

2023

The different factors affecting Chiroptera emergences with a focus on *Pipistrellus pipistrellus* and *Pipistrellus pygmaeus*

McCabe, H.

McCabe, H. (2023) 'The different factors affecting Chiroptera emergences with a focus on *Pipistrellus pipistrellus* and *Pipistrellus pygmaeus*', *The Plymouth Student Scientist*, 16(2), pp. 285-313.

<https://pearl.plymouth.ac.uk/handle/10026.1/21836>

The Plymouth Student Scientist
University of Plymouth

All content in PEARL is protected by copyright law. Author manuscripts are made available in accordance with publisher policies. Please cite only the published version using the details provided on the item record or document. In the absence of an open licence (e.g. Creative Commons), permissions for further reuse of content should be sought from the publisher or author.

The different factors affecting *Chiroptera* emergences with a focus on *Pipistrellus pipistrellus* and *Pipistrellus pygmaeus*

Hannah McCabe

Project Advisor: [Dr Catherine Gutmann Roberts](#), School of Geography, Earth and Environmental Sciences, University of Plymouth, Drake Circus, Plymouth, PL4 8AA

Abstract

Chiroptera (bats) are important within different ecosystems and biomes due to the different ecosystem services that they provide. The services that they provide to the United Kingdom include organic agricultural pest control and worldwide bats provide pollination and seed dispersal. The rationale for this study is to understand emergence preferences based on natural and anthropogenic factors such as building structure, habitats, and time. Bat roosts are species specific, with urban exploiter species relying on urban habitats such as *Pipistrellus pipistrellus* and urban-adaptor species such as *Nyctalus noctule* relying on natural roosts. A range of survey sites were studied across Hampshire Berkshire and Surrey with a variety of different habitats studied. Bat surveys were carried out from June to September 2021 using the Elekon Bat Scanner (Ecosupport, n.d.). All surveys lasted an average of two hours with extensions or shortenings judged on bat activity within the area, as well as temperature and weather conditions. Surveys were carried out at both dusk and dawn with sunset and sunrise times recorded. Secondary data was provided by Ecosupport and extracted and analysed from phase two bat reports, with specific locations and building names kept confidential. Although different urban features of buildings were measured there were no statistically significant results regarding bat species emergence locations. This differs from much of the literature studied due to *Pipistrellus pipistrellus* being a known crevice dweller. However, one similar study concluded that *Pipistrellus pipistrellus* did not have a preference on emergence location but rather on size of crevice used to emerge from. Habitat type was also investigated to evaluate if bats had a selected habitat of which they emerge within. The only species to have a conclusive significant habitat to emerge were *Pipistrellus pipistrellus* emerging within an agricultural habitat. Emergence and re-entry times of bats were also measured by the times of sunset and sunrise to see if natural light would have a direct effect on this. Sunset times did have a significant correlation to times of first emergence of total bat species with a higher level of confidence past 21:00. Sunrise times however did not have a significant correlation on re-entry times for total bat species when an outlier was removed from the data set. This study concludes that British bats do not prefer emergence location based on urban factors. *Pipistrellus pipistrellus* prefers agroecosystems with the other bats studied having no preference. Future work would include an investigation of a correlation between temperature emergences in British bat species to discuss improvements in bat box mitigation and manufacturing.

Keywords: *Chiroptera*, *Pipistrellus pipistrellus*, *Pipistrellus pygmaeus*, emergence, habitats, sunset, sunrise, pest control, bioindicators, populations, crevice dwellers, roosts.

Introduction

Importance of bats

Bats are one of the most biodiverse groups worldwide with over 1300 different species (Fenton and Simmons 2014; Russo and Jones 2015). They are the only mammal to have achieved active flight, the only other vertebrate species being birds (Makanya and Mortola 2007). This allows for high levels of distribution of bat populations across both land and water and helps with different symbiotic relationships. There is mounting evidence that bats provide a high number of crucial ecosystem services such as pest control, pollination, and seed dispersal (Russo *et al.*, 2021). These ecosystem services have both economic and ecological advantages for society as well the wider environment, which is why bat conservation is crucial for the wider environment.

