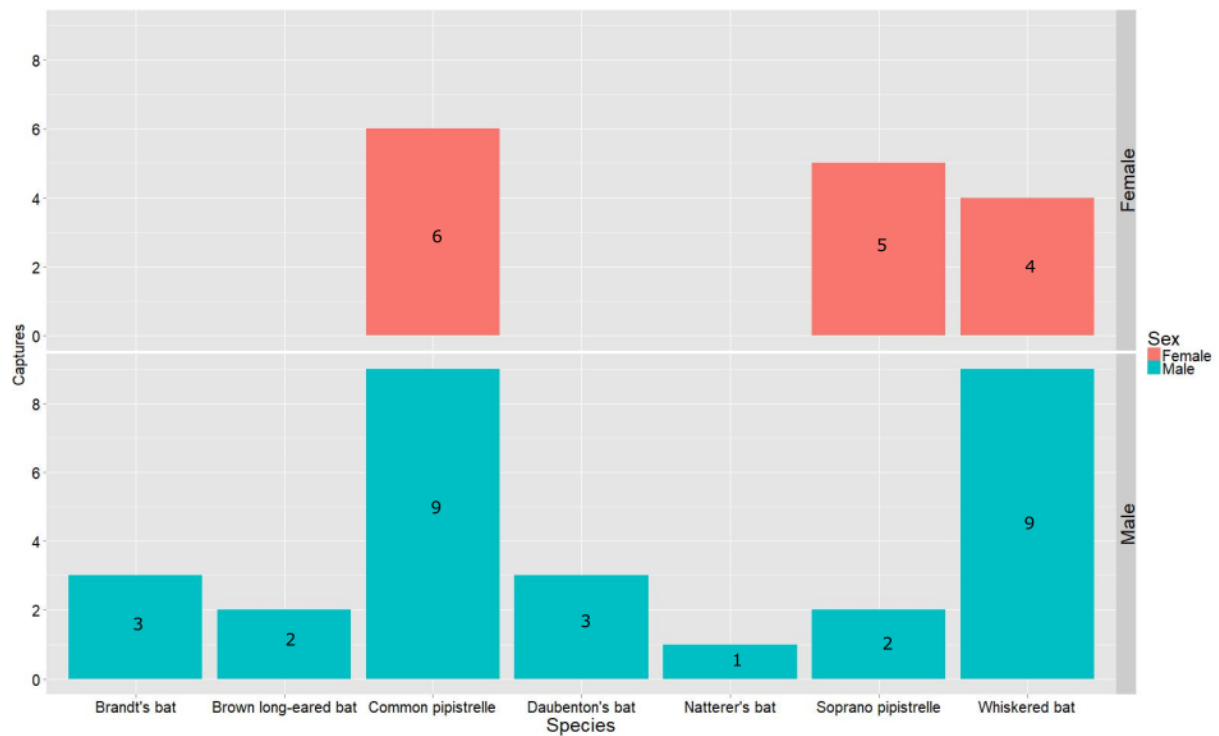


Figure 2: Bat captures by species and sex.

The whiskered bat was recorded at more sites than any other species with records obtained at six of the 12 sites surveyed. This was closely followed by the common pipistrelle which was recorded at four sites, and the Brandt's bat recorded at three sites (Appendix 1: 2018 Survey Results Plan). Of the sites surveyed, Agden Bog returned the greatest diversity of species with five species of bat recorded. This was followed by Midhope Reservoir with four species and Bitholmes with three species captured.

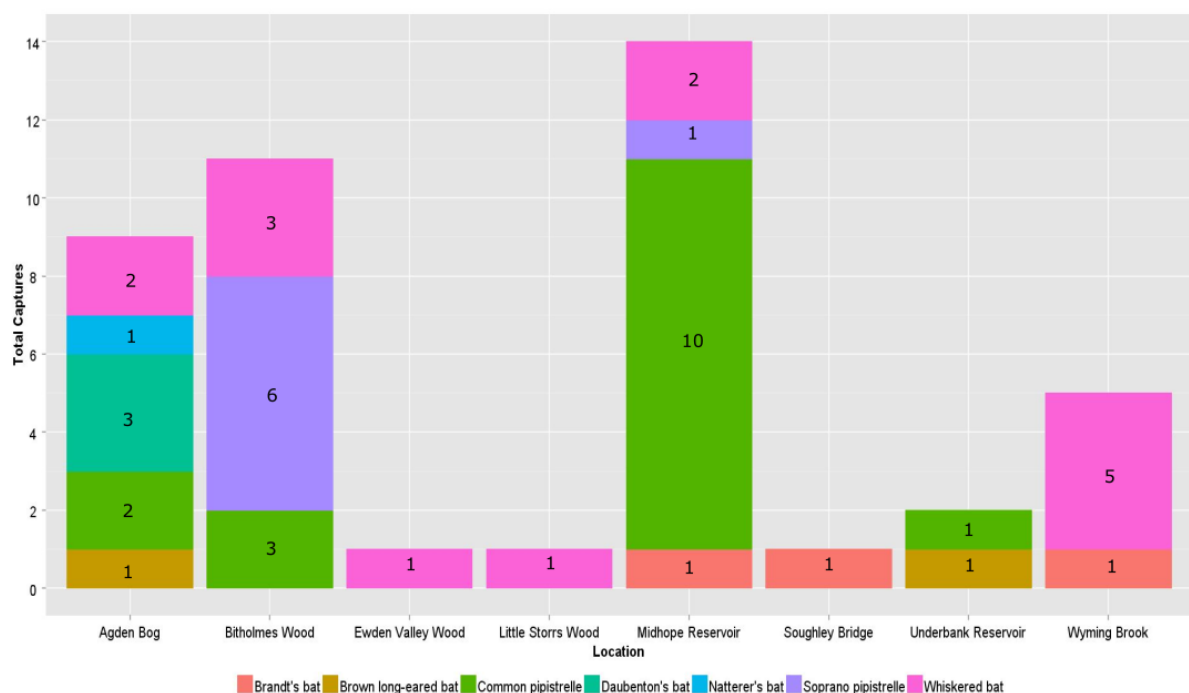


Figure 3: Total captures by location.

Male bats comprised 66% of captures with more males than females caught across all species except soprano pipistrelle. It was notable that the three Brandt's bats caught were all male, unlike the whiskered bat where four of the 13 captures were female. Female bats were only captured at three sites; Agden Bog, Bitholmes Wood and Midhope Reservoir, unlike the male bats which were captured at a greater proportion of sites (eight in total). All the female bats were captured during three trapping sessions, with these bats all caught in July or August.

All of the 16 small *Myotis* bats captured were successfully verified to species level during trapping sessions on account of their morphology, with these species identifications later confirmed by DNA analysis of fur samples.

Bat captures by month

A total of 12 trapping sessions were undertaken, with no bats captured on four of the survey nights. The six survey visits undertaken during late July and August were more productive with no zero capture nights experienced in this period. Bats were caught during two of three survey visits in May, however the average number of captures was lower than in July or August. No bats at all were captured during the two survey visits undertaken in September or the single visit in October.

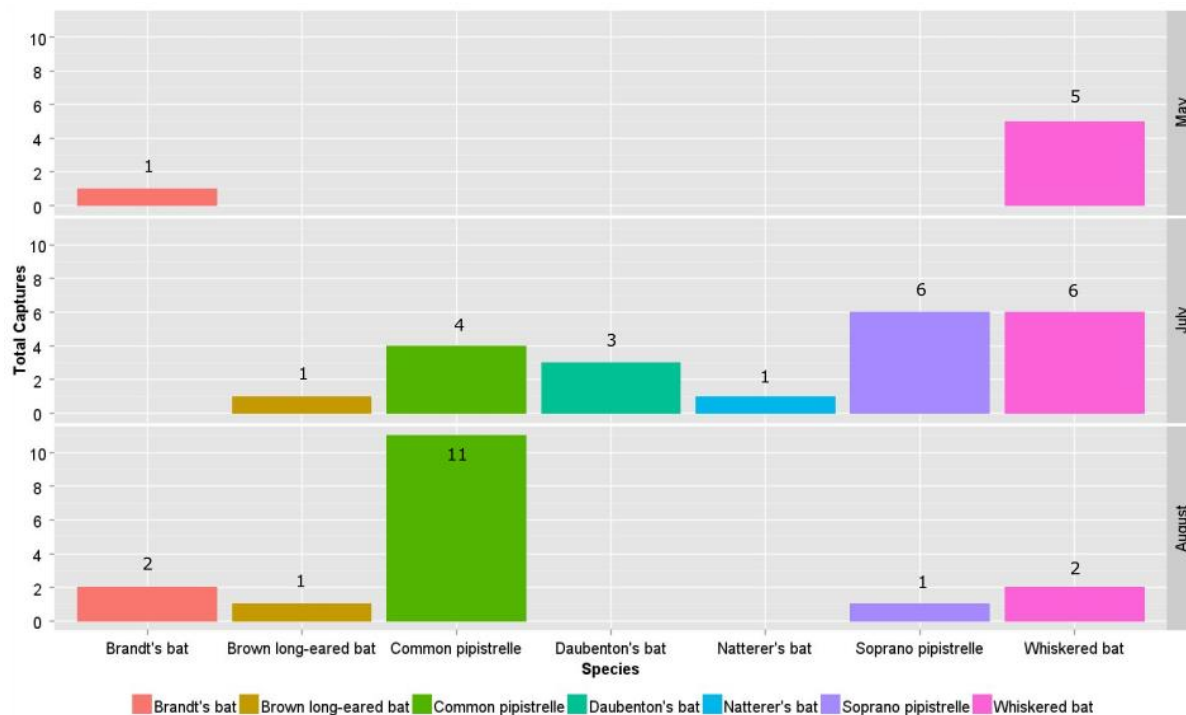


Figure 4: All bat captures by species and month.

The effectiveness of the acoustic lure

Careful interpretation is required when considering the value of acoustic lures to trapping during the project. At any one time, a maximum of half the traps were equipped with an acoustic lure. However, this lure was not in constant use, with rest periods adopted to reduce the risk of bats becoming accustomed to the lure. When the lure was playing back calls, the time spent using different sound files of different bat species was not constant and sometimes

the software was set to play a range of different species files, either on a loop or in a random order.

The acoustic lure was in operation during 73% of captures (32 of 44 bats) (Table 1). It should also be noted that of the bats caught in traps/nets without a lure, six bats were caught in a mist net across a stream at a restricted flyway formed by a bridge. It would appear from this data that the lure greatly increased the likelihood of bat capture at the harp trap where it was installed, relative to traps without a lure.

Table 1: Lure use with respect to the capture of bats.

Lure playing	Species of call played through lure	Number of bats caught
Yes	Nathusius' pipistrelle <i>P. nathusii</i>	13
	Bechstein's bat <i>M. bechsteinii</i>	13
	Unknown call	5
	Barbastelle <i>Barbastella barbastellus</i>	1
No	N/A	12

Nathusius' pipistrelle and Bechstein's bat calls when played back through the lure both accounted for the capture of 13 bats (Figure 5). Bat species appear to have shown different responses to the range of lure calls played. For example, Nathusius' pipistrelle calls were being played through the lure when the majority of common pipistrelle bats were captured, however more soprano pipistrelle and whiskered bats were caught when the Bechstein's bat calls were playing. Ultimately, given the lack of standardisation with regard to lure playback and the low number of captures it is difficult to draw conclusions in regard to the relative success of different lure calls.

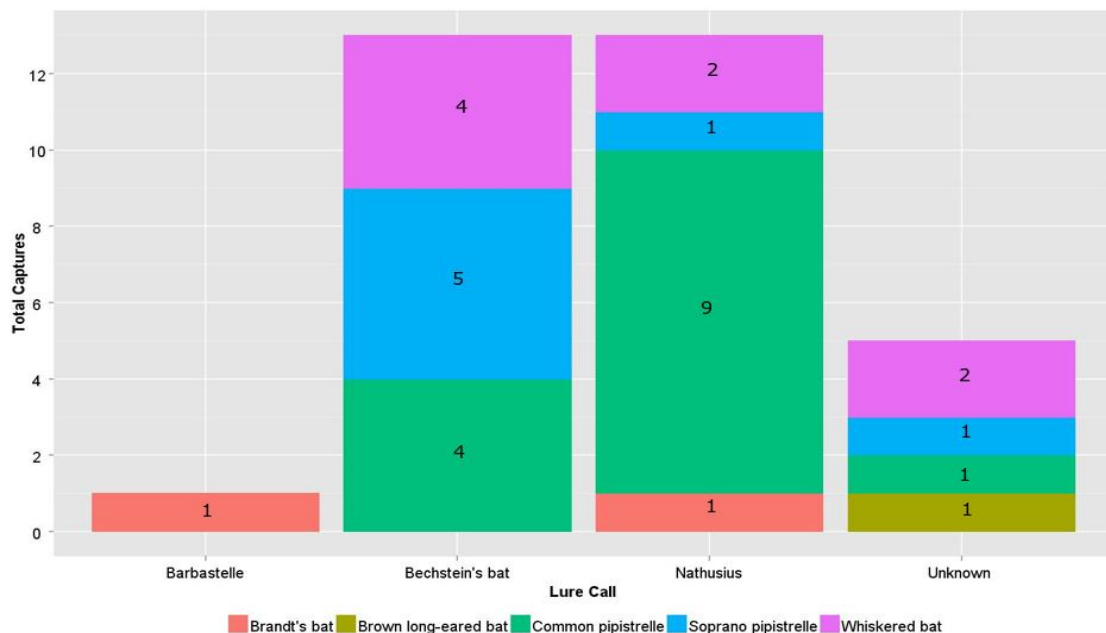


Figure 5: Stacked bar chart showing species caught in relation to lure calls.

Differences in morphology between whiskered bat and Brandt's bat

Only three Brandt's bats were captured during the summer trapping. As a result, any associations drawn by this project between the species of small *Myotis* caught and physical traits recorded should be treated with caution. However, such associations have been explored (Appendix 2) in order to help develop the ability of project surveyors to differentiate between whiskered bat and Brandt's bat and to enable comparison with other similar studies (Berge, 2007).

The dataset assembled suggests the physical traits detailed in Table 2 have the strongest association with either whiskered and Brandt's bat.

Table 2: Associations between physical traits and small *Myotis* species identification.

Physical trait	Species association
Face colour	Whiskered bat typically have a darker face
Tragus shape	Both species can have a straight tragus, however, whiskered bat seem associated with a concave tragus posterior whilst Brandt's bat appear more often to have a convex posterior edge
Tragus colouring	Brandt's bat show a tendency for the tragus base to be lighter whilst in whiskered bat it seems to normally be evenly coloured
Penis shape	Brandt's bat have a wider tip to the penis as opposed to whiskered bat, within which the penis is typically equally wide along its length
Protocone height	P4 protocone height in relation to P3 is typically higher in Brandt's bat

Assessment

Consideration of findings in relation to knowledge of whiskered and Brandt's bat in project area

The overall number of bats caught during the survey season was lower than anticipated at the beginning of the project, with no bats caught on a third of survey nights. Despite the low number of bats caught, the proportion of small *Myotis* bat captures was high, with these species comprising 37% of all bat captures. Whiskered bats were caught at more survey sites than any other bat species (75% of sites), with Brandt's bat recorded from the third highest number of sites (38% of sites).

The proportion of small *Myotis* bats caught by this study and the percentage of sites supporting this species group were both higher than recorded during similar studies. A targeted small *Myotis* survey of 59 woodlands in southern and central England over 59 survey nights in 2013 captured 25 whiskered bats (8% of total captures) from 28.8% of study sites, with six Brandt's bats (1.9% of total captures) captured from 8.5% sites (Brown, 2016). The Bechstein's Bat Survey was undertaken between 2009 and 2011 and adopted a similar survey protocol to the previous study, however no attempt was made to separate small *Myotis* bat species (Miller, 2012). The Bechstein's Bat Survey recorded small *Myotis* bats from 42.9% of survey sites, with this species group comprising 16.9% of total bat captures.

The high proportion of small *Myotis* bats caught in by the Sheffield Small *Myotis* Project is unexpected for the following reasons. Although the survey methodology was designed to target small *Myotis* bats, the surveys were carried out at sites where a diverse assemblage of bat species are either known or expected to forage. In addition, whilst the success of acoustic

lure call sequences in capturing different bat species is poorly understood, the call sequences used are widely thought to appeal to a range of species (Brown, 2016; Miller, 2012). Finally, although bat species population estimates are unreliable, particularly for small *Myotis* bat species (Mathews, et al., 2018), the limited information currently available shows both whiskered bat and Brandt's bat have small populations relative to other locally resident species (Battersby, 2005).

Given that the total number of small *Myotis* bats caught is still quite low (16 bats – 13 whiskered bat and three Brandt's bat), it would be prudent not to draw any conclusions regarding the reasons for the high proportion of captures at this stage. However, two possible explanations are proposed. It may be that the survey methodology adopted was more effective than expected at targeting and capturing whiskered and Brandt's bats. An alternative explanation would be that small *Myotis* bats are more common within the survey area than anticipated on the basis of both national population estimates (Battersby, 2005) and existing presence records held in the SYBG database (SYBG, 2018b). The whiskered bat is currently classified by SYBG as being 'uncommon' within the county, whilst Brandt's bat is considered to be 'very rare' (SYBG, 2018a). The survey results obtained to date suggest that both whiskered bat and Brandt's bat may occur more frequently within the study area than was previously supposed.

The project has increased the number of confirmed Brandt's bat records held by SYBG from one to four records, with this species now known to occur in three areas of west Sheffield. It is notable that the three Brandt's bats captured during the project all comprised male bats. Whilst this observation may be an artefact of the low number of captures or bias of the survey technique, it may also suggest that this species is on the edge of its local range, with male bats shown to sometimes extend into peripheral or marginal habitats (Angnell, et al., 2013). It is hoped that survey data gained in future years will enable more detailed investigation of this possibility.



Figure 6: Whiskered bat captured from Wyming Brook.

Recommendations for future years of small *Myotis* survey

Survey findings appear to show the value of acoustic lures in increasing capture rate at harp traps sited away from roost locations. It is anticipated that if acoustic lures are deployed with both harp traps available to the project the number of bats caught will increase, whilst the risk

of survey nights with no captures will decrease. Given that nights with no bat captures can dampen the enthusiasm of volunteer surveyors, it is considered the purchase of a second acoustic lure would comprise a worthwhile investment.

The number of bats caught during individual survey visits in 2018 showed a high degree of variation, regularly confounding the expectations of the survey team. One factor that does appear to influence the success or failure of a survey night is the survey month. Surveys undertaken in late July or August resulted in higher numbers of bat captures. Bats were also caught during two of three May survey visits; nonetheless no bats were caught in September or October. For this reason, it may be that it is not worthwhile undertaking future small *Myotis* surveys in September or October. However, the comparison between the spring, summer and autumn visits is biased due to the majority of surveys having been undertaken in the summer period (i.e. July/August).

We are not able to say which call sequences are most effective when played back through the acoustic lure however, both the Bechstein's bat and Nathusius' pipistrelle social calls were associated with capture of a range of bat species. The use of these call sequences in the future is recommended if the same flexible methodology is adopted. Alternately, a standardised sequence of calls such as the call sequence used in the Bechstein's survey could be used. This would allow more detailed and robust statistical analysis and would enable us to compare capture rates between our project and the Bechstein Bat Survey (Miller, 2012) or similar trapping studies that have used the Bechstein's Bat Survey call sequence. As would be expected, the deployment of one or more mist nets in addition to the harp traps typically increased both the number of individuals and the variety of bat species caught.

Data on physical traits collected from whiskered bats and Brandt's bats by this project highlights probable variation between the two species, particularly in relation to face colour, tragus shape, tragus colouring, penis shape and protocone height. An existing study which obtained information in relation to 22 variables from 33 bats (16 whiskered bats and 17 Brandt's bats) showed that penis shape, upper jaw dentition, lower jaw dentition, tragus shape and thumb claw length were most effective in enabling successful determination to species level (Berge, 2007). The corroboration between the findings of the two studies is encouraging and it is recommended that during future small *Myotis* trapping studies, the same range of physical trait information is recorded. This will enable a greater understanding of the physical character traits useful to the identification of whiskered bats and Brandt's bats in South Yorkshire.

It is noted that all field identifications of small *Myotis* bats made during 2018 were subsequently confirmed through DNA analysis. This finding gives confidence in the survey team's ability to identify small *Myotis* bats on the basis of their physical appearance. Given the low number of records held for the species, it is recommended that all suspected Brandt's bats captures continue to be confirmed by DNA analysis. It may however be reasonable to cease the default DNA testing of whiskered bats which are considered to conform to the typical physical appearance documented for this species.

The 2018 small *Myotis* project has gathered some valuable records and posed interesting questions in relation to the abundance and range of whiskered bat and Brandt's bat in the survey area. The success or failure of individual survey nights was hard to predict and clearly there is still a lot for the project team to learn in relation to capturing both small *Myotis* bats

and other bat species. We have, however, learnt useful lessons in relation to trapping methods and the seasonal timing of trapping nights which should aid future survey. We hope to continue this project within the existing project area during 2019, and to subsequently expand it into other parts of South Yorkshire. There is still much to learn about the distribution and abundance of small *Myotis* bats in our county!

Acknowledgements

This project could not have taken place without the financial and organisational assistance of the SLLP, who purchased the acoustic lure, funded much of the DNA analysis and arranged most of the land access. Thanks goes to all landowners who allowed the survey works to proceed on their land and to Natural England for granting the project licence. Field survey was undertaken by a large number of SYBG volunteers and particular thanks goes to Greg Slack, Peter Middleton and Kate Denton who led survey sessions. Finally, we are grateful to Daniel Whitby for sharing survey sheets used by the national small *Myotis* project and to Steve Parker and Cambridgeshire Bat Group for sharing call sequences suitable for use on the acoustic lure.

References

- Angnell, R. L., Butlin, R. K. & Altringham, J. D. (2013) *Sexual Segregation and Flexible Mating Patterns in Temperate Bats*. [Online]
<https://journals.plos.org/plosone/article/file?id=10.1371/journal.pone.0054194&type=printable>
- Battersby, J. (2005) *UK Mammals: Species Status and Population Trends: First Report by the Tracking Mammals Partnership*. Peterborough: JNCC/Tracking Mammals Partnership.
- Bell, R., McLean, B., Middleton, P., Proctor, S. and Slack, G. (2017) *South Yorkshire Bat Autumn Swarming Study 2017: New Sites and Fresh Questions*. [Online]
<http://www.northernbats.uk/index.asp?pageid=686212>
- Bell, R., Slack, G., Middleton, P. and Proctor, S. (2017) *South Yorkshire Magnesian Limestone Autumn Swarming Survey*. [Online]
<http://www.northernbats.uk/volume2.asp>
- Berge, L. (2007) *Resource partitioning between the cryptic species Brandt's bat (*Myotis brandtii*) and the whiskered bat (*M. mystacinus*) in the UK*. Bristol: University of Bristol.
- Blackburn, S. (2018). *Sheffield State of Nature Report 2018*. Sheffield: Sheffield and Rotherham Wildlife Trust.
- Brown, P. A. (2016) *The cryptic group of small Myotis bats (*M. mystacinus*, *M. brandtii* and *M. alcathoe*) and habitat use by woodland bat species in Britain*. MSc. dissertation, Bristol: University of Bristol.
- Dietz, C. and Kiefer, A. (2016) *Bats of Britain and Europe*. London: Bloomsbury Natural History.
- Jan, C. M., Frith, K., Glover, A. M., Butlin, R. K., Scott, C. D., Greenaway, F., Ruedi, M., Frantz, A. C., Dawson, D. A. and Altringham, J.D. (2010) *Myotis alcathoe* confirmed in the UK from mitochondrial and microsatellite DNA. *Acta Chiropterologica*, 12(2) pp.471-483.

Mathews, F., Kubasiewicz, L. M., Gurnell, J., Harrower, C. A., McDonald, R. A. and Shore, R.F. (2018) A review of the population and conservation status of British mammals: Technical Summary, Natural England, Peterborough: A report by the Mammal Society under contract to Natural England, Natural Resources Wales and Scottish Natural Heritage.

Microsoft Corporation. (2013) *Microsoft Excel Computer programme*. s.l.:Microsoft Corporation.

Miller, H. (2012) *Bechstein's Bat Survey, Final report*, London: Bat Conservation Trust.

QGIS Core Development Team. (2018) *QGIS Geographic Information System Version 2.18.24*. s.l.:Open Source Geospatial Foundation Project.

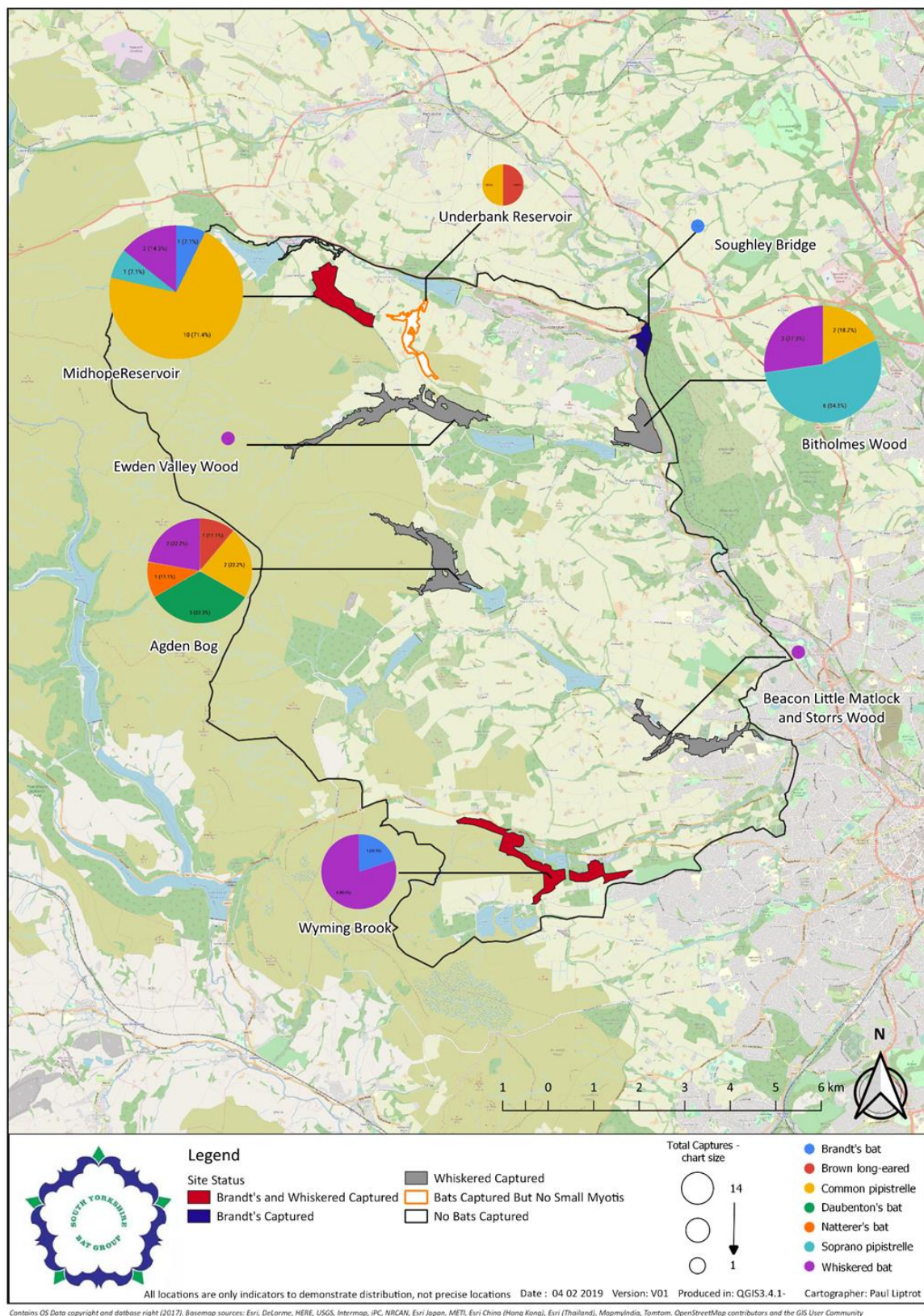
R Core Team. (2012) *A language and environment for statistical Version*. Vienna: R Foundation for Statistical Computing Version 2.15.0.

Rydell, J., Nyman, S., Eklof, J. and Jones, G. R. D. (2017) Testing the performances of automated identification of bat echolocation calls: A request for prudence. *Ecological Indicators*, 78 pp. 416-420.

SYBG, 2018a. *Bats of South Yorkshire*. [Online] [Accessed February 2019]
<https://www.sybatgroup.org.uk/bats-of-south-yorkshire>

SYBG, 2018b. *Bat Database*. s.l.: South Yorkshire Bat Group.

Appendix 1: 2018 Survey Results Plan.



Appendix 2: Small Myotis Comparison Tables.

Attribute	Brandt's bat	Whiskered bat
Average of Forearm Length (mm)	34.5	34.3
Mean Tibia Length (mm)	15.2	15.3
Average of Weight (g)	6.6	5

Attribute	Value	Species (number of captures)	
		Brandt's bat	Whiskered bat
Face colour	Black	0	4
	Very dark brown	1	6
	Chocolate brown	1	2
	Chestnut brown	1	1
Ear overall colour	Black	0	4
	Dark brown	3	8
	Light brown	0	1
Tragus overall colour	Black	0	6
	Dark brown	2	6
	Light brown	1	1
Tragus shape	Concave	0	3
	Straight	1	9
	Convex	2	1
Ear colouring	Base much lighter	1	1
	Base slightly lighter	2	4
	Evenly coloured	0	8
Tragus colouring	Base much lighter	1	1
	Base slightly lighter	2	1
	Evenly coloured	0	11
Face colour	Black	0	4
	Very dark brown	1	6
	Chocolate brown	1	2
	Chestnut brown	1	1
Penis shape (males only)	Much wider/club ended	2	0
	Slight wider at end	1	3
	Equal width	0	6
Protocone height	Equal height	1	0
	Much higher	1	0
	Small or absent	1	12
Nostril shape	Comma shaped	2	12
	Heart shaped	1	1
Ear notch - tragus height	Tragus obviously higher than ear notch	2	5
	Tragus equal - just above notch height	1	5
	Tragus shorter-equal to notch height	0	3

Romptickle Viaduct: Bat Activity at a *Pipistrellus* Hibernaculum Through the Winter.

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Abstract

Romptickle Viaduct comprises a stone viaduct crossing the River Don within a rural location in South Yorkshire. The structure was first recorded as a *Pipistrellus* hibernation roost in 2013 and to date has a peak count of 33 hibernating bats. This article details a series of surveys undertaken between 2013 and 2018 with the purpose of characterising roost usage and recording associated patterns of *Pipistrellus* flight activity during the winter months.

The findings show the viaduct is actively selected by *Pipistrellus* bats for use over the hibernation period, with seasonal patterns of usage conforming to other similar hibernacula documented in the literature. It can be confidently asserted that both common pipistrelle *Pipistrellus pipistrellus* and soprano pipistrelle *P. pygmaeus* roost in the structure across at least 43 separate crevices, with a mean group size of two bats/crevice.

Temperature monitoring has shown roost locations in the viaduct provide a frost-free refuge for roosting bats, even during the coldest periods of South Yorkshire weather. Acoustic survey has demonstrated that whilst *Pipistrellus* flight activity is highest at temperatures above 7°C, a secondary peak in activity occurs at temperatures below -1°C, with multiple bats recorded flying at air temperatures between -3°C and -4°C. It is considered most likely that *Pipistrellus* activity during sub-zero temperatures indicates bats immigrating into Romptickle Viaduct from less thermally stable roosts. The survey findings provide support for the phenomenon of 'frost swarming' recorded from a *Pipistrellus* hibernaculum in The Netherlands (Korsten *et al.*, 2016).

Introduction

During the winter months, bats in northern England enter extended bouts of torpor known as hibernation. Hibernation in bats comprises a state of inactivity characterised by lower body temperature, slower breathing and lower metabolic rates. The ability of bats to hibernate helps to preserve energy reserves at a time of year when weather conditions frequently prevent effective foraging.

Within Britain common and soprano pipistrelle are not found in caves during the hibernation period, but rather they are recorded roosting in the cracks and crevices of buildings (Racey, 1974; National Trust, 2018; Bell, 2016a) or built structures, crags (Dietz *et al.*, 2009) bat boxes (Dietz *et al.*, 2009; Parker, 2018) and in trees (BTHK, 2018). In The Netherlands, a number of large (100+ bat) *Pipistrellus* hibernacula have been recorded in large crevice-rich apartment blocks within cavity walls and/or deep expansion crevices (Korsten *et al.*, 2016). It is noted that stone and concrete crevice roosts in large structures are characterised by a high capacity for heat storage, resulting in slow heating up and cooling down (Simon *et al.*, 2004). In Germany a large *Pipistrellus* hibernaculum of over 5000 bats is known from the cellar of the castle in Marburg (Sendor, 2002). In European countries with colder winter climates, such as Slovakia and Romania, mass winter roosts can be found in caves, with a roost of 30,000-60,000 common pipistrelle known from a single cave in Romania (Dietz and Kiefer, 2016; Bucs, 2018).

Studies have shown that common pipistrelle appear to select hibernacula with cooler mean ambient temperatures than most other UK bat species, sometimes tolerating sub-zero temperatures (Nagel and Nagel, 1991; Webb *et al.*, 1996). Compared to other bat species, the hibernacula of *Pipistrellus* bats also appear to be unusually dry (Racey, 1974; Sendor, 2002). Bats typically rouse once every one to two weeks during hibernation (Altringham, 2011) however beyond that, *Pipistrellus* bats have also been shown to perform extensive hibernal roost switching (Parker, 2018; Sendor, 2002). Within tree roosts, *Pipistrellus* bats have been recorded awake in all months (BTHK, 2018) and within Britain there is strong evidence to show *Pipistrellus* bats feed through all winter months (Avery, 1985). Whether *Pipistrellus* bats rouse during winter primarily to drink or feed has been a subject of intensive study (Speakman and Racey, 1989; Sendor, 2002), however, it is likely that when conditions allow, they engage in both activities.



Figure 1: Romptickle Viaduct viewed from the south.

It has been demonstrated that hibernal metabolism in the *Pipistrellus* bat seems, in contrast to other species, to be independent of temperature within the range 4-10°C (Speakman *et al.*, 1991). At lower temperatures however, increased energy is required to regulate body temperature (Currie *et al.*, 2018; Nagel and Nagel, 1991) and Sendor (2002) demonstrated that remaining in a very cold roost where a warmer alternative exists would be costlier than switching. A long-term study of *Pipistrellus* bats overwintering in bat boxes in Norfolk has shown these bats temporarily vacate the boxes when the mean air temperature drops below 0°C (Parker, 2018). Common pipistrelle have been recorded engaging in 'frost swarming' at hibernacula during periods of very cold weather, with this activity recorded at temperatures as low as -7°C (Korsten *et al.*, 2016).

Pipistrellus bats have been recorded entering hibernacula in Britain in late November/early December (Racey, 1973; Parker, 2018) and in Germany from mid-November, with the population reaching maximum numbers around the turn of the year (Sendor, 2002). The onset of immigration in Germany and The Netherlands has been linked to the occurrence of frost, with very cold temperatures associated with high rates of immigration (Sendor, 2002; Korsten *et al.*, 2016). Around the turn of the year, emigration from a studied German hibernacula commenced if the ambient temperatures were mild, with a peak of emigration in late February (Sendor, 2002).

Romptickle Viaduct is sited in a rural location on the boundary of Thurgoland village in Barnsley. The viaduct is within the valley of the River Don in an area of mixed habitat with extensive woodland cover. This viaduct comprises a five span stone viaduct, approximately

25m high at its tallest point with a total span of approximately 30m. The undersides of the arches are generally well pointed however the piers have numerous vertical openings between stone blocks leading to deeper voids within the core of the structure. Romptickle Viaduct was first recorded as a *Pipistrellus* hibernation roost in 2013 and to date has a peak count of 33 hibernating bats, although the true number of bats using the structure is certainly higher. Romptickle Viaduct is part of a Local Wildlife Site designated for its importance to roosting bats by Barnsley Metropolitan Borough Council (Bell, 2016b).

This article details a series of surveys undertaken on the viaduct between 2013 and 2018. The purpose of this study has been to characterise roost usage and to record patterns of *Pipistrellus* flight activity associated with the viaduct during the winter months.



Figures 2 and 3: *Pipistrellus* bats roosting in viaduct crevices. Close view on left, zoomed out on right.

Methods

Visual *Pipistrellus* counts through year 2013-2015

Visual counts of the number of *Pipistrellus* bats roosting in the viaduct were made at regular intervals of one to three months, over a period of approximately one year from winter 2013/2014 to winter 2014/2015. In order to allow comparison of survey results between survey occasions, this visual inspection targeted two piers to the east of the river which were surveyed to a set height, with the location of each roosting bat precisely recorded. No attempts were made to identify roosting *Pipistrellus* bats to species level. Counts were made from ground level using a one million candlepower torch to illuminate crevices between stone blocks, which were then inspected using binoculars.

National Bat Monitoring Programme (NBMP) survey results 2015-2018

Romptickle Viaduct was registered as a NBMP survey location in winter 2014/2015. Between 2015 and 2018, South Yorkshire Bat Group members carried out counts of the number of hibernating *Pipistrellus* bats across three piers of the viaduct during single visits in January and February. The area of viaduct surveyed during the NBMP visits is larger than the area included in the 2013-2015 counts however, in other respects the survey methodology is identical.

Continuous static monitoring during peak winter period – December 2015 to February 2016

An Anabat SD1 bat detector was deployed at the base of a pier to the east of the River Don (Figure 4) from the 30/11/2015-01/03/2016. The Anabat recorded continuously, with the exception of 03-14/02/2016, during which no sound files were recorded due to an equipment failure.

The Anabat unit was placed at ground level with the microphone protected by a tight single sheet of clingfilm and with the sensitivity set to 6.5. Bat sound files recorded by the detector were analysed to species level using Kaleidoscope Pro software, with species identifications checked manually.

The temperature throughout the recording period was recorded by a Tinytag Plus 2 thermometer positioned beside Drystone Bridge in a shaded location and set to record temperature at 30 minute intervals throughout the recording period. Identified sound files were matched with the most recently recorded temperature during analysis of the survey findings.



Figure 4: Image showing survey equipment locations.

Focused cold weather monitoring - December 2017

A single Pettersson d500x full spectrum static monitoring device was deployed in the same location as previously used for the Anabat, with the Pettersson set to record for a period of three nights (09-12/12/2017) during a spell of notably cold weather. This unit was set to record continuously into five second sound files. Bats were identified to species level using the Bat

Classify software with a threshold of 0.8 used to determine a confident species identification. Sound file identifications were also manually checked.

During this period a Tinytag Plus 2 thermometer was positioned beside Drystone Bridge in a shaded location, recording temperature at 10 minute intervals.

Crevice temperature buffering

Between midnight on 06-09/02/2018, Tinytag thermometers were used to investigate the level to which crevices between stone blocks in the viaduct piers are buffered from fluctuations in the external air temperature. A high level of temperature buffering would mean the temperatures experienced within these crevices are highly resistant to fluctuations in the external air temperature.

A single Tinytag Plus 2 was positioned beside Drystone Bridge in a shaded location (Figure 4). This location was selected to record air temperature within the vicinity of the viaduct. A Tinytag Ultra 2 was installed at the base of a crevice between two blocks on the western side of the viaduct pier. Due to the width of the thermometer, it was installed approximately 2cm in from the external face of the viaduct.

The purpose of the thermometer installed in the stonework crevice was to record air temperature within a potential bat roosting location. It should be noted that *Pipistrellus* bats typically roost deeper in the crevice than the location sampled however the width of the thermometer limited options for unit placement. Thermometers recorded temperature at 30 minute intervals.

Results

Visual *Pipistrellus* counts through year

Figure 5 shows the number of roosting *Pipistrellus* bats by month, from February through to January. Where multiple counts were undertaken during a single month, the mean number of bats is shown.

The peak count of roosting *Pipistrellus* bats is reached between January and February, with a low number of *Pipistrellus* bats occupying the surveyed sections of viaduct during the summer period.

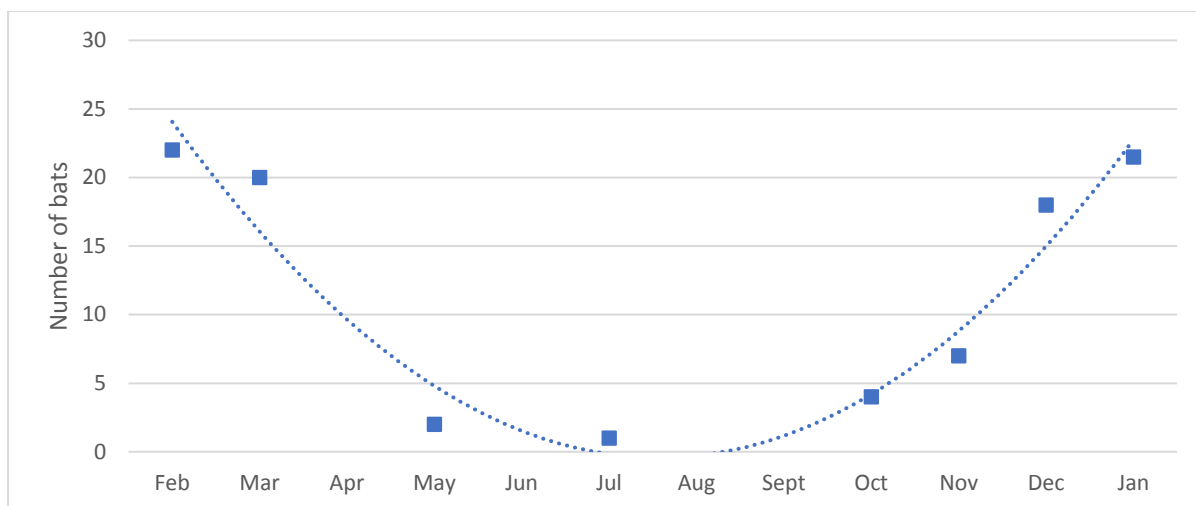


Figure 5: Variation in *Pipistrellus* count through year.

National Bat Monitoring Programme (NBMP) survey results 2015-2018

The NBMP results show the mean group size of roosting *Pipistrellus* comprises two bats per crevice, with an average of 14 occupied crevices per survey visit. On average, in any single survey, 46% of occupied crevices supported only a single bat. In total across eight survey visits, 43 separate crevices have been used on at least one occasion.

Table 1: Summary statistics from NBMP surveys.

Variable	Mean	Standard deviation	Maximum	Minimum
Group size	2.0	1.3	7	1
Number of occupied crevices	14.0	1.8	17	11

Continuous static monitoring during peak winter period – December 2015 to February 2016

A total of 5176 sound files were recorded from *Pipistrellus* bats across the recording period with 88% of recorded calls attributed to common pipistrelle and 12% attributed to soprano pipistrelle.

The highest level of bat activity was recorded in December, with the lowest level of activity in January and an increase in activity recorded during February. This pattern applied for both common and soprano pipistrelle.

Table 2: Monthly variation in number of sound files.

Species	Mean number of sound files/night		
	Dec	Jan	Feb*
Common pipistrelle	108.5	11.2	50.3
Soprano pipistrelle	14.6	0.7	8.1

*Anabat failure taken into account in calculation of this statistic

The temperature across the survey period varied from a high of 13.5°C to a minimum of -3.0°C (Table 3). December was noticeably milder than January or February, with February recording both the lowest mean temperature and the lowest minimum value. Winter 2015-2016 was the warmest experienced in England since modern records began in 1910 (Met Office, 2018) and on-site temperature monitoring showed sub-zero temperatures occurred on only 12 nights (Table 4).

Table 3: Temperature across survey period.

Month	Temperature (°C)		
	Mean	Min	Max
Dec	8.1	0.8	13.5
Jan	5.1	-1.8	13.1
Feb	3.5	-3.0	12.5

Figure 6 shows that *Pipistrellus* bat activity increases sharply during pronounced periods of increasing temperature in December and February. Activity appears to be highest at the start of these periods of mild weather. Bat activity in January did not follow this trend, with no pronounced increase in the *Pipistrellus* activity level recorded during a period of mild weather at the end of this month.

Figure 7 shows common and soprano pipistrelle activity against temperature. A Bat Activity Index level has been calculated which displays the number of sound files recorded, divided by the number of night hours at each temperature value. Activity of both common and soprano pipistrelle increases markedly when the temperature rises above 5°C, with the peak level of activity appearing to occur at temperatures above 7°C.

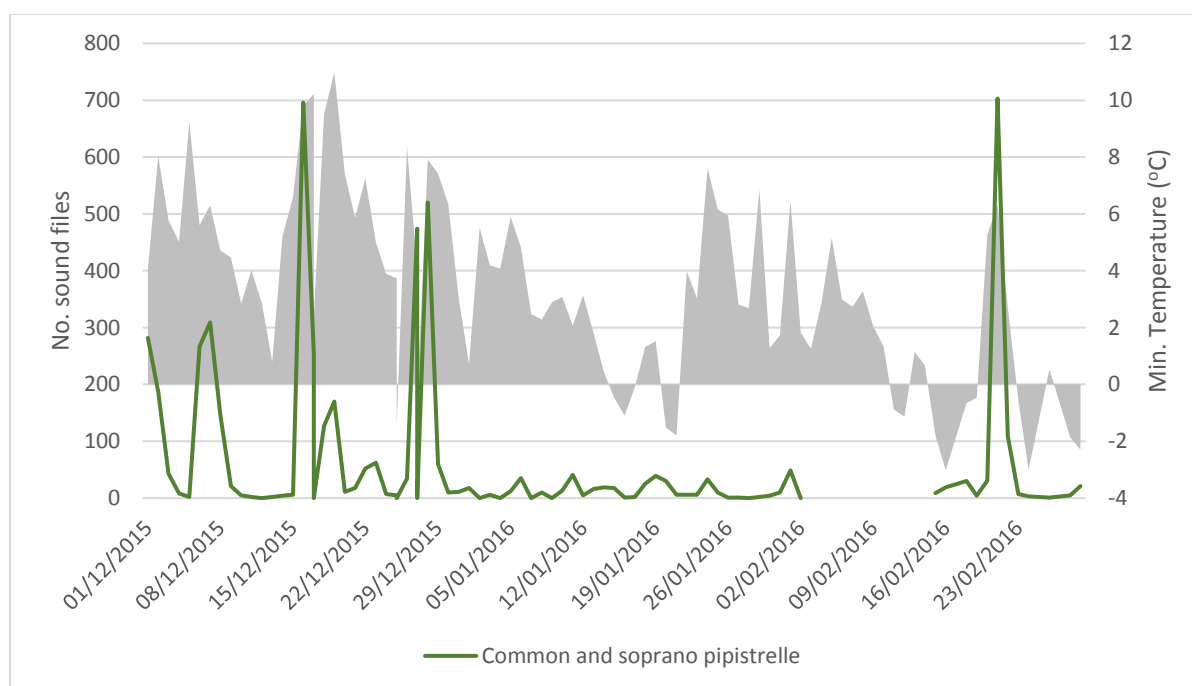


Figure 6: *Pipistrellus* activity against minimum temperature.

Figure 7 also shows a secondary peak in common pipistrelle activity when the air temperature drops to -1.5°C.

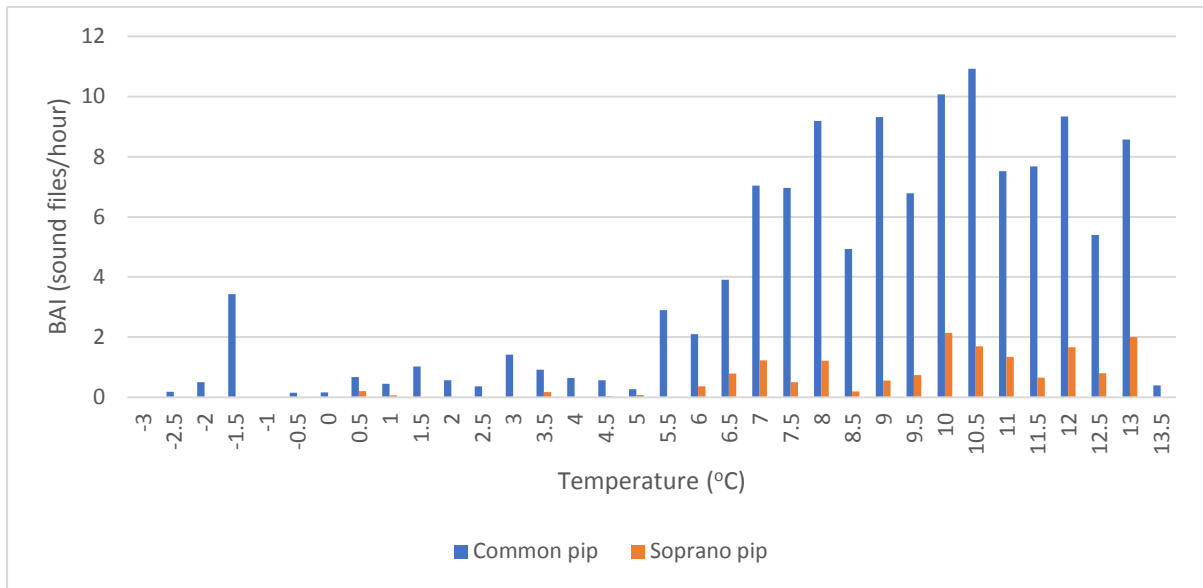


Figure 7: *Pipistrellus* activity against temperature.

As shown in Table 4, common pipistrelle activity was recorded on the first two nights during the recording period that the temperature dropped below -1°C.

Table 4: Sub-zero nights in winter 2015/2016.

Month	Night	Minimum temperature (°C)	Bat activity recorded
January	14-15	-0.5	n/a
	15-16	-0.8	n/a
	16-17	-0.1	n/a
	20-21	-1.8	30 <i>Pipistrellus</i> sound files
February	14-15	-0.2	n/a
	15-16	-2.7	15 <i>Pipistrellus</i> sound files
	16-17	-2.0	n/a
	18-19	-0.7	n/a
	23-24	-2.7	n/a
	24-25	-0.7	n/a
	27-28	-0.6	n/a
	28-29	-2.3	n/a

Figure 8 shows that on the nights of winter 2015-2016 that *Pipistrellus* activity was recorded during sub-zero temperatures, activity typically occurred between 5-8 hours of sunset.