Pest control

Pest control is the most common ecosystem service provided by the bats of Britain and Europe as all British bats are insectivorous. This enhances organic agroecosystems, reducing the volume of pesticides on the land and therefore improving biodiversity and reducing economic input (Wickramasinghe *et al.*, 2003) This also allows for regulation of insect species as a whole, so the population does not increase exponentially (Kalda *et al.*, 2015) The most common source of invertebrate nutrition amongst UK bat species are moths (Lepidoptera) which pose an important economic pest (Ricucci and Lanza 2014) within the agricultural industry. Bats also feed on midges, mosquitos, beetles. Further afield within South America they have been seen to prey on each other as well as Marsupialia and Muridae (Bonato *et al.*, 2004; Kasso and Balakrishnan, 2013). It has been recorded that depending on the abundance of pest insects that the effects of bats are greater than the effect of birds on insects (Kalka *et al.*, 2008).

Bioindicators

Bioindicators can predominantly be defined as 'biota that are developed as indicators of the quality of the environment, the biotic component, or humans within an ecosystem' (Burger *et al.*, 2006). Bat populations are affected by a wide range of stressors (Kasso and Balakrishnan 2013), which makes them impressive bioindicators for both anthropogenic and environmental changes (Mickleburgh *et al.*, 2002)

Threats to bats

Agriculture has been identified by the IUCN red list as a threat to over 50% of bat species world-wide (Fuentes-Montemayor *et al.*, 2013). This is because of the increased use of pesticides reduces dipteran populations and directly poisons bats, due to the organochlorines used. Educating farmers globally about the natural pest control that bats provide will overall decrease their usage for pesticides creating a positive feedback loop increasing bat species survival. Encouraging conservation methods such as integrated pest management principles (Lewanzik *et al.*, 2022) and promoting bat friendly spaces will also enlarge and protect populations. With urbanisation and agricultural practices increasing it is vital that we promote the protection of bats and the use of bat boxes, because of their ecological and economic importance to both the wider environment and human life (Russo *et al.*, 2021)

Environmental factors affecting bat populations

Rivers are an important habitat for bat populations as they rely on them for commuting, foraging, and drinking (De Conno *et al.*, 2018) so they often provide rich bat species assemblages (Russo *et al.*, 2021). If river quality declines this ultimately decreases a potential food source for both insectivorous (UK species) and herbivorous (worldwide species) bats (Vaughan, Jones and Harris, 1996) therefore the population around polluted water reduces. Bats can also bioaccumulate contaminants such as toxic metals (Zukal *et al.*, 2015) through ingestion of prey and polluted aquatic habitats. This can be seen in studies of the water habitat specialist Daubenton's bats through fur samples and sediment dredging in Germany (Russo *et al.*, 2021). Because of their large body surface area bats are at high risk of dehydration which is solved by drinking nightly (Russo *et al.*, 2004). With the profound effects of climate change and rising temperatures, local water sources are drying up, increasing the likelihood of dehydration for bats and all other taxa. This problem is being addressed in Europe by ClimBats (2020) who monitor changes in bat numbers and educate people about how climate change is affecting bats worldwide.

Anthropogenic factors affecting bats

Drivers of bat population decline within urban areas are commonly associated with different types of pollution. The addition of artificial lighting to otherwise naturally dark habitats has been found to disturb the navigation of migrating bats throughout urban areas (Rowse *et al.*, 2016). However, Stone *et al.*, (2009) quoted several studies showing bat species have adapted to this additional lighting by feeding on the invertebrates which are attracted to the light. Woodland bat species avoid both artificial and natural forms of light, but their prey doesn't. This leads to a reduction in insectivorous bat's food sources such as Lepidoptera (Berthinussen *et al.*, 2012). Another anthropogenic factor in bat disturbance is increased noise levels from road traffic because it interferes with their echolocation signals (Schaub *et al.*, 2008). It has been shown that the Greater Mouse-eared bat (*Myotis myotis*) (a very uncommon species in Britain) forages less when subjected to traffic noises within a laboratory (Schaub *et al.*, 2008).