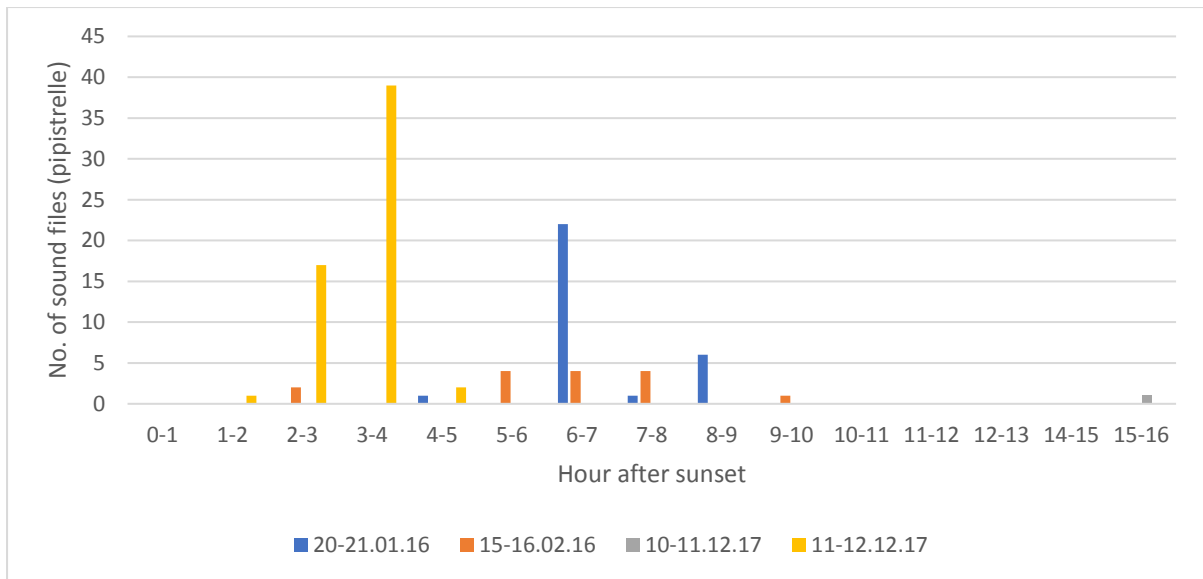


Figure 8: *Pipistrellus* activity times after sunset on three dates with sub-zero air temperatures.

Focused cold weather monitoring December 2017

Over a three night period of monitoring in mid-December 2017, sub-zero temperatures were reached each night, with a minimum temperature of -5.1°C . This contrasts sharply with the mild winter of 2015-2016, during which no sub-zero temperatures were recorded during the whole of December.

A total of 71 *Pipistrellus* bat sound files were recorded during these three nights, comprising 53 (75%) common pipistrelle and 18 (25%) soprano pipistrelle sound files. Of the total number of sound files, 87% of common pipistrelle activity and 78% of soprano pipistrelle activity was recorded between -3°C and -4°C (Figure 9). The temperature only fell within this range during 22% of the recording period (sunset – sunrise only), suggesting bats actively selected to fly during these low temperatures.

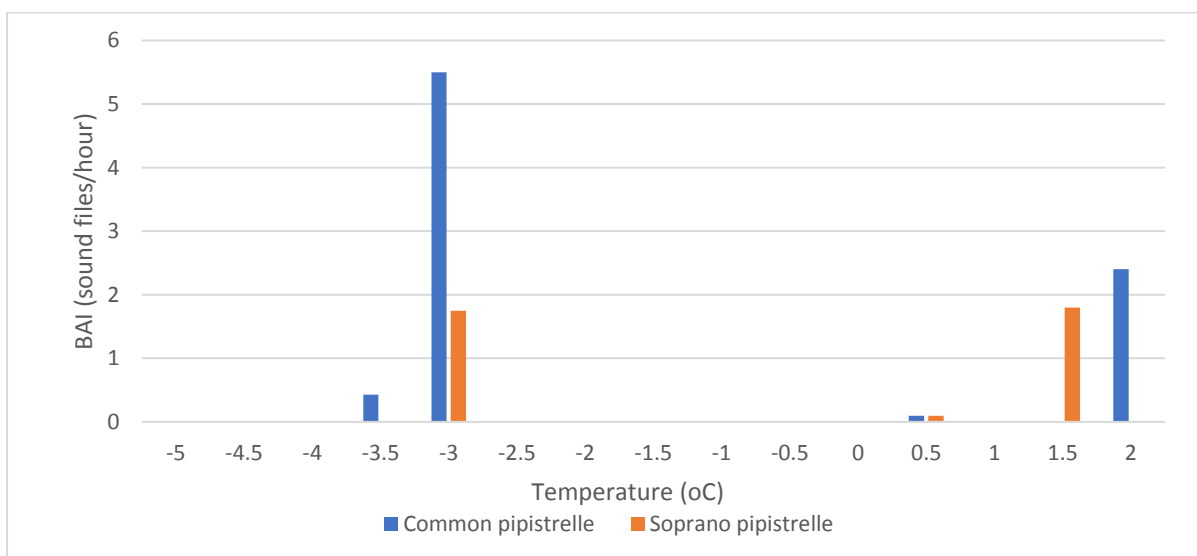


Figure 9: Bat activity distribution by temperature.

Figure 8 shows that during the December 2017 monitoring, sub-zero *Pipistrellus* activity occurred mainly within 2-4 hours of sunset.

Figure 10 shows a sound file recorded during December 2017, at a time when the air temperature was -3°C . Taking into account the peak frequencies of pulses, the inter-pulse intervals and pulse shape; it can be confidently asserted that the calls of at least four individual bats are recorded in the sonogram.

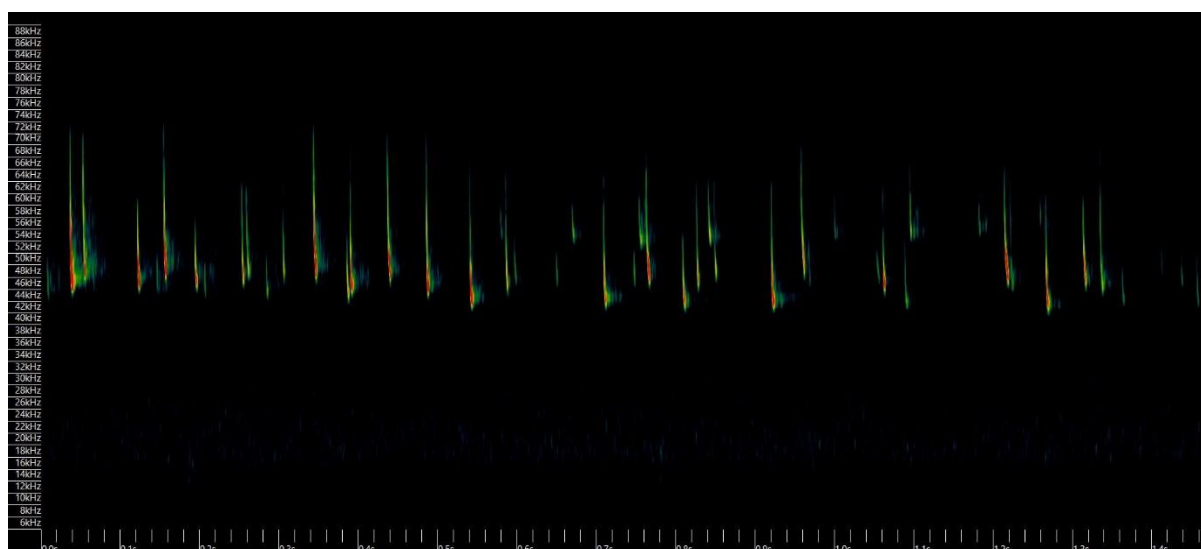


Figure 10: Sonogram recorded when the air temperature was -3.0°C .

Crevice temperature buffering

Whilst the air temperature during the study period ranged between 6.0°C and -2.6°C , the temperature in a potential roost location varied between 5.0°C and 0.6°C . Figure 11 shows the difference between the air temperature and the temperature within the potential roost location.

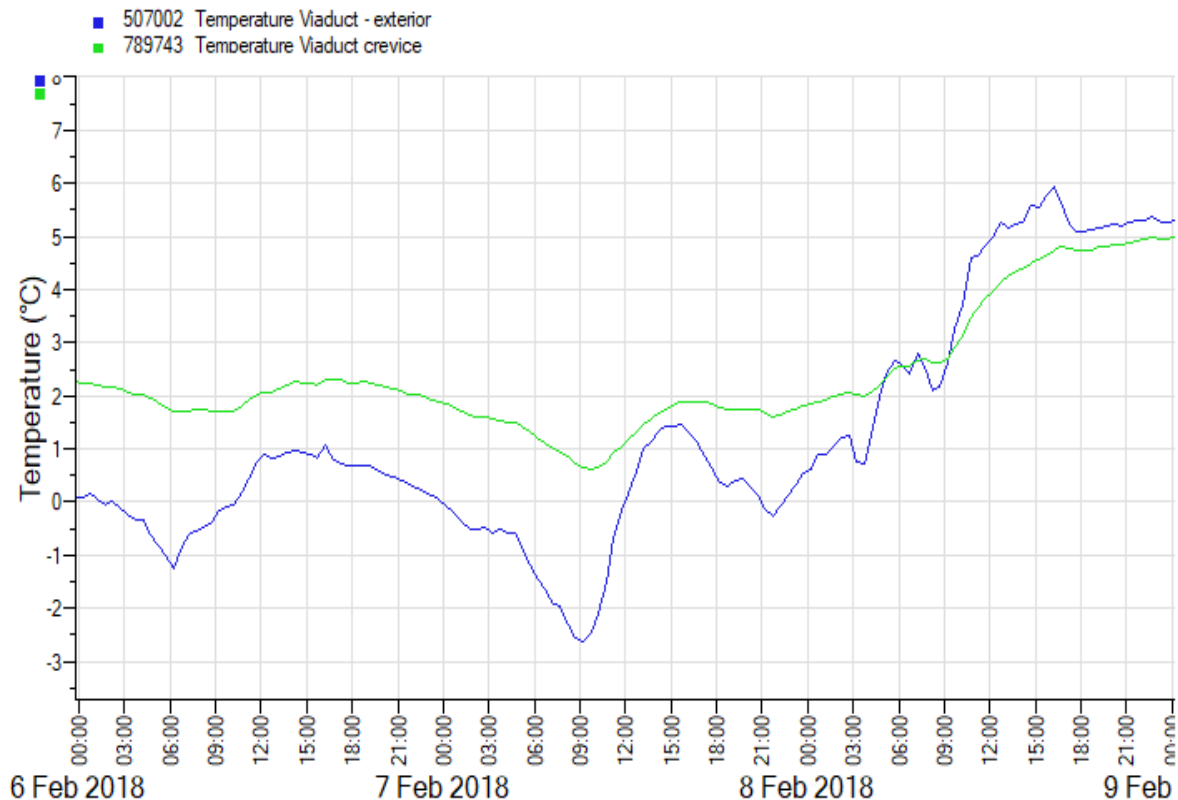


Figure 11: Viaduct temperature buffering.

Discussion

Counts through the year show that Romptickle Viaduct is actively selected by *Pipistrellus* bats for use during the hibernation period. The occupation of this hibernaculum appears to conform to seasonal pattern of use recorded from other similar hibernacula, with most bats entering the hibernaculum in late November/early December. Both common and soprano pipistrelle bats are highly likely to be over-wintering in Romptickle Viaduct, however, the majority of these bats appear to comprise common pipistrelle. Existing evidence of soprano pipistrelle using larger *Pipistrellus* hibernacula in the UK appears to be lacking. This is however likely to be due to the greater abundance of common pipistrelle across much of the UK and the difficulty in visually identifying roosting *Pipistrellus* bats to species level without handling.

Visual surveys of Romptickle Viaduct show hibernating *Pipistrellus* bats are distributed across a large number of crevice roost locations, typically singly or in small groupings, with an average of two bats recorded per occupied crevice. This spread of roosting bats across multiple crevices within the hibernaculum conforms to a pattern recorded from other larger *Pipistrellus* hibernacula in the UK (Phillips, 2018; National Trust, 2018). It is known that crevices within large stone structures experience high levels of thermal buffering and this was confirmed from Romptickle Viaduct through temperature monitoring of a potential roost crevice. Temperature monitoring showed that even when the air temperature dropped to -2.6°C, the temperature within the potential roost location remained above freezing. Temperature monitoring made use of a thermometer positioned at the crevice opening, whilst roosting bats have the option of moving deeper into the crevice, or even into the interior of the

viaduct piers; locations within which the level of temperature buffering would be expected to be at an even higher level. It is considered that the temperature monitoring undertaken gives confidence that Romptickle Viaduct provides a frost-free refuge, even during the coldest periods of weather likely to be experienced in South Yorkshire.

Acoustic survey undertaken during the mild winter of 2015/2016 recorded *Pipistrellus* activity during all winter months with activity increasing quickly when the air temperature rose above 5°C, reaching a peak at temperatures above 7°C. It was notable that sharp increases in *Pipistrellus* activity were recorded at the start of mild periods of weather in December and late February, whilst a similar spell of mild weather in January did not result in the same increase in activity. This observation can be seen as consistent with the findings of Avery (1985), who recorded *Pipistrellus* activity at a foraging site during all winter months, although lower levels of activity were recorded in mid-winter. An alternative explanation for the low level of *Pipistrellus* activity recorded during periods of mild weather in January 2016 may however be that other weather variables such as wind or rain reduced suitability for bat activity at this time. Consequently, further survey would be required to demonstrate that the typical response of *Pipistrellus* bat to periods of mild weather is reduced during mid-winter.

Acoustic survey undertaken in winter 2015/2016 recorded a secondary peak in *Pipistrellus* activity when the temperature dropped below -1°C. Further investigation revealed this activity was recorded during the first two nights that the temperature dropped below -1°C. A focused spell of acoustic monitoring during an intense spell of cold weather in December 2017 showed relatively high levels of common and soprano pipistrelle activity at air temperatures between -3 and -4°C. Inspection of sound files recorded during this period showed as least four bats present within one sound file and it is considered this activity equates to the 'frost swarming' observed by Korsten *et al.* (2016) at a *Pipistrellus* hibernaculum in The Netherlands. It is considered most likely that the recording of *Pipistrellus* activity during sub-zero temperatures indicates bats immigrating into Romptickle Viaduct from less thermally stable roosts. The increase in bat activity at Romptickle Viaduct during the first periods of cold weather, or during subsequent periods of very low temperatures, conforms to bat activity patterns recorded at other *Pipistrellus* hibernacula in mainland Europe (Korsten *et al.*, 2016; Sendor, 2002).

This study also looked at the time of *Pipistrellus* activity during periods of sub-zero weather, showing that this activity occurred at different times after sunset on different nights, most probably in response to the pattern of change in temperature level on the individual night. It was however noted that all recordings were more than one hour after sunset, conforming with patterns of frost swarming reported from The Netherlands (Korsten *et al.*, 2016).

In many respects usage of Romptickle Viaduct by hibernating *Pipistrellus* bats appears to be typical of comparable hibernacula monitored in Britain and on continental Europe. This study does however inform our understanding of the role Romptickle Viaduct fulfils for resident *Pipistrellus* populations.

Acknowledgements

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numerous *Pipistrellus* bats during the hibernation season and has been subject to very detailed recording. Romptickle Viaduct is lucky to fall within the ownership of Barnsley Metropolitan Borough Council who have been very supportive of bat survey work undertaken to date.

References

Altringham, J. (2011) *Bats: from ecology to conservation*. 2nd ed., Oxford: Oxford University Press.

Avery, M. I. (1985) Winter activity of pipistrelle bats. *Journal of Animal Ecology*, 54 pp. 721-738.

Bell, C. P. (2016a) *Seasonal variation in activity by common pipistrelle bats Pipistrellus pipistrellus at Durham Cathedral cloister*. Northern Bats. Volume 1 [Online]
<http://s3.spanglefish.com/s/34944/documents/volume1/durham-cathedral-cloister.pdf>

Bell, R. (2016b) *Romptickle Viaduct and Thurgoland Tunnel: survey and designation of a site for bats*. Northern Bats. Volume 1 [Online]
<http://s3.spanglefish.com/s/34944/documents/volume1/romptickle-viaduct-and-thurgoland-tunnel.pdf>

BTHK (2018) *Bat Roosts in Trees – A Guide to Identification and Assessment for Tree-Care and Ecology Professionals*. Exeter: Pelagic Publishing.

Bucs, S. L. (2018) The Cave Dwelling Bats of Romania. *Bat News*, 117 pp.10-13.

Currie, S. E., Stawski, C. and Geiser, F. (2018) Cold-hearted bats: uncoupling of heart rate and metabolism during torpor at sub-zero temperatures. *Journal of Experimental Biology*, 221(1) pp. 1-8.

Dietz, C. and Kiefer, A. (2016) *Bats of Britain and Europe*. London: Bloomsbury Natural History.

Dietz, C., von Helverson, O. and Nill, D. (2009) *Bats of Britain, Europe and Northwest Africa*. London: A & C Black Publishers Ltd.

Korsten, E., Jansen, E. A., Boonman, M., Schillemans, M. J. and Limpens, H. G. A. (2016) Swarm and switch: on the trail of the hibernating pipistrelle. *Bat News*, 10 pp. 8-10.

Met Office (2018) *Winter 2015/2016 Summary*. [Online]
<https://www.metoffice.gov.uk/climate/uk/summaries/2016/winter>

Nagel, A. and Nagel, R. (1991) How do bats choose optimal temperatures for hibernation? *Comparative Biochemistry and Physiology*, 99(3) pp. 323-326.

National Trust (2018) *Home to roost – largest hibernation of pipistrelle bats recorded at Seaton Deleval Hall*. [Online]

<https://www.nationaltrust.org.uk/press-release/home-to-roost---largest-hibernation-of-pipistrelle-bats-recorded-at-seaton-delaval-hall>

Parker, A. (2018) *A study to investigate how bats interact with bat boxes at Mintlyn Crematorium, Norfolk*. Dissertation. Sheffield Hallam University BSc.

Racey, P. A. (1973) The time of onset of hibernation in pipistrelle bats. *Journal of Zoology (London)*. 171 pp. 465-467.

Racey, P. A. (1974) The temperature of a pipistrelle hibernaculum. *Journal of Zoology (London)*. 173 pp. 260-262.

Sendor, T. (2002) *Population ecology of the pipistrelle bat (Pipistrellus pipistrellus Schreber, 1774): the significance of the year round use of the hibernacula for life histories*. Dissertation zur Erlangung des Doktorgrades der Naturwissenschaften. Fachbereich Biologie der Philipps – Universität Marburg, Marburg.

Simon, M., Huttenbügel, S. and Smit-Viergutz, J. (2004) Ecology and Conservation of Bats in Villages and Towns. *Schriftenreihe für Landschaftspflege und Naturschutz*, 77 pp. 1-262.

Speakman, J. R. and Racey, P. A. (1989) Hibernation ecology of the pipistrelle bat: energy expenditure, water requirements and mass loss, implications for survival and the function of winter emergence flights. *Journal of Animal Ecology*, 58 pp. 797–813.

Speakman, J. R., Webb, P. I. and Racey, P. A. (1991) Effects of disturbance on the energy expenditure of hibernating bats. *Journal of Applied Ecology*, 28 pp. 1087-1104.

Webb, P. I., Speakman, J. R. and Racey, P. A. (1996) How hot is a hibernaculum? A review of the temperatures at which bats hibernate. *Canadian Journal of Zoology*, 74 pp. 761–765.

Ravenscar Tunnel Survey 2018.

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Introduction

After the closure of the Scarborough to Whitby railway the track has been used as a public access route. The tunnel at Ravenscar was closed off with brickwork at both ends and the path bypasses the tunnel with a route between the old Ravenscar station and a point just north east of the opposite end following the road or Cleveland Way footpath.

Plans were mooted to upgrade the 'cinder track' between Scarborough and Whitby and, as an extra to this plan, it has been proposed that the tunnel should be opened up for public access.

During various data searches by North Yorks Moors National Park Authority some records were found that indicated that the tunnel held a major bat roost. Following up these records it was found that there was no direct evidence in the form of firm data for this claim but that it was assumed that as there was considerable bat usage in the area there must be a roost inside the tunnel.

When the tunnel was originally bricked off at either end a door was included in each. The brickwork also had a series of perforations along the upper section, presumably to allow bats access. Over the years the doors have rotted/been vandalised and public have regularly accessed the site.

Various surveys for bats have taken place over the last few years during the winter months as a potential hibernation site but there are no records of any checks that have been carried out regarding a roost site in the spring or summer months. The survey below was to ascertain whether there was bat usage in the tunnel.

Survey methodology

Two hibernation surveys have been undertaken in January and February 2018. This was carried out by use of light and endoscope.

Three roost surveys have been carried out. The first and second surveys were at dusk with the third covering the whole dusk and dawn period.

Surveys in April and May were carried out with fixed recorders inside either end of the tunnel immediately inside the bricked-up entrance. Volunteers were placed immediately outside the tunnel entrance equipped with recorders and to observe what bat movement there was in and out of the tunnel. The April survey was from 22.30hrs until 22.00hrs and the May survey from 21.00hrs to 22.45hrs.

The methodology was changed for the third visit as a result of the findings of the earlier two visits. For this survey volunteers were placed with recorders 25-30m inside the tunnel beyond the brickwork with others positioned alongside the doorway to better see the

comings and goings of any bats. For this survey a third fixed recorder was also placed near the middle of the tunnel (c.110m from the north entrance). The fixed recorders were left running for the whole of the night from 21.30hrs to 06.00hrs. Volunteers were present from 21.30hrs to 23.00hrs.

The sonograms from all the surveys were checked manually using a mix of Batsound and Analook methodology and the results tabulated along with any field notes from the observers. Results have been grouped into five-minute blocks for recordings where volunteers were present. The fixed recorders on visit three were recorded in five-minute blocks whilst volunteers were present and then by the minute for the rest of the night to get a clearer idea of what was happening. Recordings have been retained should there be a requirement for anyone to view them.

As a result of the findings on visit three an examination of the tunnel was carried out. This was a two and a half hour visit systematically examining the whole length of the tunnel and the associated blockwork around the entrance.

Surveys were carried out using local volunteers from Scarborough Field Naturalists and Whitby Naturalists and members of East Yorkshire Bat Group (EYBG) under a CL18 class license held by the author.

In addition to the above, surveys were also carried out in various spots around the village and sonograms recorded for added information.

Results

Hibernation surveys

Visit 1: 8th January 2018

Survey by N. Gibbons and C. Keithley. No bats were recorded in a two and a half hour survey. Ten herald moths *Scoliopteryx libatrix* were noted, one of which had been attacked by a fungus.

Visit 2: 25th February 2018

Survey by local volunteers and EYBG. No bats recorded.

As far as I can ascertain there are no confirmed bat hibernation records apart from a single *Myotis* bat (possibly whiskered bat *M. mystacinus* or Brandt's bat *M. brandtii*) that was recorded by Colin Keighley and myself on 4th February 2016.

Roost surveys

All results have been tabulated in spreadsheet form by date, as Appendices 1-3, which are available from the author on request.

Visit 1: 19th April 2018

Temperature varied from 9.9°C down to 9.3°C during the evening, light cloud and very low breeze (<force 1).

Common pipistrelle *Pipistrellus pipistrellus* was the most common bat and started to appear as recording began. At both ends of the tunnel recorders noted a single bat that appeared to come from somewhere on the stonework around the tunnel entrance, but not from within the tunnel. These bats seem to have some attachment to the tunnel and at both ends were constantly swooping into the tunnel entrance at least as far as the brick wall. It was not easy to identify visually whether the bats went through the wall into the tunnel but at the north end indications from the recorders were that this was the case. The fixed recorder in the south end of the tunnel recorded common pipistrelles in seven of the 17, five-minute periods of the evening, whilst that at the north end recorded just a faint common pipistrelle and which clearly did not pass close to the recorder beyond the brickwork.

Conditions inside the tunnel were quite odd as the warm air being sucked into the cold tunnel from the southern end by convection currents was condensing to form quite a dense mist at the lower levels and this was slow to clear as the evening went on, ending up with some really weird conditions.

No *Myotis* species of bats were recorded either around the tunnel or in the village. A few passes by Noctule *Nyctalus noctula* bats were recorded outside the tunnel and in the village and a single soprano pipistrelle *P. pygmaeus* was noted at the station square.

Visit 2: 18th May 2018

Temperature dropped to 8.1°C at end of survey after a warm day, cloud 1/10 and light breeze (<1).

As before common pipistrelle was the most common bat but nothing appeared either inside or outside the tunnel until 21.25hrs. Also, as above, there were indications that a single bat was using the stonework around the tunnel entrance with a sudden appearance noted at both ends. As before these bats seem to have some attachment to the tunnel and at both ends were constantly swooping into the tunnel entrance at least as far as the brick wall. It was not easy to identify visually whether the bats went through the wall into the tunnel.

The north end of the tunnel was again the most active with common pipistrelle again going in and out of the tunnel entrance at least as far as the brickwork. A change from our first survey was the appearance of *Myotis* bats with a single 'pass' at 21.30hrs, six passes between 21.45hrs and 21.50hrs and a further single pass at 22.00hrs. At 21.30hrs two bats were identified by sound but, with the very active common pipistrelle going in and out of the tunnel entrance, it was not clear where the *Myotis* bat appeared from. The internal recorder at this end did not record a *Myotis* bat until 21.45hrs with further passes at 21.45hrs and 21.47hrs.

At the south end, after the single common pipistrelle's appearance at 21.35hrs there were two brief passes by *Myotis* bats between 21.40hrs and 21.45hrs but only a very faint *Myotis* recording on the internal recorder.

Conditions inside the tunnel were considerably drier than in April, when there was water running down the walls and the ceiling was dripping profusely.

Visit 3: 22nd- 23rd June 2018

Temperature 11°C, cloud 0/10 and faint breeze (<1).

At the north end of the tunnel a single common pipistrelle was seen leaving the doorway at 22.02hrs which is certainly the one recorded on the fixed recorder at close to this time. The central fixed recorder also picked up a common pipistrelle at this time. There appears to be a two-minute variation apparently in clocks between the two south end recorders as shown by later records. There were some *Myotis* records again around 22.18hrs but some of these were weak and maybe were from bats coming up to the doorway whilst circulating around outside. There were however strong recordings around 22.27hrs which coincide with *Myotis* recordings from the recorder in the middle of the tunnel and from the south end. After the volunteers finished at 23.00hrs the internal recorder showed activity by both common pipistrelle and *Myotis* bats and in at least two instances (23.46hrs and 01.38hrs) the 'south' recorder had similar records to that in the centre. There were no records at the south recorder after 02.03hrs.

The south end of the tunnel also had a common pipistrelle seen leaving the doorway at 10.00hrs. There is then a gap before a number of *Myotis* bats were recorded by both the fixed and manned recorders between 22.15hrs and 22.27hrs. This again coincided with a recording in the centre of the tunnel. A bat was visually recorded both leaving and entering during this period. As for the south end after the volunteers had left the fixed recorder continued to record both common pipistrelle and *Myotis* bats, the last being a common pipistrelle at 03.16hrs. A recorder sited outside the south entrance by one of the volunteers gives a picture of what was happening there in comparison with what the tunnel recorders detected.

Visit 4: 28th June 2018

The visual examination of the tunnel could find no trace of either common pipistrelle or *Myotis* bats but surprisingly did turn up a brown long-eared bat *Plecotus auritus* hanging from the ceiling brickwork approximately 80m in from the north entrance. As a result of this find, all files relating to the 22nd June have been rechecked for the presence of brown long-eared bat but none were found. This is a 'quiet' bat and is not readily picked up acoustically unless passing very close to the recorder. A blue tit *Cyanistes caeruleus* was also observed roosting in the blockwork at the north entrance.

Conclusions

Hibernation

There is little evidence of the site being used for hibernation over the last five to six years when there are any confirmable records. As above the only record is 4th February 2016. The blockwork of the tunnel is such that there is a multitude of very deep cracks which are largely inaccessible even with an endoscope and this makes it difficult to be certain that this is a true reflection of what may be hibernating there.

Roost

There is good evidence from the surveys that the tunnel is being used by bats for roosting purposes from both the acoustic records and also the final visual inspection, but it is unlikely there is a 'major' roost from the numbers found.

It is unusual for common pipistrelle to roost so far underground but the recorder near the centre of the tunnel on the 22nd June visit shows activity by both this species and also *Myotis* bats. The visual recording undertaken by the volunteers would indicate that the common pipistrelle are using the stonework around the entrance but with two seen leaving they clearly appear to be using further inside the tunnel also. The identity of the *Myotis* species using the area is probably Natterer's bat *Myotis nattereri* based on the characteristics from the Anabat files analysed but we did not obtain any visual confirmation of this.

With bats going in and out of the tunnel it is difficult to be sure of the numbers that are actually roosting inside the tunnel. The fact that at there are records of both common pipistrelle and *Myotis* bats at similar times on all three fixed recorders does beg the question as to whether some bats are actually flying through the tunnel?

The lack of a major roost, if there was one historically, may be due other changes. When was the tunnel bricked up and, also, when were the doors removed from the tunnel brickwork? There are certainly some strange air flows through the tunnel with the doors missing. Even on a still day there is a noticeable breeze out of the northern end door and with a south-west wind this is much stronger. This would certainly be reduced with the doors in place and these maybe would have also reduced the 'fog' effect from the warm air being pulled into the cold tunnel. Weather will also play its part. This year the tunnel has been extremely wet in the early part of the year and was only really drying out a bit for the later visit. The very wet walls and brickwork would certainly deter bats and the presence of a roost may be dependent on where else the bats know locally that would be more suitable.

What is a little also surprising is the early finish of records before dawn. With dawn at 03.30hrs the last recording at the south end was 02.16hrs for a common pipistrelle and 01.02hrs for a *Myotis* and for the north end was 01.01hrs for common pipistrelle and 02.03hrs for a *Myotis* species bat. I would have expected to have found bats continuing to move into the roost right up to and maybe just after dawn if they were roosting there.

With not being able to actually see the *Myotis* and *Pipistrellus* species bats the survey seems to beg more questions than it answers but does confirm the use of the tunnel as a bat roost that would require taking into account when planning any changes as to its use.

Acknowledgements

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The impact of social networks on the roosting behaviour of soprano pipistrelles *Pipistrellus pygmaeus*.

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Summary

Soprano pipistrelles are one of the commonest bat species in the United Kingdom. Despite this, this species is generally understudied in comparison to other species, such as common pipistrelles or Bechstein's bats. Loss of roosting habitats has been identified as a major threat to this species, with declines in roost counts occurring since 2000. The roosting strategy employed by individuals may be influenced by colony social structure of this species, with fission and fusion of social subgroups influencing the use of different roost sites over time.

At Gibside National Trust estate, bi-annual or tri-annual censuses of roost boxes on site have been undertaken between 2013 and 2017, with any bats found roosting ringed and recorded. The National Trust, as the client for this study, have posed the following four questions regarding soprano pipistrelle populations on the Gibside estate:

- Do female soprano pipistrelles roost together because of 'friendship groups', or are emergent clusters of individuals simply attributable to chance?
- Do female soprano pipistrelles exhibit roost fidelity, returning to the same boxes, or mate fidelity, returning to the same males?
- Is there a significant relationship between male soprano pipistrelles and specific roost boxes during the autumn mating season? What percentage of these boxes is taken over by a new male? How can roost box clusters be managed to retain bats annually?
- Are individuals recaptured in the same cluster of roosting boxes, or is there a significant proportion of roost switching between box clusters? How can local habitats be managed to encourage bats to use roost boxes?

Detailed statistical analysis of an existing census dataset was undertaken to understand the movements of individual soprano pipistrelles, analyse the social network of bats and inform management strategies that can be used to positively influence the soprano pipistrelle population at the Gibside estate.

It was considered that the volume of data was too small to draw definitive conclusions on some of the questions posed by the client. However, weak relationships were observed between females, potentially suggesting that some 'friendship groups' may occur between female soprano pipistrelles and that females may also exhibit some form of roost and/or mate fidelity. Males defended roost boxes as territories over consecutive years, which made it difficult to ascertain whether females were returning to favoured males or favoured roost boxes. Finally, some bats exhibited roost lability, moving between different roost boxes and roost sites, but other individuals exhibited roost fidelity. Maintenance of a diverse mosaic of habitats across the estate may encourage bats to use roost boxes.

Several recommendations for future research pertaining to both the Gibside estate and soprano pipistrelle populations in general have been suggested, including genetic analysis of roosting bats and investigation into the internal characteristics of roost boxes.

Introduction

Background

Bats comprise a quarter of the world's species of mammals, with many species living communally in colonies for at least part of the year. Colonies can be mixed or single-sex, fluctuating in both size and structure over time. This variation makes bats an excellent taxon for studies of social structure and organisation of social groups. Social structure is an important component of biological studies, as it influences gene flow, fitness, information transfer about resources and predators and spatial patterns of animal populations. These factors, in turn, influence the success of conservation efforts.

Globally, bats are under threat due to light pollution (Stone *et al.*, 2015), habitat loss (Flaquer *et al.*, 2006), human-wildlife conflicts surrounding development (Dietz and Kiefer, 2016) and a lack of general understanding of species ecology and distribution (Mackintosh, 2016). The ecology and conservation of bats is highly dependent on the availability of roosting spaces and suitable adjacent habitat, and are likely to be linked to social structure (Flaquer *et al.*, 2006; Hale *et al.*, 2012; Stone *et al.*, 2015; Mackintosh, 2016). The roosting patterns of bats may influence the social structure of a colony (Patriquin and Ratcliffe, 2016). Management of sites affects the availability and quality of roosting sites; suitable management of sites can be informed by research into the social structure of current bat populations.

Seven of the seventeen British bat species, including the soprano pipistrelle have been listed as UK Biodiversity Action Plan (BAP) species (Joint Nature Conservation Committee, 2016). The soprano pipistrelle has been listed as a BAP priority species due to a 42% population decline over six years since 2001, due to a range of pressures including: the removal of hedges and copses; modification of cultivation practices; pollution and infilling of small water bodies (Joint Nature Conservation Committee, 2007). Many of the factors causing this decline are still in operation. There is also limited survey information about this species, causing a lack of confidence about population declines (Joint Nature Conservation Committee, 2010). Soprano pipistrelles have been found at the Gibside National Trust estate, Tyne and Wear, as well as Daubenton's bats *Myotis daubentonii*, whiskered bats *M. mystacinus*, Brandt's bats *M. brandtii*, and common pipistrelles *P. pipistrellus*, all of which are protected under the Wildlife and Countryside Act (1981) (as amended) and the Conservation of Habitats and Species Regulations (2010). The client, the National Trust, would like to understand how soprano pipistrelles in particular use man-made roosting boxes erected across the estate. Investigating long-term social structure trends will contribute to the understanding of population trends for this species, and consequently help focus conservation efforts.

Project purpose

At Gibside National Trust, Tyne and Wear, 34 bat roosting boxes erected between 2006 and 2010 have been checked bi-annually or tri-annually for roosting bats since 2013. Soprano pipistrelle bats were the only bat species to have used these boxes, with any

individuals found ringed and recorded. The overall objective of this study is to investigate the social structure of this species, focusing on roost switching behaviour and long-term relationships between individual bats. Specifically, this report will address the following questions:

- Do female soprano pipistrelles roost together because of 'friendship groups', or are emergent clusters of individuals simply attributable to chance?
- Do female soprano pipistrelles exhibit roost fidelity, returning to the same boxes, or mate fidelity, returning to the same males?
- Is there a significant relationship between male soprano pipistrelles and specific roost boxes during the autumn mating season? What percentage of these boxes is taken over by a new male? How can roost box clusters be managed to retain bats annually?
- Are individuals recaptured in the same cluster of roosting boxes, or is there a significant proportion of roost switching between box clusters? How can local habitats be managed to encourage bats to use roost boxes?

Literature review

Soprano pipistrelle bats are a common species spread throughout most of the United Kingdom (Figure 1). Despite this, they are not a well-studied species (Joint Nature Conservation Committee, 2010). A search of 'Web of Science' for papers with 'soprano pipistrelle' or '*Pipistrellus pygmaeus*' in the title rewarded 36 results, whereas 244 results were generated for the closely related species 'common pipistrelle' or '*Pipistrellus pipistrellus*'.

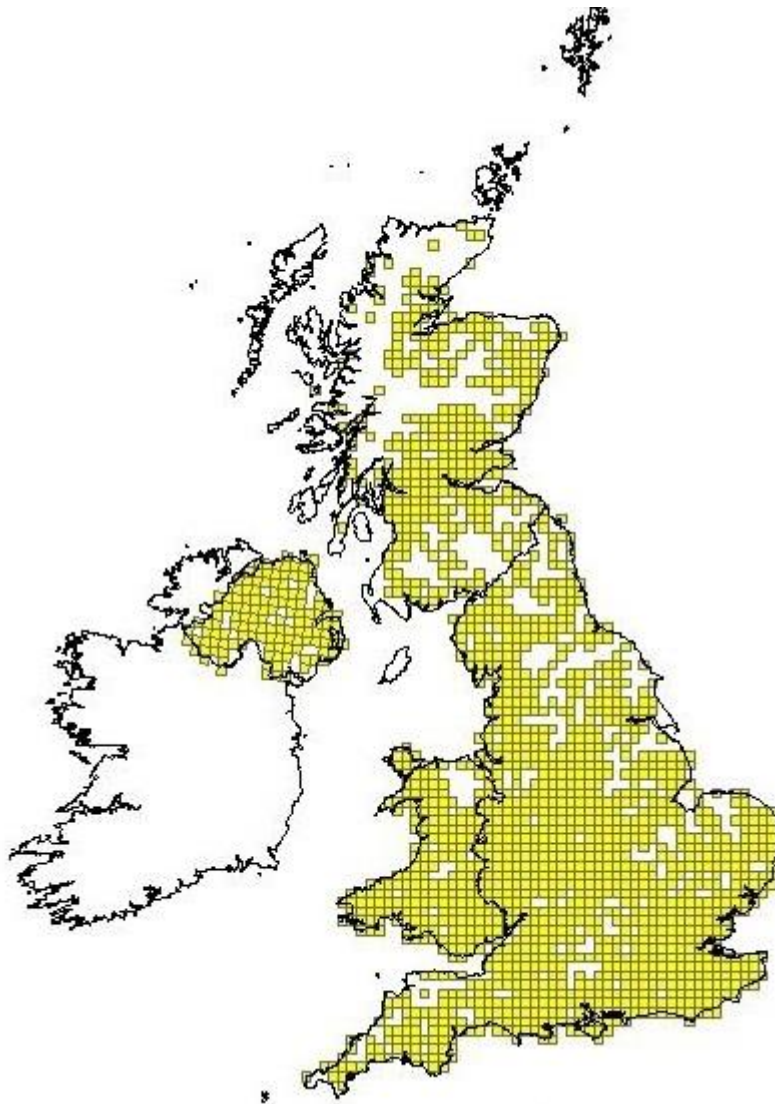


Figure 1: Current distribution of soprano pipistrelles in the United Kingdom (Joint Nature Conservation Committee, 2012).

Across Great Britain since 2000, a significant decline in roost counts for soprano pipistrelles has been observed (Joint Nature Conservation Committee, 2016). Reasons cited for this apparent decline include modification and loss of key habitat features, such as hedgerows and small water bodies, and the homogenization of habitats (Joint Nature Conservation Committee, 2007). This apparent decline may also be at least partly attributable to frequent roost switching- 'roost lability'- during the course of a year, leading to under-estimation of roost counts. Furthermore, prior to 2000, roost counts may also be unrealistically high, as soprano pipistrelles were only deemed different species through genetic analysis in 1999, suggesting that common pipistrelle roosts may be included in previous counts (Joint Nature Conservation Committee, 2012).

This species is often found in close association with humans, using man-made roost boxes (Flaquer *et al.*, 2006), natural tree hollows (Bartonicka and Rehak, 2007), and spaces in houses as roosting sites, the latter particularly by maternity colonies (Lourenço and Palmeirim, 2004). Bartonicka and Rehak (2007) described this species as 'hemi-synanthropic': although well-adapted to living in close proximity to humans, this species also

switches to roosts in the natural environment at different times of the year (Joint Nature Conservation Committee, 2010).

Roosts provide protection from predators and environmental extremes, as well as acting as an important site for social interaction within a colony (Lourenço and Palmeirim, 2004). Accordingly, the loss of roosting areas has been identified as one of the major threats to this species (Joint Nature Conservation Committee, 2012), and changes to roosting sites may negatively impact populations of this species. Understanding the roosting habits of this species is therefore important for the success of targeted conservation efforts. Targeted management suggested by the Joint Nature Conservation Committee (2010) also includes the improvement of key habitats for foraging, monitoring of current populations and research into the effectiveness of current management strategies.

Benefits of roost fidelity or roost lability

Soprano pipistrelle bats may be attracted to a roost due to its beneficial qualities, such as stable microclimatic conditions, or small entrance slits that prevent larger bat species from entering and regulate air movement within a box (Rhodes and Jones, 2011). Roost fidelity may be an attempt at reducing the costs involved with leaving a familiar area, which include physical energy outputs associated with searching for new roosts, and the disruption of social bonds. Bats that practice roost fidelity may benefit through greater reproductive and hibernation success, as less energy is expended searching for suitable roosting locations (Lewis, 1995). Roosts with stable, warm microclimates accelerate gestation and growth of young, and may also benefit young bats incapable of independent thermoregulation during the night (Lourenço and Palmeirim, 2004). Some roost box designs, such as double-chamber boxes (Flaquer *et al.*, 2006) and concrete boxes (Poulton, 2006) appear to be more attractive to soprano pipistrelles, potentially due to the large surface area of boxes with double compartments, or better thermoregulatory properties (Figure 2).

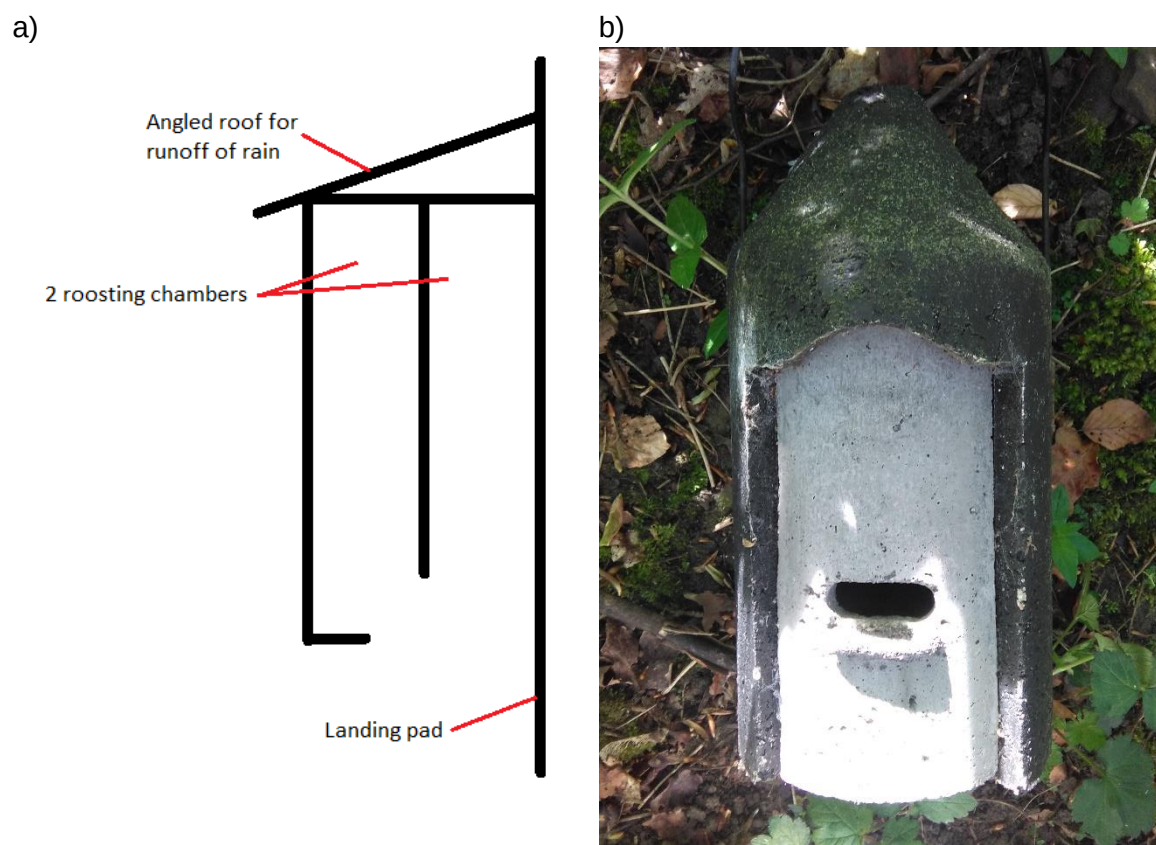


Figure 2: a) Double chamber roost box design. b) Popular Schwegler 2f concrete roost box design.

Roost fidelity appears to be related to the type of roost occupied: permanently accessible roosts appear to be correlated with roost fidelity. However, increasing availability of roosts appears to be inversely correlated with roost fidelity (Lewis, 1995). This may be as a result of bats making decisions between the benefits of leaving or remaining in a roost when there are multiple other roost sites with different internal properties available (Lewis, 1995).

In southern Europe, soprano pipistrelles appeared to prefer warmer roosting locations, tolerating temperatures up to 40°C, but not beyond (Lourenço and Palmeirim, 2004). Black coloured roost boxes were preferred in this study by soprano pipistrelles due to their ability to reach higher internal temperatures than grey or white painted boxes (Lourenço and Palmeirim, 2004). Bartonicka and Rehak (2007) observed that the number of bats present in a roost directly correlated to the thermoregulatory properties of a roost.

Male and female bats have been found to use different types of roosting sites, splitting into single-sex groups for portions of the year. Maternity colonies of female soprano pipistrelle bats form during spring and summer, before disintegrating over winter for hibernation. A maternity colony splits into multiple smaller roosting groups during July to September, when mating occurs.

In comparison, males tend to roost singularly, or with groups of females. Roost sites may be defended as territory by males and used as a resource to aid a male in attracting females (Gerell and Lundberg, 2005). Soprano pipistrelles follow a courtship mating system akin to lek mating, where males claim territories and display for females, but take no part in caring for the resulting offspring (DuVal, 2013). The choice of courtship territories may be due to

the local habitat and proximity to resources such as communal roosts; those sites closer to foraging areas have been identified as more attractive to lactating female soprano pipistrelles and courting males holding territories near these areas may be selected as a result (Patriquin and Ratcliffe, 2016). The mating system in pipistrelle bats has therefore been characterised as ‘resource defence polygyny’; males monopolise roosting sites early in the breeding season in an attempt to maximise their potential for mating success (Gerell and Lundberg, 2005).

Potentially as a result of following a resource defence mating system, high roost fidelity has been observed in genetically similar species to the soprano pipistrelle. 93% of male common pipistrelles were observed to claim territories and remain in the same roost box from June until September (McCracken and Wilkinson, 2000). Where females of a lekking community have been observed to exhibit roost site fidelity, for example the lance-tailed manakin bird *Chiroxiphia lanceolata* opportunities for young or low-ranking males to join lekking displays are provided, although the likelihood of immediate reproduction is low (DuVal, 2013).

In contrast, roost lability may also have benefits to species which switch roosts often. This would explain why soprano pipistrelles often choose to move roosts frequently. The probability of inbreeding, and intraspecific competition for food and other resources may decrease when roost lability causes individuals to move away from familiar areas (Lewis, 1995).

Roost switching may also be an attempt at reducing roost ectoparasites (Ngamprasertwong *et al.*, 2014). Ectoparasites can lower the fitness of bats through shortened resting periods and longer grooming periods (Lewis, 1995). Ngamprasertwong *et al.*, (2014) observed soprano pipistrelle maternity colonies, as well as co-roosting Daubenton’s bats and brown long-eared bats *Plecotus auritus*, changing roosting locations within an attic complex, potentially to minimise parasite loads.

Direct disturbance from humans or predators may also cause bats to switch roosts (Stone *et al.*, 2015). Indirect disturbance to areas around a roost may include artificial lighting damaging bat foraging areas by making an area unsuitable for foraging, or impacting commuting routes (Stone *et al.*, 2015).

Although individual bats may practice roost lability, the same roosting sites may be frequently re-used by a bat colony as a whole. Kerth and König (1999) explored the idea of a large bat colony undertaking fission into subgroups in multiple roosting sites in different trees, before fusing back into one colony during other times of the year. This has been described as a ‘fission-fusion’ population structure (Figure 3). Subgroups of bats may return to the same roosting area during fission phases due to roost fidelity, or due to associations with other roosting individuals. The colony maintains social links despite the splitting and merging of groups, which are variable in composition of sex, age, reproductive status and genetic relatedness (Kerth and König, 1999). Fission-fusion may benefit colonies through social thermoregulation and information sharing about roosting and feeding sites (Patriquin and Ratcliffe, 2016).

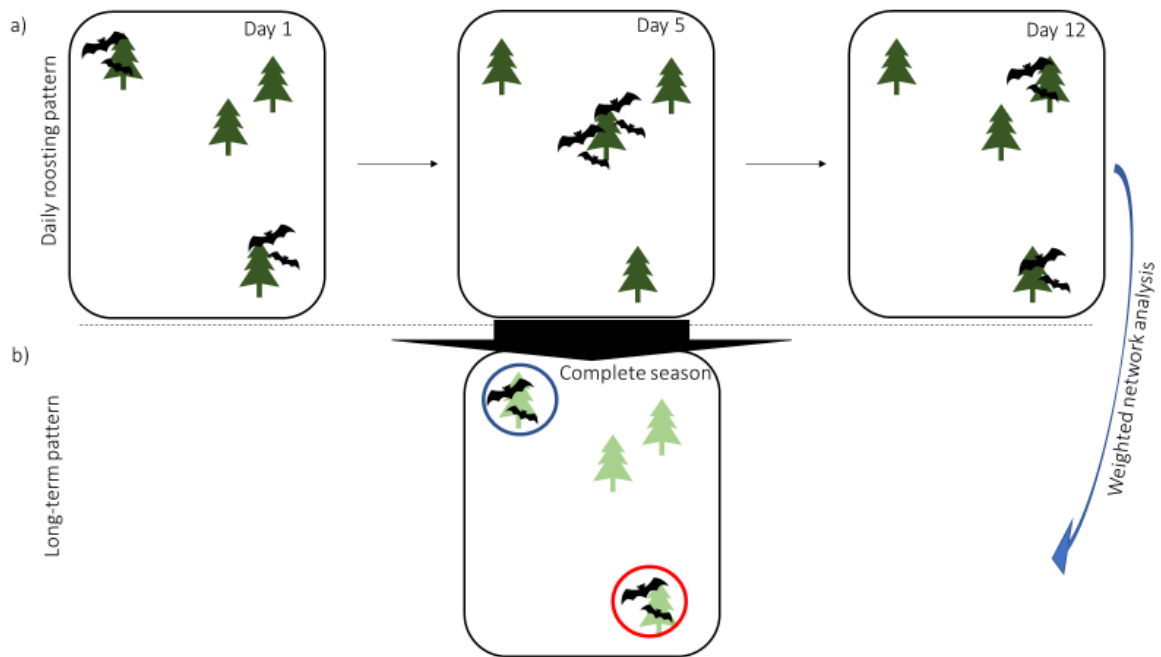


Figure 3: Fission-fusion dynamics of a Bechstein's bat *M. bechsteinii* colony. (a) Typical pattern of roost occupation for the colony on three randomly chosen days (1, 5, 12) illustrating fission-fusion of bat subgroups. (b) Distinct communities and underlying social structure identified through weighted network analysis, based on the roosting association of individuals over an entire five month season (adapted from Kerth *et al.*, 2011).