Factors affecting emergences from different bat species

The current expansion of urbanisation across the world has an estimate of between '430,000 km² to 12,568,000 km² increase in urban land cover by 2030' (Seto *et al.*, 2011). Organisms which once chose natural shelter such as caves and trees are now preferring urban alternatives. This is seen in bats, with an increase in use of artificial structures, such as houses, being widely used for roost accommodations with some species roosting almost exclusively in these sites (Jenkins *et al.*, 1998). However urban ecosystems provide suitable habitat for only 'urban-exploiter' and 'urban-adaptor' species (McKinney 2006). Urban-exploiters are categorised as bats which can fully depend on urban resources and areas to survive whereas, urbanadaptors require foraging locations within the natural environment but still utilise urban roost sites such as buildings (Schoeman 2015).

Of the 17 known species of bat in the United Kingdom, 14 are known to roost within: houses, barns and abandoned structures (Bat Conservation Trust 2021) Of the bats that choose to roost in buildings rather than more natural structures they can be separated into 4 categories:

- Crevice dwelling bats: *Pipistrellus pipistrellus* (Common Pipistrelle), *Pipistrellus pygmaeus* (Soprano Pipistrelle), *Pipistrellus nathusii* (Nathusius' Pipistrelle), *Myotis brandtii* (Brandt's bat) and *Myotis mystacinus* (Whiskered bat).
- Roof void dwelling bats: *Eptesicus serotinus* (Serotine), *Nyctalus leisleri* (Leisler's bat), *Myotis dubentonii* (Daubenton's bat) and *Barbastella barbastellus* (Barbastelle).
- Flight space needed within the roost: *Myotis nattereri* (Natterer's bat), *Plecotus auritus* (Brown Long-eared bat) and *Plecotus austriacus* (Grey long-eared bat).
- Flight space needed to gain access to the roost: *Rhinolophus ferrumequinum* (Greater Horseshoe bat) and *Rhinolophus hipposideros* (Lesser Horseshoe bat) (Bat Conservation Trust 2021)

Roosts are important for bat survival as they protect them from environmental extremes such as wind, rain, and temperature as well as predation. They are also crucial for social interaction within the colony (Entwistle *et al.*, 1997) as this allows for both reproduction and the caring of pups within a large maternity roost. Unlike other urban mammals, bats mostly only produce one litter a year (Lakudzala 2019) usually consisting of one pup, thus making community roosts vital to maintaining the population.

Factors affecting emergences, range from anthropogenic sources, such as artificial light (Stone 2009) and habitat change (Perry, 2012) to natural elements, such as temperature and cloud cover, as well as predation and food availability. Bats with high wing loadings (or fast flying bats), such as, the Soprano Pipistrelle are expected to emerge earlier during lighter conditions (Jones and Rydell 1994). This is due to the fact that these bats feed on small aerial insects whose peak flight activity is during dusk. These peak dipteran feeding times however are still during daylight hours which increases the risk of bat predation from birds of prey and domestic cats. Other species of bats have developed to feed independently from the dusk peak of dipterans and feed on moths or flightless insects. This gives the advantage of a later emergence under the cover of darkness which therefore minimises predation risk. Examples of later emerging bats include the Daubenton's bat and Brown Long-eareds. *Nyctalus noctule* (Noctules) however have adapted to forage with swifts at higher elevations within daylight hours (Jones and Rydell 1994) which has the advantage of avoiding ground predators such as domestic cats.

Pregnancy can cause a later emergence due to decreased flight performance with a higher risk of predation (Dunvergé *et al.*, 2000). However, within protected areas, bats are seen to emerge earlier and can extend their foraging hours benefiting bats with inhibited flight patterns such as pregnancy or injury. This pushes for the enhancement of biodiversity within bat populated areas, such as increased tree cover for predator avoidance. Higher numbers of dipteran levels would also increase because of this, which gives all bat species a larger food source during sunset time (Rydell and Speakman 1995). Pregnancy however does not affect all bat emergence times with the Common Pipistrelle emerging around 35 minutes after sunset with little flexibility (Swift 1980).

Bats need to be able to access a building from the outside and have specific internal features for roosting. External and internal building features where bats are known to take up roosts, include spaces between slates and wooden snarking boards, cavity walls, crevices, etc (Jenkins *et al.*, 1998). Building features are crucial to increase roosting opportunities especially for urban-exploiter species as this is their favoured roosting site.