The degree of association between individuals influences social interactions, resulting in non-random associations of bats to roosts when individuals return to the same areas to roost with other individuals, rather than through active preference for that roosting area (Kerth and König, 1999). Stable individual relationships persist in these networks, despite frequent splitting and reformation of colonies through fission-fusion (Kerth *et al.*, 2011).

Benefits of social bonding in bats that exhibit roost lability

Bats are social animals with complex social networks (Gerell and Lundberg, 2005). There is, however, little information on how bats maintain these long-term relationships and whether they are based on simple aggregative characteristics such as age, reproductive status or size (Kerth *et al.*, 2011). Social bonds have been described as 'non-random associations', with studies comparing associations between bats to determine whether roosting patterns are a by-product of mutual roost preferences, or whether non-random associations are occurring due to social bonds between individuals (McCracken and Wilkinson, 2000; Bartonicka and Rehak, 2007; Patriquin and Ratcliffe, 2016). Association indices have been used to study the composition of subgroups and investigate the presence of social bonds between individuals (Kerth and König, 1999).

Passive aggregations, where there are not social bonds between co-roosting bats, give benefits such as increased vigilance (Gardner *et al.*, 2002), enhanced thermoregulation (Lewis, 1995) and dilution of risks. However, individuals do not gain the additional fitness benefits of cooperation from social bonds (Patriquin and Ratcliffe, 2016).

Social bonds between females of the same colony have been observed in Bechstein's bat (Kerth and König, 1999; Kerth *et al.*, 2011), vampire bats (Wilkinson, 1985) and big brown

bats *Eptesicus fuscus* (Patriquin and Ratcliffe, 2016). Within Bechstein's bat colonies, females exhibit fidelity to natal colonies, with members of the same natal colonies choosing to roost together repeatedly (Kerth and König, 1999; Kerth *et al.*, 2011). Currently there is a lack of information about social bonds between female soprano pipistrelle bats.

In greater horseshoe bats *Rhinolophus ferrumequinum*, females have been observed returning to the same males over multiple breeding seasons, suggesting a level of mate fidelity in this species (Rossiter *et al.*, 2005). In this study, some females returned to males that had established different territories to previous censuses, suggesting that mate fidelity was not solely a result of roost fidelity (Rossiter *et al.*, 2005). However, these two factors may be interrelated. Due to the extended association between males and territories, with many males establishing and defending long-term territories, the consequences for social evolution will be similar, despite the choice by females to exhibit roost or mate fidelity (Rossiter *et al.*, 2005).

Mate fidelity may benefit individuals through avoidance of inbreeding (Stow and Sunnucks, 2004; Rossiter *et al.* 2005; DuVal, 2013), and increased success of reproductive efforts due to decreased energy spent searching and courting potential mates (DuVal, 2013). Males may also benefit from greater reproductive success when defending previously occupied territories if females exhibit roost fidelity. Aggregation of females to male territories has been observed in the common pipistrelle during the autumn mating period, with 54% of females returning to sites where males that previously attracted females were present (McCracken and Wilkinson, 2000).

Conclusions

Due to the close proximity of soprano pipistrelles to humans, frequently inhabiting human dwellings or man-made roost boxes and the tendency of this species for high roost lability, understanding annual changes in roosting habits is important for bat conservation measures.

Species such as soprano pipistrelles that conform to a fission-fusion population structure require multiple different types of roosts within an area to maintain social relationships between a colony and meet thermoregulatory needs (Patriquin and Ratcliffe, 2016). Research into social relationships in soprano pipistrelle bats is limited, with further research needed into social links between females of natal colonies and male-female mate fidelity in this species.

Male soprano pipistrelles spend much of the summer months establishing and defending territories to attract females in a resource defence polygyny mating structure, potentially establishing patterns of roost fidelity of preferred territories and roosting sites within these areas.

Roost switching may also be a product of a fission-fusion population structure, with social bonds forming between subgroups of a larger colony. Much of the information about fission-fusion population structures has focused on a few species of bat, particularly Bechstein's bats, and many questions remain about how different groups of bats use roosts of varying availability and permanency.

Methodology

Observations were made of soprano pipistrelles roosting in roost boxes at Gibside National Trust estate, Tyne and Wear. The National Trust, as the client for this study, have posed the following research questions to be answered:

- Do female soprano pipistrelles roost together because of ‘friendship groups’, or are emergent clusters of individuals simply attributable to chance?
- Do female soprano pipistrelles exhibit roost fidelity, returning to the same boxes, or mate fidelity, returning to the same males?
- Is there a significant relationship between male soprano pipistrelles and specific roost boxes during the autumn mating season? What percentage of these boxes is taken over by a new male? How can roost box clusters be managed to retain bats annually?
- Are individuals recaptured in the same cluster of roosting boxes, or is there a significant proportion of roost switching between box clusters? How can local habitats be managed to encourage bats to use roost boxes?

Study area

The Gibside estate is mainly coniferous plantation woodland, with areas of broadleaved plantation and semi-natural woodland. A maternity colony of soprano pipistrelles has been observed using the stable block at the centre of the estate grounds. Multiple species of bats have been recorded on site, including Daubenton’s bats, whiskered bats, Brandt’s bats, common pipistrelles and soprano pipistrelles. Roost boxes are arranged in ten different clusters around the site.

Field methodology: Mark recapture methods

Between 2013 and 2017, 12 censuses of 34 accessible roost boxes across the Gibside estate were undertaken. Bats were captured during the day by checking roost boxes and removing any individuals inside. For each bat, a ring bearing a unique identification number was either fitted to the bat’s right forearm, or if a ring was already present, the ring number was recorded. The box number (postcode) was also recorded, along with data on the individual, including: age; sex; forearm length; weight; breeding condition and any other distinguishing features or notes. Adults were distinguished from juveniles by looking at the fusion of metacarpal-phalangeal joints (Dietz and Kiefer, 2016). Individuals were released back into roost boxes immediately after processing.

Statistical analyses: Do female soprano pipistrelles roost together because of ‘friendship groups’?

Statistical analyses to answer all the research questions were undertaken in R version 3.4.2 (R Core Team, 2017). To determine whether friendship groups of female soprano pipistrelles occur, the symmetrical index of Fager (the I_{ij} -index, or I_{ij} for short) and the χ^2 statistic were used to determine dyadic roosting associations between individuals (Appendix 1). The I_{ij} -index measures the proportion of time two individuals roost together in relation to the number of days they are observed in the study area (Kerth and König, 1999; Kerth *et al.*, 2011). The significance of associations were tested using a Student’s t-test. Significant associations indicate that two individuals prefer to roost together (Wilkinson, 1985; Kerth *et al.*, 2011). The χ^2 statistic discriminates between the ‘passive’ association of two individuals both independently attracted to a roost box, due to shared roost preference, or ‘active’ association to the other bat (Kerth *et al.*, 2011).

Based on these analyses, weighted undirected networks of the bats' social links were constructed using the graph package in R (Kerth *et al.*, 2011). Graphs were drawn using a force-directed layout using a Fruchterman-Reingold layout algorithm, which places nodes (bats) so that there are visually as few crossing edges (social links) as possible. The social structure of the soprano pipistrelle colony that uses roosting boxes at the Gibside estate was characterised by the weight of the links (I_{ij}) connecting colony members. A Mantel test was then undertaken to understand the importance of successive recaptures of bats over multiple censuses on the strength of individual associations.

Statistical analyses: Do female soprano pipistrelles exhibit roost fidelity or mate fidelity?

To understand whether female soprano pipistrelles exhibited roost fidelity, adapted I_{ij} and χ^2 statistics were performed on female bats to compare use of different roost boxes (

Appendix 2). The adapted I_{ij} allowed the proportion of time a female individual roosting in a specific roost box in relation to the number of days she was observed in the study area to be calculated. The χ^2 statistic discriminates between the 'passive' association of an individual attracted to a roost box, due to roost quality, or 'active' association to a particular roost box due to roost fidelity.

The importance of mate fidelity was analysed using the original I_{ij} -index and the original χ^2 statistic for male and female bats. Network analyses were then undertaken to graphically represent the strength of associations between female and male soprano pipistrelles, and between females and roost box clusters. Graphs used the Fruchterman-Reingold layout algorithm as above. Mantel tests were also undertaken to understand whether successive recaptures over multiple censuses would increase the significance of associations between female and male bats and female bats and roost box clusters.

Statistical analyses: Is there a significant relationship between male soprano pipistrelles and specific roost boxes during the autumn mating season?

To understand territorial changes during the mating season, records of adult male bats found during late summer and autumn were extracted from the raw dataset. Records of adult male bats found during the non-breeding season in spring were also extracted to a second subset of data. Juvenile bats were then removed from both subsets of data, as males do not become sexually mature until they have reached one year of age (Bat Conservation Trust, 2015). Adapted I_{ij} and χ^2 statistics were performed on these remaining adult male records to understand whether adult males were significantly associated with roost boxes during the breeding season, in comparison to the non-breeding season.

Analysis of Variance (ANOVA) tests were used to determine whether roost box orientation or box type were significant factors affecting the use of roost boxes by males.

Statistical analyses: Are individuals recaptured in the same cluster of roosting boxes, or is there a significant proportion of roost switching between box clusters?

Roost switching behaviour of individuals was assessed for bats that had been recaptured more than once. The mean return rate of bats to each roost box cluster was first calculated, followed by a one-way ANOVA test to understand whether there were significant differences in the return rate of bats to different roost box clusters. Tukey HSD post-hoc tests were then undertaken to further understand the differences between the different roost

box clusters. The percentage of roost box usage per bat was calculated to investigate the use of different roost boxes by individual bats (

Appendix 3).

Results

Do female soprano pipistrelles roost together because of ‘friendship groups’?

Between April 2013 and October 2017, 97 unique soprano pipistrelles were extracted from roost boxes across the Gibside estate and ringed. Most bats were female (80 individuals). Only 17 of the bats captured during this study were males. Pairwise roosting associations (I_{ij}) were calculated to measure how often any two individuals share the same roost box, to quantify social relationships. Whilst 5.1% of female-female associations and 6.5% of male-female associations were significant when considering I_{ij} , there were no significant non-random associations occurring when considering χ^2 (Table 1). This suggests that roosting patterns of both females and male-female pairs occur by chance, not due to stable social bonds within colonies. These results may, however, be due to a lack of data; very few bats were recaptured more than three times, creating difficulties for the χ^2 statistic to achieve significance with such small sample sizes.

Table 1: Mean number of significant associations per individual bat amongst all pairwise comparisons within and between sexes.

Sex	Index	Mean	Number significant	Number of dyads	Proportion significant (%)	Number of bats
Females-females	I_{ij}	2.038	161	3160	5.1	80
	χ^2	0.710	0	3160	0	80
Males-males	I_{ij}	0.000	0	136	0	17
	χ^2	0.000	0	136	0	17
Males-females	I_{ij}	0.711	65	1000	6.5	97
	χ^2	0.671	0	1000	0	97

Network analysis illustrated up to seven (largely) distinct social subgroups in female soprano pipistrelles, though these subgroups were often linked by a handful of individuals, and multiple individuals unconnected to other females (Figure 4). Stronger associations between individuals are represented by greater I_{ij} weighting, and increasing thickness of lines. Bats that were never seen sharing with other individuals are represented as unconnected nodes. Some subgroups of individuals were frequently found roosting together (such as H5075, H5072, H5073, H5074 and H5071), suggesting that these individuals may be collecting in friendship groups. These bats may alternatively be exhibiting mate fidelity to a male that returns to the same box as these females annually. There was a statistically significant positive correlation between the strength of individual associations with successive recaptures over multiple years (Mantel test: $r = 0.834$, $p < 0.001$). This contrasts with the above χ^2 findings, supporting the conclusion that with more data, statistical significance might have been achieved.

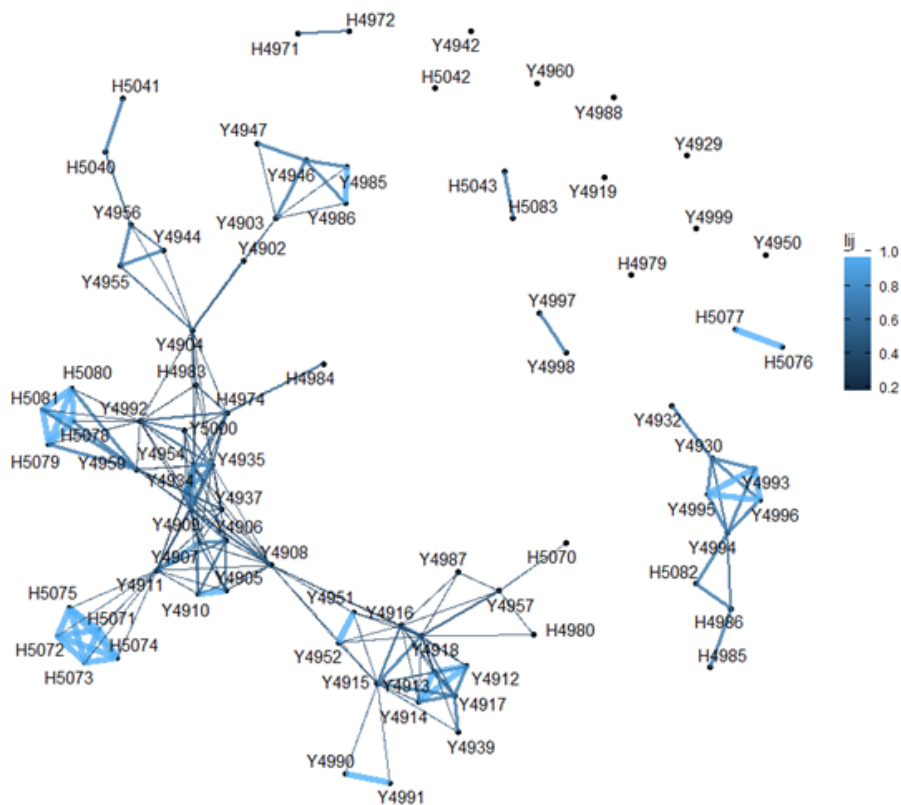


Figure 4: Network analysis of social relationships between female soprano pipistrelle bats. Greater I_{ij} scores are represented by brighter colour and thicker connecting lines between bat nodes, which are labelled with bat ring numbers.

Do female soprano pipistrelles exhibit roost fidelity or mate fidelity?

Comparison of the mean number of significant associations of female soprano pipistrelles to roost boxes and males illustrated that more non-random associations occur between roost boxes, suggesting that females may exhibit some level of roost fidelity, as opposed to mate fidelity (

Table 2). However, the greater volume of data available for roost boxes (as every box was recorded every census), means that roost boxes were observed more than bats, which allows a greater significance to be achieved than when considering associations between male and female individuals.

Table 2: Mean number of significant associations per individual female bat amongst all pairwise comparisons within and between roost box occupation and males.

Season	Index	Mean	Number significant	Number of dyads	Proportion significant (%)	Number of bats
Roost boxes-females	I_{ij}	0.002	100	1440	6.9	80
	χ^2_3	14.82	102	1440	7.0	80
Males-females	I_{ij}	0.711	65	1000	6.5	97
	χ^2_0	0.671	0	1000	0	97

Weighted undirected networks showed that females generally appeared to favour one male, with only a small proportions of females occurring in boxes with multiple different males over time (Figure 5). Increasing thickness and brighter colour of lines represents stronger social bonds, as measured by I_{ij} . Red nodes are female bats, whereas blue nodes are male bats. Bats that do not have connecting lines and are instead single nodes were never seen sharing with bats of the opposite sex.

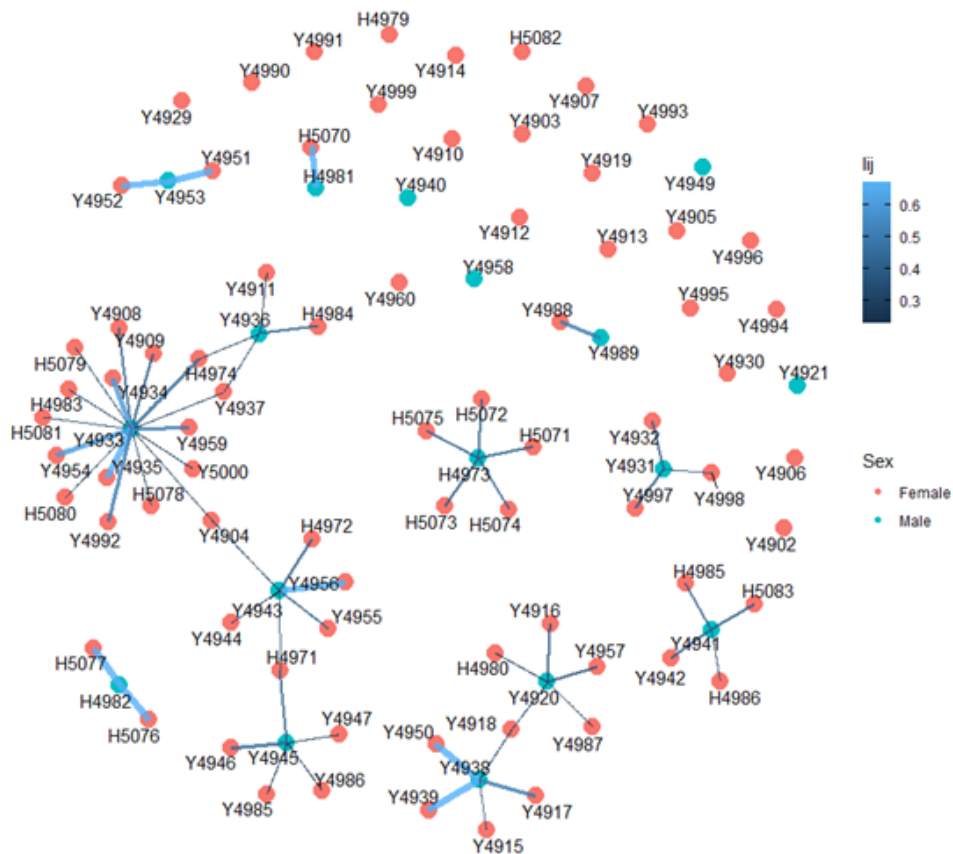


Figure 5: Network analysis of relationships between female (red nodes) and male (blue nodes) soprano pipistrelle bats. Increasing thickness and brighter colour of lines represents stronger I_{ij} scores.

Individual female-male associations appeared to be positively correlated with successive recaptures over multiple years (Mantel test: $r = 0.889$, $p < 0.01$). These associations appear to be marginally stronger than associations between females and roost box clusters, with more females moving between roost box clusters than between males (Figure 6). This may suggest that with more data, mate fidelity would emerge as statistically significant for this species. Females using the Rowan cluster for roosting appeared to have the strongest relationship with this cluster. Most bats seemed to only be loosely associated with roost clusters however. Individual female-roost box cluster associations appeared to be positively correlated with successive recaptures over multiple years (Mantel test: $r = 0.739$, $p < 0.01$), as would be expected.

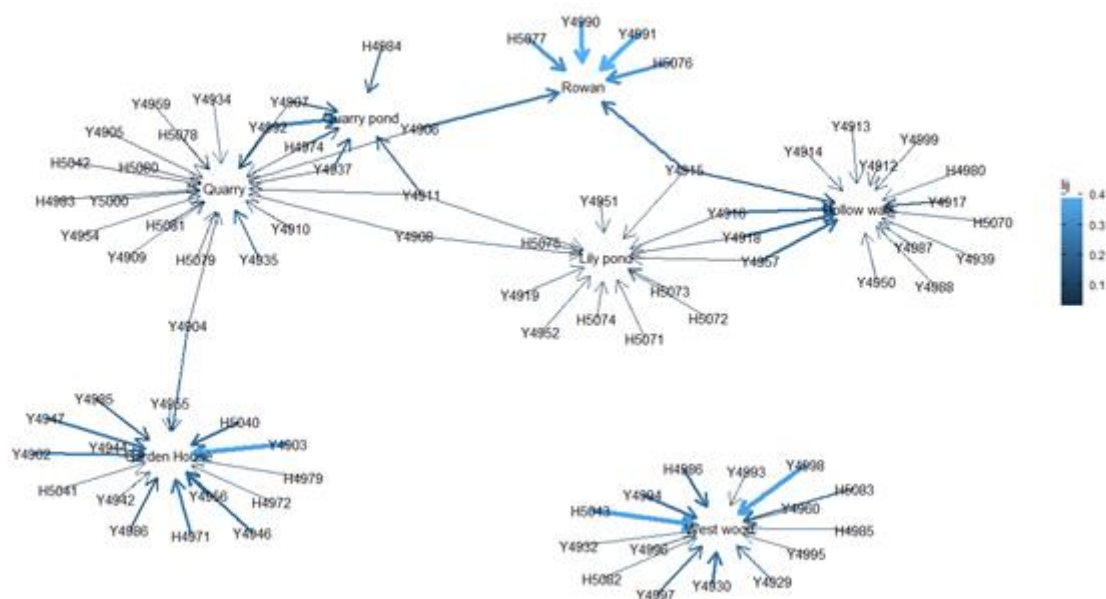


Figure 6: Network analysis of relationships between female soprano pipistrelles and roosting sites. Increasing thickness and brighter colour of lines represents stronger I_j scores.

It is difficult to conclusively identify whether females are exhibiting roost or mate fidelity due to the large overlap in these two variables caused by the extended association between males and territories. Nonetheless, the above network analysis does suggest that one (or a combination of) the two is occurring. The larger amount of data available on roost boxes, which were observed in all 12 surveys, relative to bats, with individuals only observed an average of 4.2 times, explains why statistical significance is achieved more often when considering roost fidelity to mate fidelity in Table 1. More data would be needed to disentangle the two factors.

Is there a significant relationship between male soprano pipistrelles and specific roost boxes during the autumn mating season?

No males were ever observed roosting together (Table 1). During autumn, roost boxes appear to be defended as mating territories (

Table 3). Comparison of the mean number of significant associations per individual soprano pipistrelle between and within the breeding and non-breeding seasons illustrated that non-random associations occur more frequently between males and roost boxes during the breeding season.

Table 3: Mean number of significant associations per individual male bat amongst all pairwise comparisons within and between seasons.

Season	Index	Mean	Number significant	Number of dyads	Proportion significant (%)	Number of bats
Non-breeding	I_j	0.023	4	32	12.5	17
	χ^2	10.083	4	32	12.5	17

Breeding	I_{ij}	0.011	26	306	8.5	17
	χ^2	27.185	27	306	8.8	17

Changes in bat territories may be evident from observing changes in roost box ownership. 25% of roost boxes used by territorial males underwent changes in occupant, suggesting changes in territory. Changes in territorial male occurred in four separate roosting boxes: roost boxes 28, 48, 39 and 31 (Figure 7). Three territorial changes occurred in the latter two roosting boxes (roost box 39: bats Y4921, Y4933, Y4953; roost box 31: bats Y4941, Y4958, H4973).

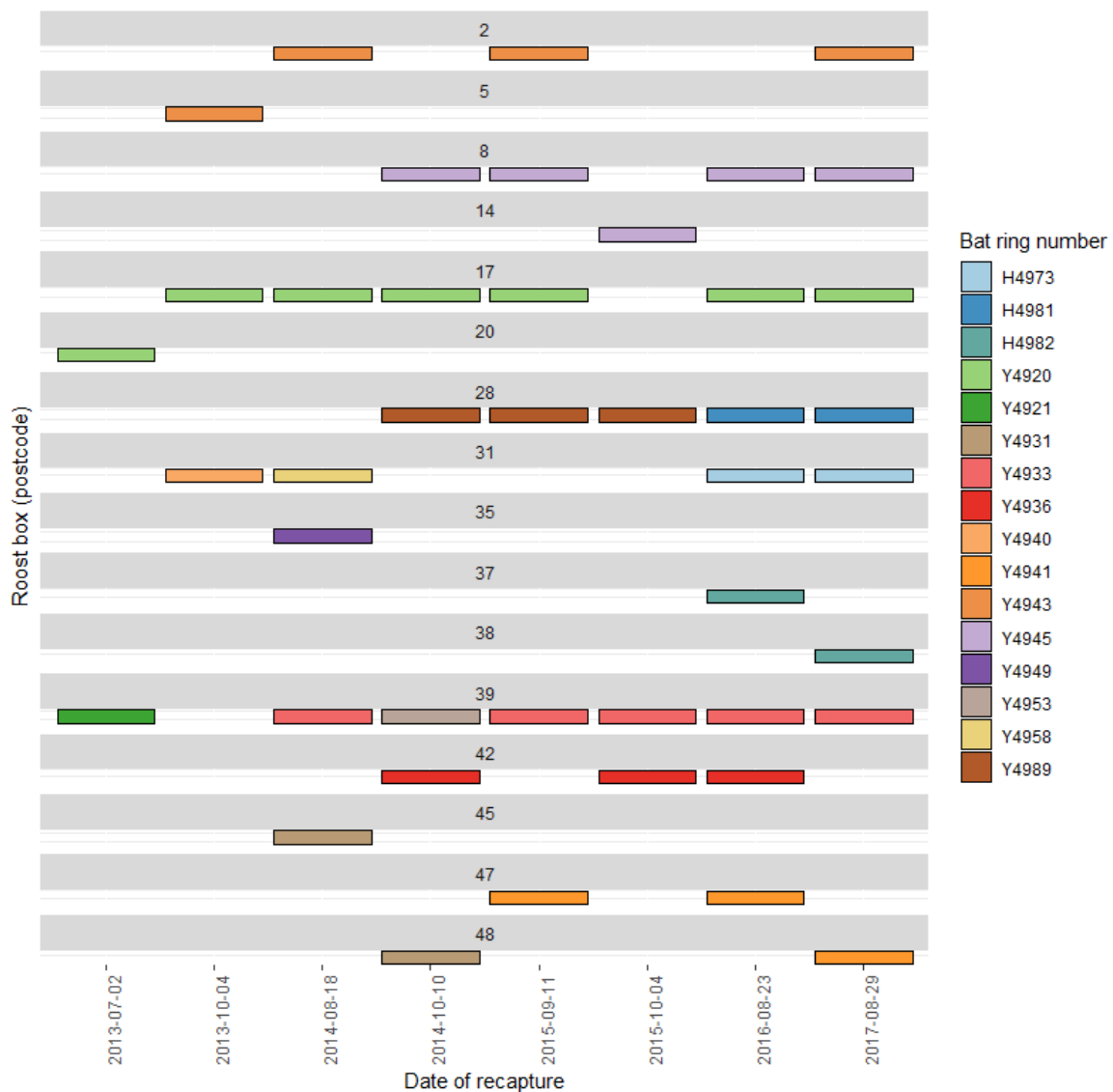


Figure 7: Changes in occupancy of territorial soprano pipistrelle males in roosting boxes during consecutive mating seasons from 2013 to 2017. Each bat is represented by a different colour.

Roost boxes used by males in the mating season were found in close proximity to roost boxes that were not used, suggesting that general habitat may not affect which boxes are chosen as territorial roost boxes. There was no association between roost box orientation

and usage by males ($\chi^2_{(18, n=16)} = 21, p > 0.05$) or box type ($\chi^2_{(9, n=16)} = 12, p > 0.05$) during the breeding season.

Are individuals recaptured in the same cluster of roosting boxes, or is there a significant proportion of roost switching between box clusters?

158 roost boxes were occupied by one or more bats during these inspections, representing an occupation rate of 38.73%. This suggests that there were always empty roost boxes for bats to roost in if desired. The mean return rate of bats to roost box clusters was calculated. The lowest mean return rate of bats observed were individuals to the Lily Pond cluster (51.1%); the highest return rate was to the Quarry cluster at 85.7% (Figure 8). However, standard deviation bars illustrated that there was a large variation for all sites in the return rate of bats, largely as very little capture data is available for many of the seemingly less-preferred sites.

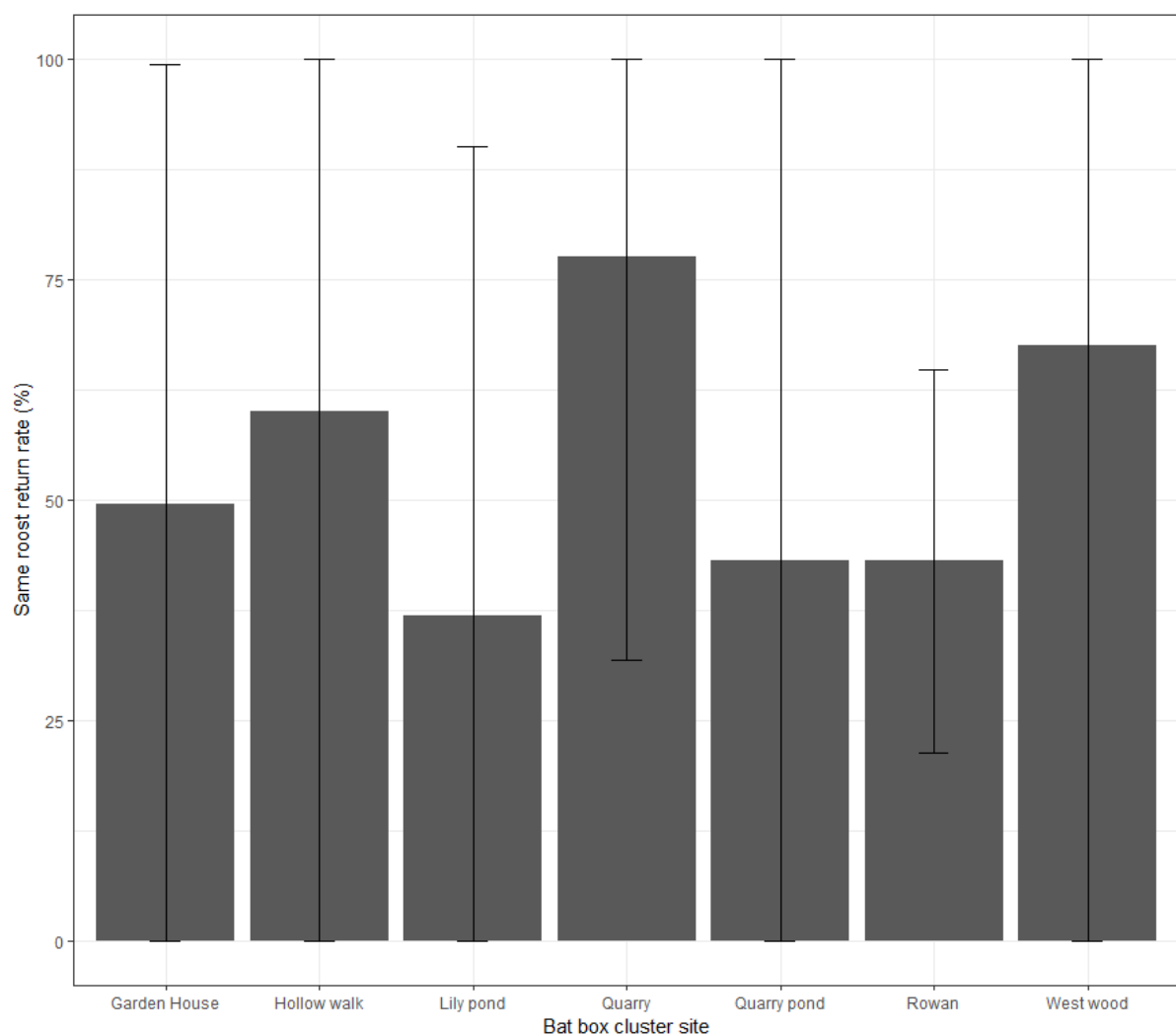


Figure 8: Barplot with standard deviation bars showing the return rate of all bats (%) to clusters of roost boxes.

A one-way ANOVA showed that the usage of sites differed to a statistically significant degree ($F_{(6,70)} = 3.185, Pr < 0.001$). A post-hoc Tukey test indicates that the only significant difference occurred when comparing the roost usage of the Quarry and the Lily Pond roost box clusters, the most and least used clusters.

Roost switching of individual bats between roost box clusters illustrated that many bats chose to remain in the same cluster of roost boxes (Figure 9). Frequently, those bats that moved cluster returned to the roost box cluster they were initially observed in. This may suggest that bats use different roost box clusters during different times of the year due to changing microclimates within roost boxes, which fluctuate in their suitability. Note that two bats (H4974 and Y4992) were observed twice on the 28th April 2015 in two different clusters due to being disturbed from one roost box during census observation and flew into a different roost box that was subsequently checked. In October 2013, half of the boxes were checked on the 4th of the month, and the remaining half on the 8th of the month, resulting in 13 surveys being displayed in Figure 9.

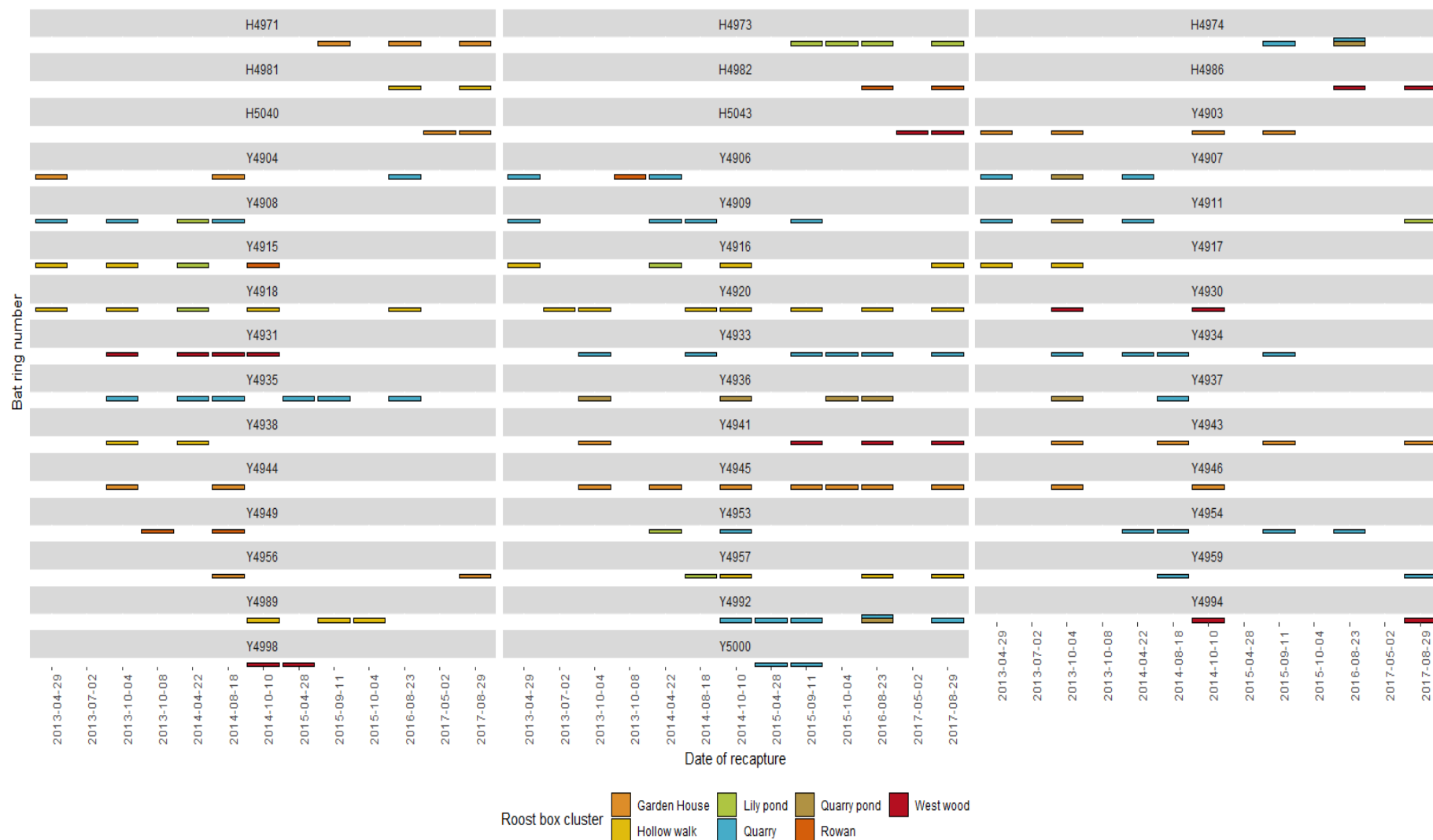


Figure 9: Roost switching of soprano pipistrelle bats observed on more than one census between 2013 and 2017. Different roost box clusters are represented by different colours.

The return rate of bats to individual roost boxes was also analysed. Bats that were only captured once were removed from this analysis to avoid distortion of roost fidelity trends, leaving 44 bats in this analysis. 49% of bats that were observed on more than two occasions were always found in the same roost box. 15 bats were found in two separate roosting boxes and nine bats were found to have moved between three different roosting boxes.

Adjusting the criteria for the minimum number of times a bat was observed from two to three observations caused the trend in roost fidelity to decrease, with more frequent roost switching observed in those bats that were recaptured more often (Figure 10). Bats that were not caught as often may still be exhibiting high roost lability, but were simply not observed, so these results are not conclusive.

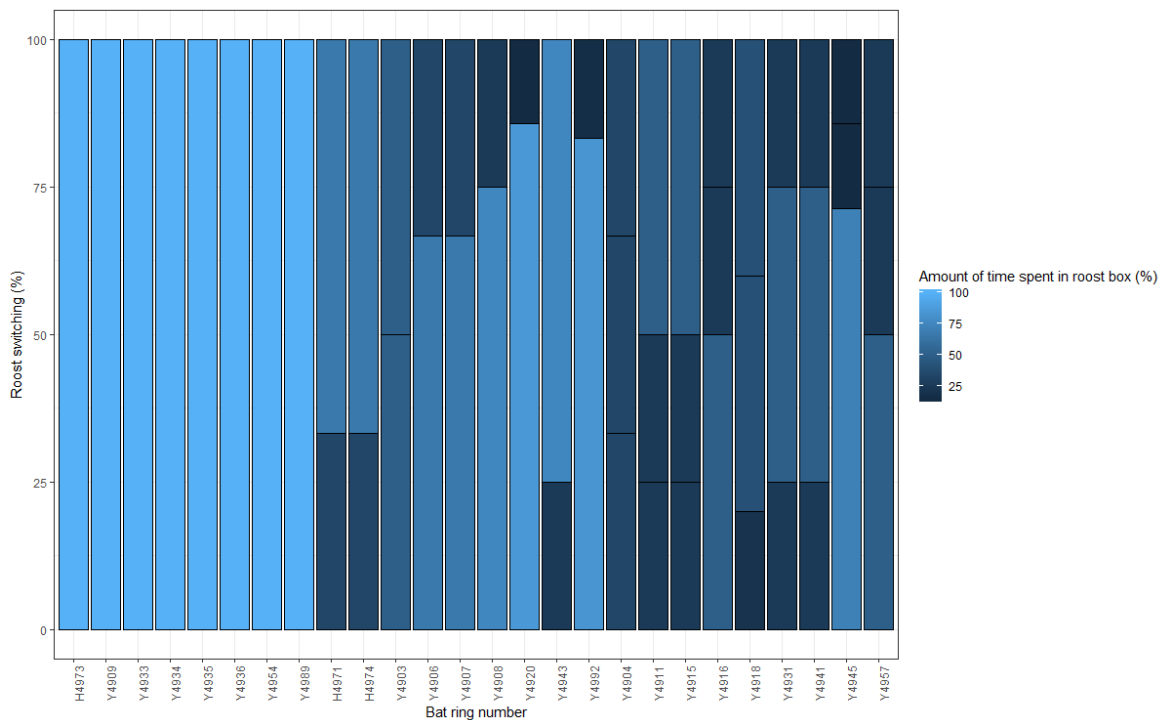
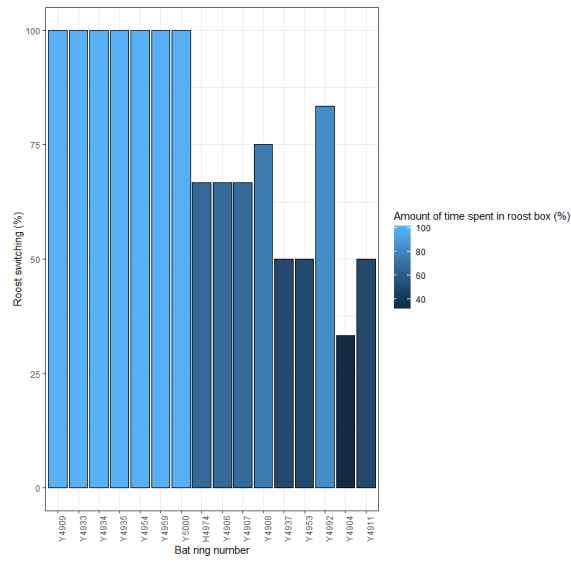


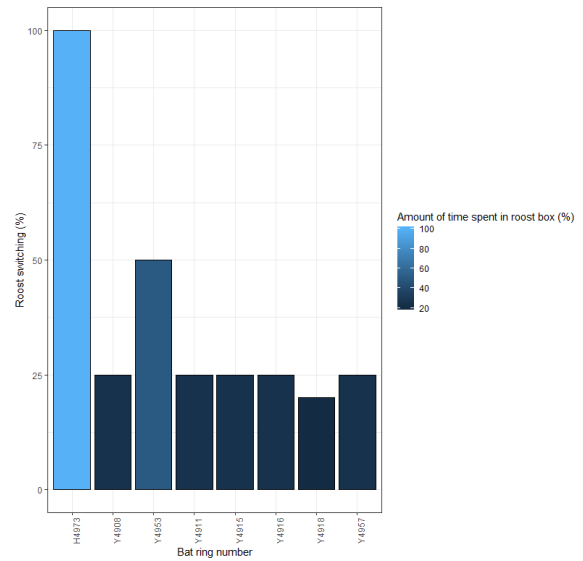
Figure 10: Roost switching rate (%) of bats recaptured more than twice in roosting boxes. Brighter colours represent a greater proportion of time spent by a bat in a unique roost box. Where roost switching has occurred, the bar for that bat is divided into two or three sections, depending on how many switches were recorded. Roost switching bars are proportional to the amount of time spent in each box by the bat.

Clusters with more roost boxes had greater frequency of roost switching within that cluster (Figure 11). Seven bats switched roost boxes within the Garden House cluster over time, which contains 16 roost boxes in total, whereas only two of ten bats switched to different clusters from the Garden House cluster. In contrast, the Lily Pond cluster contains four roost boxes in total, and roost switching from the Lily pond cluster to other clusters occurred in seven out of eight bats that were ever recorded in this area. The eighth bat was only recaptured at the Lily Pond cluster.

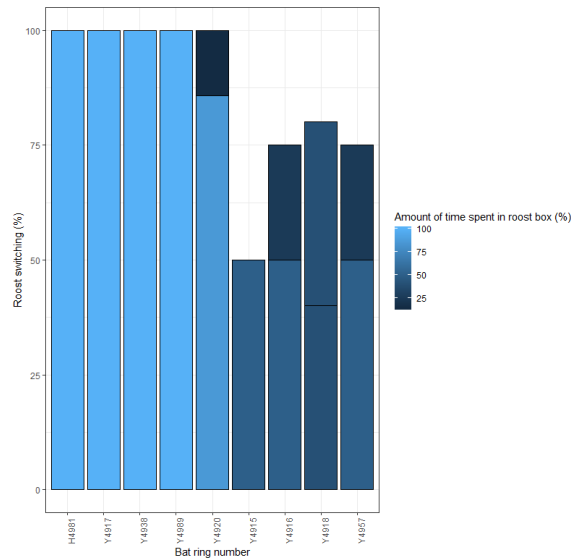
a) Quarry



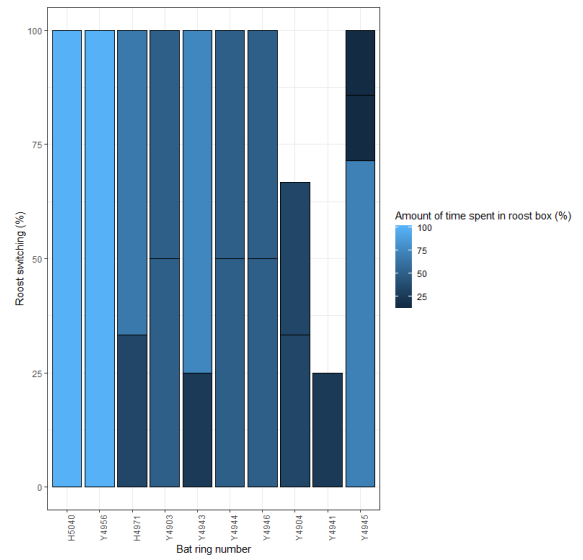
b) Lily Pond



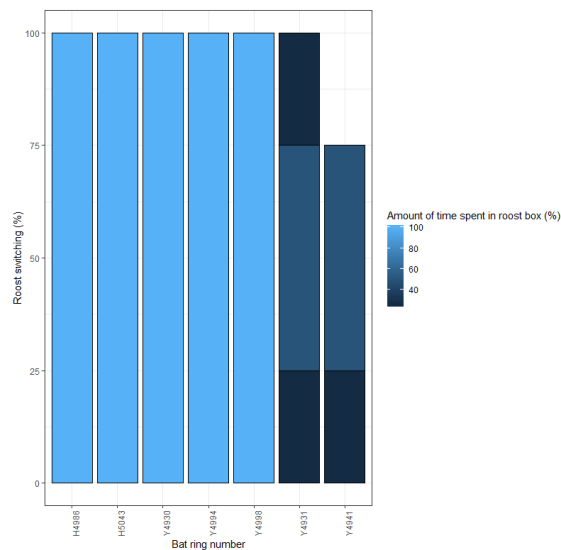
c) Hollow Walk



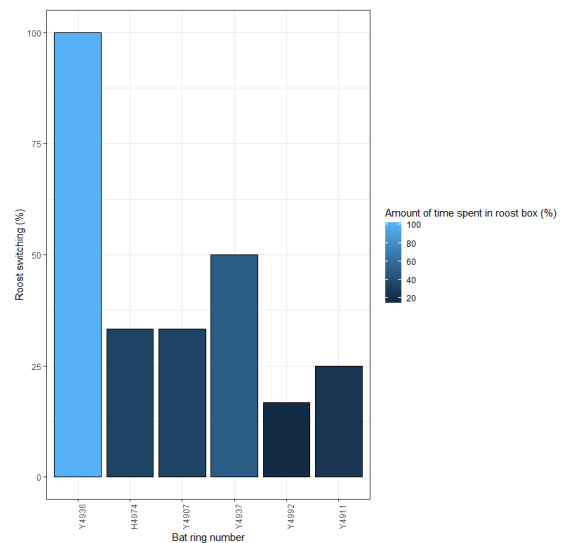
d) Garden House



e) West Wood



f) Quarry Pond



g) Rowan

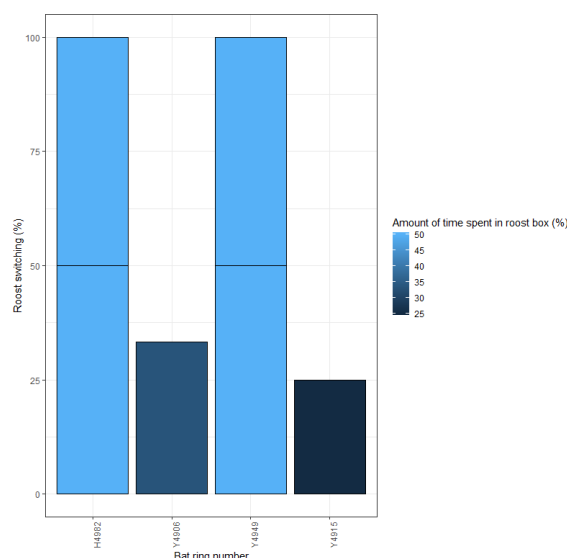


Figure 11: Roost switching rate (%) in each cluster of roosting boxes: a) Quarry; b) Lily Pond; c) Hollow Walk; d) Garden House; e) West Wood; f) Quarry Pond; g) Rowan. Brighter colour represents a greater proportion of time spent by a bat in that roost box cluster. Where roost switching has occurred within a roost box cluster, a bar is divided into multiple sections, proportional to the amount of time spent by the bat in each roost box. Where roost switching has occurred between roost box clusters, bars are shorter, with the bat represented in multiple roost box cluster graphs.

Bats Y4917 and Y4936, found in the Hollow Walk cluster and Quarry Pond cluster respectively on multiple occasions, were recorded having orange mites and eggs around the ears and muzzle. Both these bats were always found in the same roosting box. Bat Y4917 was also found with another bat (Y4914) in April 2013 that had orange mites in roost box 28. However, other bats that also were captured in this box on this date did not have any condition notes relating to mites. Roost fidelity may be related to increased ectoparasite loads, but firm conclusions cannot be drawn due to the lack of records involving mites in this study.

Discussion

Do female soprano pipistrelles roost together because of ‘friendship groups’?

This study showed that when preference for particular roost boxes has been accounted for, female soprano pipistrelles do not roost together with other adult females more often than expected by chance. Soprano pipistrelles still reap benefits from roosting in groups through increased vigilance and improved thermoregulation and decreased risk from predators, due to passive cooperation of individuals within a subgroup. However, additional benefits derived from social bonds, such as information transfer, cannot be proven occur in soprano pipistrelle populations. In Bechstein’s bats, one of the potential reasons cited for a limit to the number of social bonds bats can form may be cognitive restraints, that limit the number and duration of social relationships individuals are able to maintain (Kerth *et al.*, 2011). In this study into soprano pipistrelles, a lack of data may have resulted in the underestimation

of non-random associations between individuals, as only two to three censuses were undertaken per year over a five year period; during these censuses many bats were only found once or twice across all surveys. This may limit the significance of the findings of this study, as only a small proportion of the data could be considered as 'long-term' records of bats seen over multiple years.