Important British bat species

The cryptic species Common Pipistrelles and Soprano Pipistrelles were originally thought to be one species; *Pipistrellus pipistrellus*, when initially identified morphologically. However, the detection of two different echolocation calls suggested the existence of a second pipistrelle species (Häussler *et al.*, 2000); *Pipistrellus pygmaeus*. Cryptic species are defined as species where 'diagnosable features of which are not easily perceived' (Mayr 1977). Whilst when the new pipistrelle species was identified it was assumed that the foraging strategy would be similar if not the same as the Common Pipistrelle. However recently it was discovered although baring similar morphology clear foraging distances and ranges occur within the two species (Speakman *et al.*, 2003; Davidson-Watts *et al.*, 2006). The Common Pipistrelle was seen to forage in larger areas within specific habitats such as woodlands and farmlands and are most found within large areas of deciduous woodland. The Soprano Pipistrelle however is seen to disperse and forage within a wider range of habitats further away from the roost site, not specifically sticking to the same type each night. Soprano Pipistrelles however have a higher chance of foraging within riparian habitats compared to Common Pipistrelles as they have filled in that niche within the ecosystem (Davidson-Watts *et al.*, 2006).

Biodiversity enhancing infrastructure

Enhancing infrastructure and the surrounding area is crucial for the survival of bats within an ever-urbanising society. This can be established by adding to existing infrastructure such as bat boxes and creating bat friendly spaces within an already urbanised ecosystem (Boyd 1989). This reduces ecosystem fragmentation therefore increasing biodiversity (Smith and Agnew 2002).

Dark and green corridors

Continued growth in the use of artificial light at night ranks among the most important global threats to biodiversity (Davies and Smyth 2017) especially to nocturnal organisms such as bats. The effects of artificial lighting such as streetlights are species dependant but with a majority of bat species being negatively affected. *Rhinolophus hipposideros* has seen a disruption in foraging within areas which are artificially lit compared to naturally dark corridors (Zeale *et al.*, 2018). Within Europe, as much as 88% of the land surface is affected by light pollution (Falchi *et al.*, 2016) which is why it is crucial to have dark corridors (also referred to as green corridors) within urban and semi urban environments. Enhancing and upcycling corridors such as old or unused railways and tramways ensures a safe dark and un-motorised space for bats to translocate to forage, breed and communicate (Carlier *et al.*, 2019). This can be done also by the addition of a tree or manufactured canopy preventing predator risk from aerial-hawking birds and counteracting habitat fragmentation.

Bat boxes

Extra roosting sites are being added to urban areas because of the recognition of the importance of bats within all environments. This also helps to encourage and increase bat populations within Britain as they are a protected species under the Wildlife and Countryside act (1981) These take the form of bat boxes and bricks which can be added to the sides of buildings and trees, to support bat roosts and increase breeding (Boyd 1989)

Due to external stress such as temperature, predators and weather conditions bats can spend up to 20 hours a day within a roost in the summer months (Jenkins *et al.*, 1998). However, the placement of said boxes is critical to ensuring the bats survival to allow a warm temperature for maternity roosts but cool enough so they do not over heat. A bat box designed by Brittingham and Williams (2000) exceeded temperatures of 40°C which is known to cause heat stress within bat species such as the Little Brown bat (*Myotis lucifugus*). However, in Licht and Leitner's (1967) study when bats have been seen to move vertically to avoid exceeding temperatures of between 33-35°C within a roost. It is crucial that when designing bat boxes and internal bat friendly spaces that they have a warm consistent temperature that does not exceed the species habitable temperature range. This would require knowledge of local species maximum temperature range in order to model the bat boxes accordingly.

The most common bat box used for Common and Soprano Pipistrelles is the 1FF bat box. This bat box is designed for crevice dwelling bats as it has a long slit stretching the width of the bottom of the box (Dodds and Bilston 2013). This mimics similar slits and crevices that these species will use either in trees or under roof tiles and slates. This box fits with their morphology, having a small body frame with small wings linking with their flight performance to that of fast flyers (Norberg and Rayner 1987). This bat box was also the most frequented by Common Pipistrelles within Collins' *et al.*, (2020) study. The highest number of Common Pipistrelles were found when box boxes were located on walls totalling at 71%. Soprano Pipistrelles within the same study frequented the boxes the most when mounted within trees with 52% of total species found throughout the study.