Despite this study showing that groups of female soprano pipistrelles appear to be roosting together by chance based upon statistical analysis, multiple small subgroups of females were observed roosting together across censuses through network analysis. These individuals may be exhibiting some level of fidelity to natal colonies that does not emerge as statistically significant due to the aforementioned lack of data. Nepotism within bat colonies has been observed in multiple bat species, where individuals cooperate preferentially with relatives (Patriquin and Ratcliffe, 2016). These small subgroups of females that appear to be preferentially roosting together may be genetically related, with these genetic bonds shaping social bonds. Further research into this population of soprano pipistrelles could focus on understanding the genetic relationships between individuals and whether this is a key factor in roosting patterns of this species. Roosting groups may also be formed of individuals with similar physical characteristics, such as size or reproductive period (Patriquin and Ratcliffe, 2016), due to these individuals requiring similar roosting conditions.

The use of multiple roosting sites by individuals, with splitting and merging of groups over short timescales, in a fission-fusion population structure, may prevent the formation of meaningful long-term relationships. This would mean that twice or thrice yearly surveys cannot detect social groups that form and break up on a much shorter timescale. Bats found in reoccurring groups may be an effect of passive aggregation, with each individual bat attracted to the characteristics of a roost box, rather than the other individuals known to roost in a particular roost box. To better understand the movements of bats, and whether females congregate in 'friendship groups', more censuses could be undertaken each year.

Do female soprano pipistrelles exhibit roost fidelity or mate fidelity?

This study showed that some level of roost fidelity may occur in soprano pipistrelle females. There appeared to be a high roost fidelity to the Rowan and West Wood roost box clusters, despite the mean number of bats within these clusters being relatively low. This may be due to these roost box clusters being furthest away from adjacent roost box clusters. Bats may remain in these clusters to take advantage of nearby foraging areas and reduce commuting distances to these key resources. The Quarry was the most popular roost box cluster, although I_{ij} scores for this roost box cluster were low overall due to the higher total number of bats that chose to move from this cluster to other roost box clusters and the low number of bats that were recaptured at this cluster multiple times.

Mate fidelity may also be evident in soprano pipistrelles, although a lack of data means that it cannot be conclusively said that this species does or does not exhibit mate fidelity. Eleven of the seventeen total males were generally found with multiple females, with only two cases of males found with only one female and four males were found without any females in the same roosting box. One of the males found without any females was a young male, which had been recorded as a juvenile in the previous year (bat Y4949). Mate fidelity benefits females through increased reproductive success, because of decreased energy lost through searching for potential mates and avoidance of inbreeding (DuVal, 2013). To

establish whether females do exhibit mate fidelity, further research involving genetic analysis comparing males to the offspring of mated females over multiple years could be undertaken.

It is difficult to distinguish between whether females exhibit roost or mate fidelity. Male soprano pipistrelles control territories during the breeding season, establishing territories early in the breeding season to assert dominance over prime resources that may be favoured by females. This results in an inherent link between roost and mate fidelity in females that cannot be disentangled without larger datasets. Ultimately, whichever is the case, the social evolution of this species will be the same.

Is there a significant relationship between male soprano pipistrelles and specific roost boxes during the autumn mating season?

Male soprano pipistrelles were never found sharing roost boxes with other males at any time of the year; males only shared boxes with females. Roost boxes were used more by male soprano pipistrelles during the breeding season, suggesting that males may use roost boxes as territories to attract females. Proximity to feeding sites has been cited as a key factor influencing roost choice by pipistrelle bats (Patriquin and Ratcliffe, 2016). As such, male territories may be established from the same roost boxes annually to take advantage of nearby habitat features that attract females to a particular roost box in a resource defence polygyny breeding structure. Soprano pipistrelles are commonly associated with wetland and riparian habitats (Flaquer *et al.*, 2006; Bat Conservation Trust, 2015), and may be preferentially choosing boxes near these habitats to provide shorter commuting distances to foraging sites for potential mates. This may suggest a reason for the high density of males and high frequency of roost boxes that changed between multiple males, in the Hollow Walk cluster. The Hollow Walk cluster is situated close to both a small stream and a larger pond nearby, both of which may provide large volumes of riparian insects to feed on. Conservation for enhancing soprano pipistrelle populations across the estate should include maintenance of key foraging habitats, to enhance bat populations. Soprano pipistrelles appear to favour complex mosaic habitats with open woodlands (Joint Nature Conservation Committee, 2007); management of the Gibside estate could focus on maintaining an open woodland understorey through management of large rhododendron plants present across much of the estate.

In the Hollow Walk, Garden House and West Wood clusters, some trees hosted multiple roost boxes containing territorial males. This may suggest that soprano pipistrelle territories overlap, with the local habitat having an impact on the initial choice of roost box. Females may then choose males from these boxes through following roost or mate fidelity, choosing beneficial fitness characteristics of a male, or favourable internal roost box characteristics. The Hollow Walk cluster is found on the fringe of coniferous plantation trees; future management should focus on enhancing the boundary between beneficial semi-natural deciduous woodland and conifer plantation in this area, to continue to encourage bats to roost in these roost boxes.

Roost boxes that appeared to be used more frequently by female soprano pipistrelles were also roost boxes that appeared to change territories between males more frequently. Males may then be attracted to these roost boxes by high levels of female activity, or for similar roost qualities such as stable thermoregulation and low ectoparasite loads that attract females. On three out of four occasions when roost boxes were used by new males, the

previous male was not observed during a census again. This may be a product of territorial dispute, with a new male forcing the old male out of both his previous territory and the cluster site. This however, does not explain why a previous male is not seen in another roost cluster. A previous male may no longer occupy a roost box due to total emigration of the Gibside estate, or due to fatality during the course of the year, allowing a new male to enter a known breeding territory.

Are individuals recaptured in the same cluster of roosting boxes, or is there a significant proportion of roost switching between box clusters?

Roost lability was observed in this study, with around half of all bats that were captured more than once choosing to move roost boxes. Roost switching may be a product of high roost availability (Lewis, 1995). The Quarry cluster was the roost box cluster with the largest number of bats and also the smallest number of roost boxes. Roost switching from this cluster may be low due to the low availability of roost boxes in the immediate vicinity; bats may see greater benefits from the local habitat to sacrifice any drawbacks to the few roost boxes available.

Bats may also switch roosts to reduce the commuting distance to foraging areas; high roost availability may benefit individuals by allowing bats to forage over a larger area than normal, as there are guaranteed roost boxes spread across the Gibside estate that offer safe, protected sites to roost in, and reduce the commuting distance to new feeding sites. The greater availability of food resources may result in greater reproductive and hibernation success, with lower depletion of food resources due to decreased intraspecific competition between individuals, as bats spread over a larger foraging area. Soprano pipistrelles have been described as a specialist feeder, and may move between multiple small habitats that provide non-biting midge Chironomidae and biting midge Ceratopogonidae larvae that prefer stagnant water (Russ and Montgomery, 2002). To maintain the current soprano pipistrelle populations at the Gibside estate, these small water bodies should be preserved, with areas of wet woodland managed through scrub clearance, to avoid drying out of stagnant water sources by local vegetation.

Roost lability may also be a response to roost ectoparasites. Those bats that were recorded with orange mite ectoparasites did not appear to switch roosts and were often found in the same roost boxes over multiple censuses. Some group members found in a box may not switch roosts if they have different priorities for roost suitability, including parasitism (Patriquin and Ratcliffe, 2016). Roost suitability may be a focus for further research, to understand factors that attract soprano pipistrelles to particular roost boxes, such as box design, thermoregulation or orientation of box. Different individuals may also perceive different costs and benefits to moving from one known roost to another roost with unknown conditions. Although these bats experience ectoparasite build up due to roost fidelity behaviours, the costs of switching roosts are minimised, which may be perceived as outweighing ectoparasite costs. Other individuals that were observed to switch roosts more often did not suffer from ectoparasite build up, but would accrue other costs due to switching roosts. During future roost box censuses, ectoparasite build up could be countered by manual removal of any guano and other debris within roost boxes by bat workers, to maintain cleanliness of boxes and improve overall bat fitness.

A large proportion of individuals were recaptured in the same roost box over multiple censuses, or a roost box in the same cluster as previous recaptures. Bats that practice

roost fidelity may benefit from greater reproductive and hibernation success, through minimising the costs of moving roosts (Lewis, 1995). However, it may be the case that overestimation of roost fidelity trends has arisen in this study where lower numbers of recaptures occur. Roost switching may not yet have been observed in some bats due to these bats moving to natural roost sites, or roost boxes in the nearby area that are not routinely checked. Further research involving more frequent data collection would allow these roosting patterns to be better investigated, and establish whether a proportion of the soprano pipistrelle population do choose to undertake roost fidelity.

Conclusions and recommendations

Project conclusions

Despite the lack of data for some aspects of this study, some tentative conclusions can be drawn from the available data.

- According to statistical analysis, female soprano pipistrelles do not appear to preferentially roost with other females. Network analysis illustrated that small subgroups of females were found on consequent censuses. These individuals may be roosting together due to natal fidelity of mothers and daughters.
- Roost and/or mate fidelity may occur in soprano pipistrelles, although due to the behavioural habit of males establishing similar territories each year, it is difficult to confirm whether females are returning to the same roost clusters or the same males. The social evolution of this species will be the same regardless of whether females exhibit fidelity to mates or roosts, due to the close relationship between males and territories.
- Males were never found roosting with other males, suggesting that roost boxes are used as territories for attracting mates. Roost boxes chosen as territories may be situated close to foraging areas to reduce the time spent commuting and attract females through this beneficial placement. Enhancing these areas through maintenance of understorey woodland areas and conservation of stagnant water bodies may encourage more bats to prime foraging areas and nearby roost boxes.
- Around half the bats recaptured in roost boxes chose to move roost boxes over the course of data collection. This may be a product of high roost availability, and attempts to avoid ectoparasite build up or predators. Those individuals that chose to exhibit roost fidelity over time may do so due to viewing the costs of roost switching as higher than the costs of remaining in a known roost box. Cleaning boxes of guano and ectoparasites by bat workers during bi-annual censuses may reduce the costs of roost fidelity.

Further recommendations

Greater number of samples per year

One of the difficulties in this study was investigating social bonds between individuals, due to limited data per year. This resulted in only a few records of individual bats. Many bats were only recorded once or twice; these individuals may still be using the Gibside estate as a roosting area, although may have been using natural roosts, or roost boxes that were erected but not checked on census days. Increasing the number of census days would permit greater significance levels to be achieved in studies investigating social bonds and

help establish whether fission-fusion population dynamics were occurring over short-term scales as well as long-term scales.

Influence of kinship on roosting patterns

Social bonds between females may form because of genetic similarity, between mothers and daughters. Persistent social bonds between kin have been observed in Bechstein's bats (Kerth *et al.*, 2011) as well as other mammals such as primates and African elephants. Due to the lack of genetic information in this study, kinship cannot be identified as a key driver of social bonds in soprano pipistrelles. Further study into social bonds in this species could reflect this research gap, to understand the influence of kinship. Genetic analysis of offspring of known males over multiple years could also inform research involving mate fidelity of soprano pipistrelles. Long-term breeding patterns could be understood through genetic identification of males, mated females and offspring from consequent years.

Roost characteristics

Roost boxes may differ in their attractivity to soprano pipistrelles due to external factors, such as roost box type or orientation, or internal factors, such as thermoregulatory properties. Research into preferred roost boxes by this species could be undertaken through comparison of new roost boxes with differing factors, such as box type or orientation. Current roost boxes could be further investigated to understand the internal properties that may attract bats over the long-term, through the installation of thermal cameras to understand how the internal temperature and humidity of a roost box changes.

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References

- Bartonicka, T. and Rehak, Z. (2007) Influence of the microclimate of bat boxes on their occupation by the soprano pipistrelle *Pipistrellus pygmaeus*: possible cause of roost switching. *Acta Chiropterologica*, 9 pp.517–526.
- Bat Conservation Trust (2015) *Soprano pipistrelle trends for Great Britain*. [Online] [Accessed 4th July 2018] http://www.bats.org.uk/pages/-soprano_pipistrelle-823.html
- Dietz, C. and Kiefer, A. (2016) *Bats of Britain and Europe*. London: Bloomsbury Natural History.
- DuVal, E. H. (2013) Female mate fidelity in a lek mating system and its implications for the evolution of cooperative lekking behavior. *The American Naturalist*, 181(2) pp.213-222.
- Flaquer, C., Torre, I. and Ruiz-Jarillo, R. (2006) The value of bat-boxes in the conservation of *Pipistrellus pygmaeus* in wetland rice paddies. *Biological conservation*, 128(2) pp.223-230.
- Gardner, M. G., Bull, C. M. and Cooper, S. J. B. (2002) High levels of genetic monogamy in the group-living Australian lizard *Egernia stokesii*. *Molecular Ecology*, 11(9) pp.1787-1794.

Gerell, R. and Lundberg, K. (1985) Social organization in the bat *Pipistrellus pipistrellus*. *Behavioral Ecology and Sociobiology*, 16(2) pp.177-184.

Hale, J. D., Fairbrass, A. J., Matthews, T. J. and Sadler, J. P. (2012) Habitat composition and connectivity predicts bat presence and activity at foraging sites in a large UK conurbation. *PloS one*, 7(3) p.e33300.

Joint Nature Conservation Committee (2012) *European Community Directive on the Conservation of Natural Habitats and of Wild Fauna and Flora Third Report by the United Kingdom under Article 17 Conservation status assessment for Soprano pipistrelle (Pipistrellus pygmaeus)*. Totnes.

Joint Nature Conservation Committee (2016) *UK BAP priority terrestrial mammal species*. UK BAP Priority Species [Online] [Accessed 2nd August 2018] <http://jncc.defra.gov.uk/page-5170>

Joint Nature Conservation Committee (2007) *Second report by the UK under Article 17 on the implementation of the Habitats Directive from January 2001 to December 2006*. Peterborough.

Joint Nature Conservation Committee (2010) *UK priority species pages – Pipistrellus pygmaeus*. Peterborough.

Kerth, G. and König, B. (1999) Fission, fusion and nonrandom associations in female Bechstein's bats (*Myotis bechsteinii*). *Behaviour*, 136(9) pp.1187-1202.

Kerth, G., Perony, N. and Schweitzer, F. (2011) Bats are able to maintain long-term social relationships despite the high fission–fusion dynamics of their groups. *Proceedings of the Royal Society B: Biological Sciences*, 278(1719) pp.2761-2767.

Lewis, S.E. (1995) Roost fidelity of bats: a review. *Journal of Mammalogy*, 76(2) pp.481-496.

Lourenço, S. I. and Palmeirim, J. M. (2004) Influence of temperature in roost selection by *Pipistrellus pygmaeus* (Chiroptera): relevance for the design of bat boxes. *Biological Conservation*, 119(2) pp.237-243.

Mackintosh, M. 2016. *Bats and licensing: a report on the success of maternity roost compensation measures* (No. 928). Scottish Natural Heritage Commissioned Report.

McCracken, G. F. and Wilkinson, G. S. (2000) Bat mating systems. In Crichton, E. G. and Krutzsch, H. P. (eds) *Reproductive biology of bats*. 1st ed., London: Academic Press, pp. 321-362.

Ngamprasertwong, T., Piethney, S. B., Mackie, I. and Racey, P. A. (2014) Roosting habits of Daubenton's bat (*Myotis daubentonii*) during reproduction differs between adjacent river valleys. *Acta Chiropterologica*, 16(2) pp.337-347.

Patriquin, K. J., Ratcliffe, J. M. (2016) Should I Stay or Should I Go? Fission–Fusion Dynamics in Bats. In Ortega, J. (ed) *Sociality in Bats*. Mexico City, pp. 65–104.

Poulton, S. M. (2006) An analysis of the usage of bat boxes in England, Wales and Ireland. Ledbury: The Vincent Wildlife Trust.

R Core Team. (2017) *R: A language and environment for statistical computing*. R Foundation for Statistical Computing.

Rhodes, M. and Jones, D. (2011) The use of bat boxes by insectivorous bats and other fauna in the greater Brisbane region. *In* Law, B., Eby, P., Lunney, D. and Lumsden, L. (eds) *The Biology and Conservation of Australasian Bats*. Mosman: Royal Zoological Society of NSW, pp. 424–442.

Rossiter, S. J., Ransome, R. D., Faulkes, C. G., Le Comber, S. C. and Jones, G. (2005) Mate fidelity and intra-lineage polygyny in greater horseshoe bats. *Nature*, 437(7057) p.408.

Russ, J. M. and Montgomery, W. I. (2002) Habitat associations of bats in Northern Ireland: implications for conservation. *Biological Conservation*, 108(1) pp.49-58.

Stone, E. L., Harris, S. and Jones, G. (2015) Impacts of artificial lighting on bats: a review of challenges and solutions. *Mammalian Biology*, 80(3) pp.213-219.

Stow, A. J. and Sunnucks, P. (2004) High mate and site fidelity in Cunningham's skinks (*Egernia cunninghami*) in natural and fragmented habitat. *Molecular Ecology*, 13(2) pp.419-430.

Wilkinson, G. S. (1985) The social organization of the common vampire bat. *Behavioral Ecology and Sociobiology*, 17(2) pp.123-134.

Appendix 1: The symmetrical index of Fager and χ^2 -statistic.

The symmetrical index of Fager (I_{ij}):

$$I_{ij} = \frac{2N_{ij}}{(N_i + N_j)}$$

N_i - Number of censuses on which bat i was observed

N_j - Number of censuses on which bat j was observed

N_{ij} - Number of times bat i and bat j were observed roosting in the same roost box

This is tested using the t -statistic with infinite degrees of freedom, to understand whether associations occurred by chance:

$$t = \frac{(N_i + N_j)(2N_{ij} - 1)}{(2N_iN_j - 1)(N_i + N_j - 1)}$$

The χ^2 statistic was then used to discriminate between passive attraction of bats to roost boxes and active attraction to individuals within a roost box, by estimating the expected number of times two bats should be seen together if random visiting of roosts occurred, in proportion to the number of times they were observed.

$$X^2 = \frac{(N_{ij} - \sum_{K=1} P_{ik}P_{jk}T)^2}{\sum_{K=1} P_{ik}P_{jk}T}$$

N_{ij} - Number of times bat i and bat j were observed roosting in the same roost box

P_{ik} - The proportion of observations that bat i spent in roost box k, tested using one degree of freedom

P_{jk} - The proportion of observations that bat j spent in roost box k, tested using one degree of freedom

T - The smaller of N_i or N_j generated from the symmetrical index of Fager

K - Total roost boxes involved in equation

Appendix 2: Adapted symmetrical index of Fager and χ^2 -statistic formula to assess association of bats to individual roost boxes.

The adapted symmetrical index of Fager (I_{ij}):

$$I_{ij} = \frac{2N_{ij}}{(N_i + N_j)}$$

N_i - Number of censuses on which bat i was observed

N_j- Number of censuses on which a roost box was monitored (always 12 in this research, as each box was checked each census)

N_{ij}- Number of times bat i was observed roosting in a particular roost box

The adapted χ^2 statistic:

$$\chi^2 = \frac{(N_{ij} - \sum_{K=1} P_{is} P_{rs} T)^2}{\sum_{K=1} P_{is} P_{rs} T}$$

N_{ij}- Number of times bat i was observed roosting in a roost box

P_{is}- The proportion of surveys that bat i was observed, tested using one degree of freedom

P_{rs}- The proportion of times that a roost box was observed (always 1 in this research, as each box was checked in every census)

T- The smaller of N_i or N_j generated from the symmetrical index of Fager

K- Total roost boxes involved in equation

Appendix 3: The percentage of individual roost box usage per individual bat

$$U_{ij} = \frac{N_{ij}}{T_i} \times 100$$

U_{ij}- Percentage usage of roost box j by bat i (%)

N_{ij}- Number of times bat i was observed roosting in roost box j

T_i- Total recaptures of bat i

Understanding the roosting niche use of artificial bat boxes as further evidence of resource partitioning in two cryptic *Pipistrellus* species.

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Abstract

For a long time it was assumed that cryptic bat species, being similar in morphology, share a similar ecology. However recent studies have shown levels of resource partitioning in the habitat type and feeding strategies employed by two cryptic *Pipistrellus* species. The results of artificial roost box schemes at four sites across East Yorkshire were analysed to determine whether two cryptic *Pipistrellus* species exhibited differing roosting niches through selection preferences for different types of roost box. Both species displayed some levels of avoidance of certain types of box models and varying amounts of usage in others. The data suggest clear niche segregation between the two species that does not vary dramatically over time.

Introduction

Cryptic species are defined as being similar in morphology, so much so that they are often indistinguishable to the human eye, whilst also remaining reproductively quarantined from one another (Aldridge, 1987; Mayr, 1970). Cryptic species amongst bats are not uncommon (Jones and Barlow, 2004) and the similarities in morphology make them ideal taxa in relating differences in physiology to ecological resource partitioning (Parsons *et al.*, 2003). The common pipistrelle *Pipistrellus pipistrellus* and the soprano pipistrelle *P. pygmaeus* were formally separated into two species in 1999, and since then a number of studies have emerged confirming resource partitioning between these two species exists in the form of habitat selection (Nicholls and Racey, 2006; Davidson-Watts *et al.*, 2006; Scott *et al.*, 2010) and foraging strategy (Barlow, 1997; Davidson-Watts and Jones, 2006) with soprano pipistrelle tending to favour riparian habitat and food sources. Morphological differences between cryptic species is becoming increasingly less important as indicators of differences in ecology between taxa (Davidson-Watts *et al.*, 2006), therefore understanding the resource partitioning of threatened cryptic bat species at the mesoscale is of paramount importance for the implementation of future conservation schemes.

Both biological and environmental parameters have a huge influence in the selection preferences of roosting ecology (Alcock, 1998; Kerth *et al.*, 2001). In the UK, bats use natural cavities, including trees hollows and gaps behind bark (Kunz, 1982), as well as synthetic ones, such as holes in buildings (Baranaukas, 2007) for roosting. Whilst habitat is of key importance, resource partitioning, in the form of roost boxes, between cryptic *Pipistrellus* bats has never previously been investigated. This is of particular significance when habitat overlaps occur between cryptic species (Parsons *et al.*, 2003) and the study of resource partitioning and morphology can lead to developments in conservation biology of cryptic species.

The provision of artificial roosts in the form of bat boxes is a conservation method currently widely in practice across Britain. Despite having been used for the best part of a century as a

conservation method, there is growing concern about the efficacy of bat boxes as a conservation tool for their role in the potential for bat species that commonly use the boxes to gain a competitive advantage over other species (Griffiths *et al.*, 2017; Ruegger, 2016). Despite this, bat boxes offer alternative roosting sites in areas where only limited natural sites occur, drawing bats away from human activity and mitigating potential conflict (Brittingham and Williams, 2000), whilst also allowing the study of bat populations in high detail (Boyd and Stebbings, 1989; Kerth *et al.*, 2001).

Currently the literature reviews selection preferences of roost boxes based on physical aspects; such as location, orientation (Dodds and Bilston, 2013) and temperature (Flaquer *et al.*, 2006; Lourenco and Palmeirim, 2004). Dodds and Bilston (2013) reported that the location of the roost box itself was the most important factor in selection. The same study revealed that Natterers bats *Myotis nattereri* showed bias towards the Schwegler Woodcrete 2F (Woodcrete being a model consisting of a mix of wood and concrete) over other Schwegler Woodcrete box models 2FN, 1FS and 1FF, and that brown long eared bats *Plecotus auritus* preferred the 1FS boxes featured within their study site in Buckinghamshire (Dodds and Bilston, 2013). Work conducted by the Vincent Wildlife Trusts also confirm that there is some apparent preference for some boxes by different bat species (Poulton, 2006). Few studies in the literature examine species specific preferences to artificial bat boxes over long-term studies and this study aimed to establish knowledge of the most suitable box types for the two cryptic *Pipistrellus* species in the UK; common pipistrelle and soprano pipistrelle with this information potentially a valuable element for future box design in conservation implementation (Ruegger, 2016).

Methodology

Study Sites

This study was conducted using previously collated data from four separate bat box schemes conducted by East Yorkshire Bat Group (EYBG). The locations of the sites and individual survey lengths are described in Table 1.

Table 1: Description of study sites and location for each area featured within bat box surveys by East Yorkshire Bat Group.

Site	O.S Grid Reference	Description of Site	Dates of Survey	Size of Site (hectares)
Allerthorpe Woods	SE 752478	Mixed woodland. Dominated by Pine species.	03/10/1997 27/09/2015	- 148.69
Wheldrake Woods	SE 659468	Dominated by Pine species	26/11/1994 18/10/2015	- 116.00
Millington Wood	SE 838530	Dominated by Ash species.	12/04/1997 26/09/2015	- 21.04
Tophill Low Nature Reserve	TA 073486	Two large reservoirs surrounded by a variety of woodland ecotopes.	13/09/1992 04/10/2015	- 121.40

Allerthorpe Woods

A mixed plantation, composed mainly of pine, but large areas of oak and other species. Part of the area is leased by the Yorkshire Wildlife Trust as a nature reserve. It is highly managed in order to ensure the high levels of biodiversity are maintained (The Forestry Commission, 2019a).

Wheldrake Woods

A small wood close to the city of York, this largely coniferous area consists mainly of Scots pine *Pinus sylvestris*, larch and spruce trees although also features some oak and birch. It was planted and is owned by The Forestry Commission (The Forestry Commission, 2019b).

Millington Wood

A Site of Special Scientific Interest (SSSI) designated for both its Geological and Biological interests. This wood is dominated by ash trees (East Riding of Yorkshire 2016), although in the 1960's the area was used for commercial forestry and saw the introduction of beech, and Norway spruce *Picea abies*, in large parts of the wood.

Tophill Nature Reserve

This Nature Reserve is an active Yorkshire Water treatment site, with two large reservoirs dominating the reserve. However it also features a variety of ecotopes including grasslands, marshes, ponds and woodland and is well known for its high biodiversity (Yorkshire Water, 2019).

Methods

Boxes were erected by the East Yorkshire Bat Group after a premeditated habitat transect walk to establish ideal locations (Figure 1.).



Figure 1: Series of bat box checks by East Yorkshire Bat Group throughout the sites. Box checks were conducted by relevantly licensed individuals. Boxes were placed high enough off the ground to prevent predation of bats by ground predators such as cats and foxes, as well as vandalism.

All boxes were established in accordance with guidelines laid out by the Joint Nature Conservation Committee (Joint Nature Conservation Committee, 2007; Entwistle *et al.*, 2001; Stebbings and Walsh, 1991) with roost boxes purchased through a grant awarded by the British Ecological Society. For analysis, the various box models throughout the study were grouped into four categories, as shown in Table 2.

Table 2: Summary of the bat box categories featured within the study.

Box Type	Description
Standard Design	A variety of different shapes and sizes, mostly handmade and donated to EYBG by various other groups, including a local school. Entrance holes vary in size and location on the box. Constructed from wood.
Flat Warwickshire Design	A flat box model designed originally by the Warwickshire Bat Group. The slim internal dimensions prevent usage by birds but the relatively large height of this box can accommodate large numbers of bats. The entrance slit is located at the bottom of the box. Bat species of small to medium size are the target occupants.
Woodcrete Designs	Termed 'woodcrete' due to the combination of wood and concrete as construction materials. Multiple box models by Schwegler (2019). Generally domed and round boxes that closely replicate natural roosts. Entrance holes usually found in the front and at the back of each model. Rough texture allows for extra grip.
Combination Boxes	Combinations of different style box, most commonly a standard design attached to a flat Warwickshire. Internal volumes and entrance hole number and location widely varied.

Individual box location, tree type the box was positioned on and orientation was recorded. However, this data was not consistently updated with the erection of new boxes, and so this data was omitted from the study. For this study boxes were grouped into four basic categories. When boxes were deemed irreparable the box number was removed from the list and replacement boxes installed. Surveys were conducted biannually at variable months before and after each summer throughout the years of the study's operation, with individual surveys lasting for approximately two to three hours.

Ethical Considerations

Bat box checks were carried out by suitably licensed individuals of East Yorkshire Bat Group, and evidence of bat usage was recorded according to relevant guidelines and literature. This included, where possible; box number and corresponding box type, bat droppings (Agnelli *et al.*, 2010; Bat Conservation Trust, 2018) as well as deceased individuals or skeletal remains (Meddings *et al.*, 2011). Bat individuals were captured where possible and species, gender and the number of specimens logged. Bird presence was also recorded in the data gathering, either by established nests, individuals, eggs and/or droppings (Baranauskas, 2007). Other organisms recorded when present were wasps and hornets where nests had been established. Any damage to boxes caused by squirrels (Juškaitis, 1999) and woodpeckers, was also recorded (Baranauskas, 2007). Boxes that contained large gatherings of bats were often subjected to estimation, in order to minimise disturbance.

Statistical analysis

Data was obtained in the form of field notebooks, which had vague descriptions of box type, specifically the woodcrete boxes. These were later classified under the Schwegler model number according to an email from a member of the bat group (Wilson, 2017).

A chi square test for association was used to test for any significant preferences of individual species and certain box types in order to reveal any selection preferences (Dytham, 2003), using SPSS 25 (IBM Corp, 2017) The analysis and all associated statistical significance was conducted to a 95% significance level (Fowler *et al.*, 1998). Whilst 'preferences' were determined through differences in observed counts, conclusive selection for a box type, is difficult to conclude.

Results

The total numbers of each *Pipistrellus* species at each site in this study suggest clear niche segregation between the two species that does not vary dramatically over time. Common pipistrelle is dominant at Millington Wood and Wheldrake Wood and soprano pipistrelle is dominant at Tophill Low and Allerthorpe Wood (Figure 2). The presence of both species at the same site in the same year only occurs in 23% of the data; more commonly occurring at sites with fewer total bat numbers.

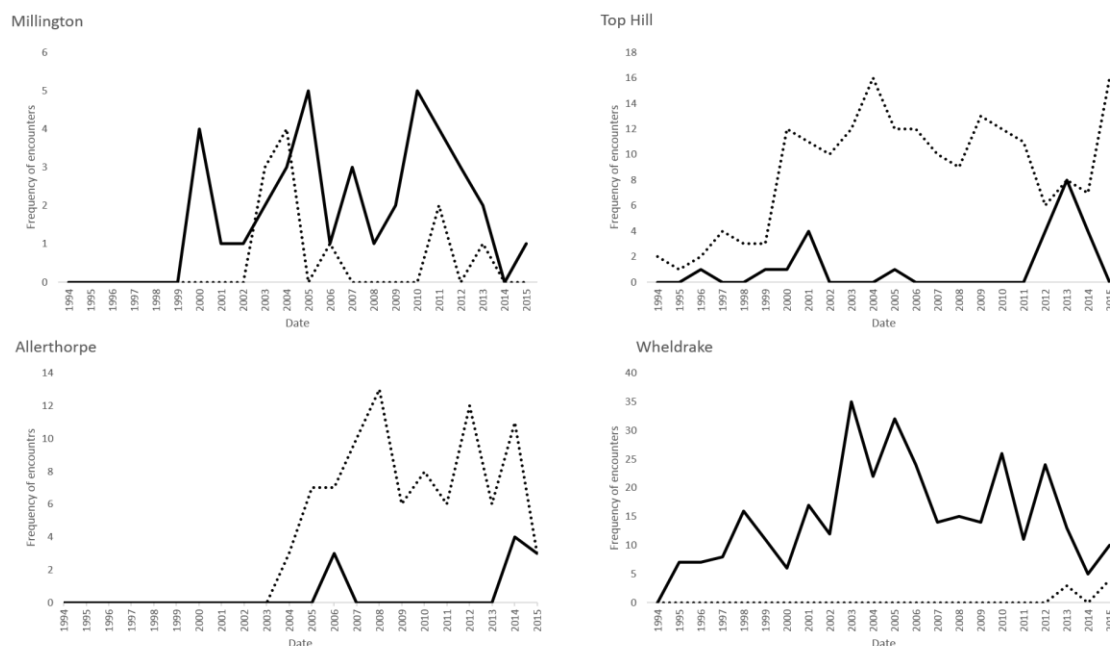


Figure 2. *Pipistrellus* counts at the four sites across the 26 years of study. Solid lines indicate common pipistrelle counts and dashed lines indicate soprano pipistrelle counts. Not all sites were surveyed for the whole time period. Records start in 1994 for Tophill, 1995 for Wheldrake, 2000 for Millington and 2004 for Allerthorpe.

Preferences for boxes were determined by the observed frequency values being significantly higher (or lower in the cases where species avoided certain box types) than the expected result (Waite, 2000). The occupation of boxes by both common pipistrelle and soprano pipistrelle was significantly different between box type (Chi-squared tests $X^2 = 282.953$, $df = 3$, $P < 0.001$) and ($X^2 = 199.953$, $df = 3$, $P < 0.001$) respectively. Common pipistrelle displayed a significant association for Flat Warwickshire boxes (Observed Value = 178.228, Expected Value = 116.75), whilst avoiding the Combination style boxes (Observed value = 10, Expected Value = 116.75). Soprano pipistrelle, on the other hand, showed a significant association for Standard boxes (Observed = 240, Expected = 152.75) and Woodcrete boxes (Observed = 206), whilst also avoiding usage of the Combination boxes (Observed value = 11, Expected value = 152.75).

Discussion

Differences between Sites

Using morphology to understand the ecology of different species is a conservation technique that has proved successful in the literature (Luo *et al.*, 2019; Voigt *et al.*, 2017). However whilst morphologically similar, the two cryptic *Pipistrellus* species exhibit different habitat selection preferences (Davidson-Watts *et al.*, 2006), with the literature recognising common pipistrelle as a generalist (Wickramasinghe *et al.*, 2003), foraging in a large number of different habitats and soprano pipistrelle as a specialist forager of riparian habitats (Vaughan *et al.*, 1997; Russ and Montgomery, 2002). Riparian vegetation contains a higher density of insects than in other ecotopes (Warren *et al.*, 2000), including aquatic insect larvae of the Nematoceran families: Chironomidae and Ceratopogonidae. Barlow (1997) reports these as a main food source of soprano pipistrelle. However, common pipistrelle feeds mainly on the Psychodidae and Muscidae flies, whose larvae is found in the damp leaf litters of areas such as deciduous woodland (Barlow, 1997) and managed coniferous forest (Coyler and Hammond, 1951). Millington Wood comprises mainly of deciduous trees, with some conifers, and common pipistrelle was found at the site in higher abundances than soprano pipistrelle. This is possibly resultant of the distribution of prey species found in differing habitats. Wheldrake Wood, conversely, is made up largely of managed coniferous trees, but features some oak and birch. Again, the dominance of common pipistrelle here suggests as selection for a habitat of mixed tree species, potentially related to prey choice (Wickramasinghe *et al.*, 2003).

The Tophill Low Nature Reserve site best exhibited riparian ecotopes and may explain the large numbers of soprano pipistrelle found there, featuring two large reservoirs and multiple other water bodies. Whilst water bodies were present at both Allerthorpe and Wheldrake to a degree, they did not exist on other sites at the same scale as at Tophill Low. The site also revealed low numbers of common pipistrelle in comparison to soprano pipistrelle (55 to 390 individuals encountered respectively). Exclusion by *Pipistrellus* species from habitat and foraging ranges has been hinted in the literature, with studies in Scotland showing little overlap in foraging areas of adjacent colonies of the two cryptic species (Le Comber *et al.*, 2006). Allerthorpe, the other site where soprano pipistrelle was dominant, also has a network of water bodies in the form of interconnecting ponds and pools, whilst Wheldrake also offers a riparian environment as a wetland due to the river Derwent's seasonal flooding, it is not on the same scale as either Allerthorpe or Tophill Low. In the study sites where *Pipistrellus* species were found, one of the two cryptic species would dominate in the number of bats observed in boxes,

supporting evidence that the two cryptic *Pipistrellus* species may exclude one another from foraging ranges (Davidson-Watts *et al.*, 2006). Boxes in Tophill Low and Allerthorpe Woods observed more occupancy by soprano pipistrelle than common pipistrelle, and vice versa for the other two sites (low numbers of soprano pipistrelle, high numbers of common pipistrelle). This is a factor that should be considered in future when laying foundations for conservation projects or citizen science.

Species usage of Bat Boxes

There are clear associations between differing bat box types and the species that use them. Mering and Chambers (2014) describe how boxes that mimic a specific species' natural roost preferences are the most successful. Species whose natural roosts are flattened cavities, such as those found beneath exfoliated tree bark, selected artificial roosts that were flattened, and those that naturally roosted in natural tree hollows, such as those excavated by woodpeckers and other birds, preferred rounder, more open artificial roost boxes (Kerth and Dechmann, 2009).

Commonly seen in both *Pipistrellus* species was the reoccurrence of single males within the roost boxes, although harems of a large number of females and a single or multiple males were also occasionally seen, suggesting that the boxes may also be used as mating sites (Kasprzyk and Ruczynski, 2001). Both *Pipistrellus* species are known to regularly roost in the crevices on the exteriors of buildings in large colonies (Kowalski *et al.*, 2001), and as such, smaller boxes are probably inappropriate for such large groups of these bats. Temperature may also be a key factor and Brittingham *et al.* (2000) states that only boxes that receive seven or more hours of direct sunlight were successful in attracting maternal colonies for housing displacement. Temperature measurements within boxes would need to be taken to establish any correlations between box types and the effect of temperature on maternal colonies. Analysis of gender would also be beneficial in determining whether the box composition is influenced by gender preference. For females the size of the cavity may influence the attractiveness, where a larger cavity greatly increases the attractiveness (Ruczynski and Bogdanowicz, 2005). By providing larger boxes this may provide more opportunity for larger cluster sizes of maternity colonies. The larger the colony, subsequently the less energy expenditure due to shared thermoregulation (Russo *et al.*, 2017).

Evidence for exclusion between the two cryptic *Pipistrellus* species is shown through the differences in roost box usages. Common pipistrelle and soprano pipistrelle both used all types of boxes within the study, however the two species were more readily discovered using different box types, with Flat Warwickshire boxes more often occupied by common pipistrelle, and both Woodcrete and Standard box types utilised more frequently by soprano pipistrelle. Similarly, a study by Northumberland Bat Group from 2013-2015 found that soprano pipistrelle used the Standard style boxes more than others (Makepeace, 2015). Of the individual Woodcrete boxes used by soprano pipistrelle, the most commonly used model was the 1FD model, a flatter box specifically designed for smaller bats (Schwegler, 2019), whilst the 2F was also utilised by the species in a high proportion. Both species showed an active avoidance of the Combination style boxes. These boxes comprised of the combination of two different box types joined together, usually the Standard attached to a Flat Warwickshire box, offering multiple entry holes and a large interior volume. Both of these types of boxes are made primarily from wood, and as such are particularly vulnerable to damage by squirrels, woodpeckers and weathering. Such damage often results in cracks and failures in the wood,

which can lower the core temperature of the boxes interior and prove unfavorable to bats (Baranauskas, 2009), possibly explaining an avoidance of this box style.

Accounting for Error

Boxes were subjected to changes in location as they were removed or replaced, due to damage or following tree felling or similar works or new boxes added. Documentation of new box locations was not always recorded and so it is assumed that these boxes were erected locally unless otherwise indicated. This has resulted in the particular difficulty of being unsure if our box preference values are the result of uneven distribution of different box types across sites. Whilst some initial statistics have been conducted to clarify this issue, we cannot totally confirm that preference values above are wholly representative of decisions made by the bats. Whilst factors such as orientation and type of tree that the box was placed on were originally recorded, this data was not continuously updated. There was also a large number of bat specimens recorded which were not identified to species, with an overall total of 6.7% of all bats across all four survey sites unidentified.

Conclusions

Our data suggest that cryptic *Pipistrellus* species niche segregation extends beyond habitat choice to roosting preferences. Consistently with previous studies, soprano pipistrelle was found in higher abundances at sites with standing water bodies and supports evidence that the two exclude each other from foraging ranges (Davidson-Watts *et al.*, 2006). Differences in artificial roost preference between species may be related to position of the access hole, temperature and box type, but further study is required. More broadly, a diversity of artificial roost types that replicate natural roosting sites may be key to maximising bat biodiversity, even among phylogenetically and physiological similar species. Due to the dissemination of this study in the form of a dissertation for a Bachelors level degree, the zero data was excluded to examine specific usage of bat boxes by certain species. In the event of further study the inclusion of this data to perform selection indices such as the Ivlevs electivity index (Ivlev, 1961) would be beneficial. Long-term studies such as this are of high conservational importance and establishing updated guidelines enables the maximum reward from both Academic and Citizen Science based Bat Monitoring Programmes.

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References

- Agnelli, P., Maltagliati, G., Ducci, L. and Cannicci, S. (2010) Artificial roosts for bats: education and research. The “Be a bat’s friend” project of the Natural History Museum of the University of Florence. *Hystrix Italian Journal of Mammalogy*, 22 pp. 215-223.
- Alcock, J. (1998) *Animal behavior: an evolutionary approach*. 6th ed., Sunderland, Massachusetts: Sinauer.
- Aldridge, H. D. J. N. and Rautenbach, I. L. (1987) Morphology, echolocation and resource partitioning in insectivorous bats. *The Journal of Animal Ecology*, pp. 763-778.
- Baranauskas, K. (2007) Bats (Chiroptera) found in bat boxes in southeastern Lithuania. *Ekologija*, 53(4) pp. 34-37.
- Baranauskas, K. (2009) The Use of Bat Boxes of Two Models by Nathusius' Pipistrelle (*Pipistrellus nathusii*) in southeastern Lithuania. *Acta Zoologica Lituanica*, 19(1) pp. 3-9.
- Barlow, K. E. (1997) The diets of two phonic types of the bat *Pipistrellus pipistrellus* in Britain. *Journal of Zoology*, 243(3) pp. 597-609.
- Bat Conservation Trust. (2018) Bat Conservation Trust. [Online] [Accessed 3rd December 2018] <http://www.bats.org.uk/index.php>
- Boyd, I. L. and Stebbings, R. E. (1989) Population Changes of Brown Long-Eared Bats (*Plecotus auritus*) in Bat Boxes at Thetford Forest. *Journal of Applied Ecology*, 26(1) pp. 101–112.
- Brittingham, M. and Williams, L. (2016) Bat Boxes As Alternative Roosts For Displaced Bat Maternity Colonies. *Wildlife Society Bulletin*, 28(1) pp.197-207.
- Coyler, C. N. and Hammond, C. O. (1951) *Flies of the British Isles*. London: Warne.
- Davidson-Watts, I. and Jones, G. (2006) Differences in foraging behaviour between *Pipistrellus pipistrellus* (Schreber, 1774) and *Pipistrellus pygmaeus* (Leach, 1825). *Journal of Zoology*, 268(1) pp.55-62.
- Davidson-Watts, I., Walls, S. and Jones, G. (2006) Differential habitat selection by *Pipistrellus pipistrellus* and *Pipistrellus pygmaeus* identifies distinct conservation needs for cryptic species of echolocating bats. *Biological conservation*, 133(1) pp. 118-127.
- Dodds, M. and Bilston, H. (2013) A Comparison of Different Bat Box Types by Bat Occupancy in Deciduous Woodland, Buckinghamshire, UK. *Conservation Evidence*, 10 pp.24-28.
- Dytham, C. (2003) *Choosing and using statistics*. Malden, Massachusetts: Blackwell Publishing.
- East Riding of Yorkshire (2019) Millington Wood. [Online] [Accessed 9th January 2019] <http://www2.eastriding.gov.uk/EasySiteWeb/GatewayLink.aspx?allId=175102>
- Entwistle, A. C., Harris, S., Hutson, A. M., Racey, P. A., Walsh, A., Gibson, S. D. and Johnston, J. (2001) *Habitat management for bats*. Peterborough: Joint Nature Conservation Committee.
- Flaquer, C., Torre, I. and Ruiz-Jarillo, R. (2006) The value of bat-boxes in the conservation of *Pipistrellus pygmaeus* in wetland rice paddies. *Biological conservation*, 128(2) pp. 223-230.

- Forestry Commission. (2019a) Allerthorpe Wood (England). [Online] [Accessed 17th January 2019] <http://www.forestry.gov.uk/forestry/englandeastyorkshirenoforestallerthorpewood>
- Forestry Commission. (2019b) Wheldrake Woods and Broad Highway Car Park (England). [Online] [Accessed 17th January 2019] <http://www.forestry.gov.uk/forestry/englandnorthyorkshirenoforestwheldrakewoods>
- Fowler, J., Cohen, L. and Jarvis, P. (1998) *Practical statistics for field biology*. London: John Wiley and Sons.
- Griffiths, S. R., Bender, R., Godinho, L. N., Lentini, P. E., Lumsden, L. F. and Robert, K. A. (2017) Bat boxes are not a silver bullet conservation tool. *Mammal Review*, 47(4) pp. 261-265.
- IBM Corporation. (2017) *IBM SPSS Statistics for Windows, Version 25.0*. Armonk, New York: IBM Corporation.
- Ivlev, V. S. (1961) *Experimental ecology of the feeding of fishes*. New Haven, Connecticut: Yale University Press.
- Joint Nature Conservation Committee. (2007) Second Report by the United Kingdom under Article 17 on the implementation of the Directive from January 2001 to December 2006. S1026-Helix pomatia-Roman snail. Peterborough: Joint Nature Conservation Committee.
- Jones, G. and Barlow, K. E. (2004) Cryptic species of echolocating bats. *Echolocation in bats and dolphins*, pp. 345-349.
- Juškaitis, R. (1999) Mammals occupying nestboxes for birds in Lithuania. *Acta Zoologica Lituanica*, 9(3) pp. 19-23.
- Kasprzyk, K. and Ruczynski, I. (2001) The structure of bat communities roosting in bird nest boxes in two pine monocultures in Poland. *FOLIA ZOOLOGICA-PRAHA*-, 50(2) pp. 107-116.
- Kerth, G. and Dechmann, D. K. (2009) Field-based observations and experimental studies of bat behavior.
- Kerth, G., Wagner, M. and König, B. (2001) Roosting together, foraging apart: information transfer about food is unlikely to explain sociality in female Bechstein's bats (*Myotis bechsteinii*). *Behavioural Ecology and Sociobiology*, 50(3) pp.283-291.
- Le Comber, S. C., Nicholls, B., Rossmo, D. K. and Racey, P. A. (2006). Geographic profiling and animal foraging. *Journal of Theoretical Biology*, 240(2) pp. 233-240.
- Lourenço, S. I. and Palmeirim, J. M. (2004) Influence of temperature in roost selection by *Pipistrellus pygmaeus* (Chiroptera): relevance for the design of bat boxes. *Biological Conservation*, 119(2) pp. 237-243.
- Luo, B., Santana, S. E., Pang, Y., Wang, M., Xiao, Y. and Feng, J. (2019) Wing morphology predicts geographic range size in vespertilionid bats. *Scientific reports*, 9(1) p. 4526.
- Makepeace, H. (2015) *Gosforth Park Nature Reserve – Bat Box Scheme 2013-2015*. Northern Bats Volume 1 [Online] [Accessed 5th February 2019] <http://s3.spanglefish.com/s/34944/documents/volume1/gosforth-park-bat-boxes.pdf>

- Mayr, E. (1970) *Populations, species, and evolution: an abridgment of animal species and evolution*. Harvard: Harvard University Press.
- Meddings, A., Taylor, S., Batty, L., Green, R., Knowles, M. and Latham, D. (2011) Managing competition between birds and bats for roost boxes in small woodlands, north-east England. *Conservation Evidence*, 8 pp. 74-80.
- Mering, E. D. and Chambers, C. L. (2014) Thinking outside the box: a review of artificial roosts for bats. *Wildlife Society Bulletin*, 38(4) pp. 741-751.
- Nicholls, B. and A. Racey, P. (2006) Habitat selection as a mechanism of resource partitioning in two cryptic bat species *Pipistrellus pipistrellus* and *Pipistrellus pygmaeus*. *Ecography*, 29(5) pp. 697-708.
- Parsons, K. N., Jones, G., Davidson-Watts, I. and Greenaway, F. (2003) Swarming of bats at underground sites in Britain—implications for conservation. *Biological Conservation*, 111(1) pp. 63-70.
- Poulton, S. M. (2006) An analysis of the usage of bat boxes in England, Wales and Ireland. Ledbury: The Vincent Wildlife Trust.
- Rueegger, N. (2016) Bat boxes—a review of their use and application, past, present and future. *Acta Chiropterologica*, 18(1) pp. 279-299.
- Russ, J. M. and Montgomery, W. I. (2002) Habitat associations of bats in Northern Ireland: implications for conservation. *Biological Conservation*, 108(1) pp. 49-58.
- Russo, D., Cistrone, L., Budinski, I., Console, G., Della Corte, M., Milighetti, C. and Ancillotto, L. (2017) Sociality influences thermoregulation and roost switching in a forest bat using ephemeral roosts. *Ecology and evolution*, 7(14) pp. 5310-5321.
- Schwegler. (2019). Schwegler-natur.de. [Online] [Accessed 18th January 2019] <http://www.schwegler-natur.de/fledermaus/>
- Scott, S. J., McLaren, G., Jones, G. and Harris, S. (2010) The impact of riparian habitat quality on the foraging and activity of pipistrelle bats (*Pipistrellus* spp.). *Journal of Zoology*, 280(4), pp. 371-378.
- Stebbing, R. E. and Walsh, S. T. (1991) *Bat boxes: a guide to the history, function, construction and use in the conservation of bats*. London: Bat Conservation Trust.
- Vaughan, N., Jones, G. and Harris, S. (1997) Habitat use by bats (Chiroptera) assessed by means of a broad-band acoustic method. *Journal of Applied Ecology*, pp. 716-730.
- Voigt, C. C., Frick, W. F., Holderied, M. W., Holland, R., Kerth, G., Mello, M. A. and Yovel, Y. (2017) Principles and patterns of bat movements: from aerodynamics to ecology. *The Quarterly review of biology*, 92(3) pp. 267-287.
- Warren, R. D., Waters, D. A., Altringham, J. D. and Bullock, D. J. (2000) The distribution of Daubenton's bats (*Myotis daubentonii*) and pipistrelle bats (*Pipistrellus pipistrellus*) (Vespertilionidae) in relation to small-scale variation in riverine habitat. *Biological Conservation*, 92(1) pp. 85-91.

Wickramasinghe, L. P., Harris, S., Jones, G. and Vaughan, N. (2003) Bat activity and species richness on organic and conventional farms: impact of agricultural intensification. *Journal of Applied Ecology*, 40(6) pp. 984-993.

Wilson, G. (2017) Bat Box Scheme - Box Analysis. [email]

Yorkshire Water (2019) New wildlife viewing centre at nature reserve set to be a soaring success. [Online] [Accessed 16th January 2019] <https://www.yorkshirewater.com/about-us/newsroom-media/tophill-low-visitor-centre>