Roost selectivity

The Brown Long-eared bat has been seen to have preferences for roost selection within locations in Scotland. Roost sections have been chosen based on water and woodland distance within a 0.5km radius of the roost site. This elevates their natural food sources, compared to locations further away (Entwistle *et al.*, 1997). This is crucial for their foraging behaviour to be within close range of food and water. The Brown Long-eared bat does not move large distances from roost sites with 60% of foraging occurring within 0.5km from their roost site (Entwistle *et al.*, 1996; Fuhrmann and Seitz 1992). As the Brown Long-eared bat emerges later than most slow flying bats, up to an hour after sunset, further flight for foraging could cause a time difference in their emergences. If Brown Long-eared bats emerged earlier this may increase their vulnerability to predators. If their emergence time stayed the same however, this could reduce the amount of food available due to longer commuting routes (Ancillotto and Russo 2020). The Brown Long-eared bat also has selective roost features with buildings (mostly houses) chosen based on their internal structure with Brown Long-eared's favouring large complex wooden structures and apexes.

Hypotheses

There are three main objectives to this study with the overarching aim focussing on factors affecting emergences in different bat species.

Building features

1. To examine whether bats have a preference of emergence location in order to identify the ideal placement of bat boxes on or within a property. The identified hypothesis is that there will be a higher number of all bat species bats emerging from 'All Tiles' compared to 'All Other Building Features' (now referred to as 'Tiles' and 'Other Features'). This is because the majority of bats surveyed in this study are crevice dwellers and tiles (which create suitable 'crevice' habitats for bats) are the most prominent building feature found on all buildings surveyed. For both the Common Pipistrelle and Soprano Pipistrelle species (both crevice dwellers) the hypothesis is that again there will be a higher number of emergences from Tiles compared to Other Features.

Habitat location

2. To identify if bats have a preferred habitat location in which they dwell and emerge within. This will have a higher chance of identifying the probability of maternity roosts within specific habitats. The total bat species will have a higher chance of emerging from locations in rural areas rather than urban areas. This is because even though there are more available sources of nutrition within some urban areas e.g., street lighting attracting moths and other insects, the majority of bats are discouraged from foraging in artificially lit areas (Zeale *et al.*, 2018). There are also more anthropogenic disturbances such as noise and traffic pollution found in urban areas. Common Pipistrelles and Soprano Pipistrelles are predicted to fall into these same habitats because of their foraging ability and increase in prey in these areas.

Sunset and sunrise times

3. To consider whether sunset and sunrise (natural light) have a direct effect on bat emergence and re-entry times. Bats appear to be affected by both sunrise and sunset times due to the fact they are nocturnal hunters that rarely surface during lighter hours. The identified hypothesis is that natural light from sunset and sunrise times has an effect on bat emergence and re-entry times of all bat species.

Objectives

There are three main objectives to this study all with the overarching aim of understanding factors affecting bat emergence.

1. To understand bat roost location preferences within different artificial structures
2. To understand bat roost preference within different habitats relating to urbanisation.
3. To understand bat emergence timings relating to sunset and sunrise timings.

Methodology

Study sites

Number of emergences were counted from each urban aspect of every building surveyed. Original categories were; 'Tiles' and 'Other Features' however they were later simplified to Tiles and Other Features. All buildings surveyed had a least one of every feature from each category.

Emergence and re-entry numbers were recorded within different habitat locations across Hampshire and Berkshire in the United Kingdom (Fig. 1) stretching from Brockenhurst to Bracknell with an estimated distance of 80km. Ninety-four different surveys were carried out at 31 different properties each ranked by their habitat type. Each habitat rank has been categorised on level of urbanisation within the area with the ranks being: rural (1), agricultural (2), semi-rural (3), semi-urban (4), and urban (5). Factors such as number of residential areas, agricultural land, and Sites of Special Scientific Interest (SSSI) were taken into consideration when determining an areas rank. Rural locations often had ancient woodlands and isolated buildings present with little to no residency and disturbance. Agricultural building such as barns and other farm buildings with surrounding working farmlands including crops and livestock form the agricultural category. Semi-rural landscapes include small villages surrounded by green spaces (excluding farmland) and or woodlands with a small residential population. Semi-urban includes larger populations seen in towns or large villages also with higher levels of anthropogenic interference. Urban areas included cities and large towns such as Winchester and Reading, with high levels of anthropogenic disturbances such as transport and higher artificial light levels.

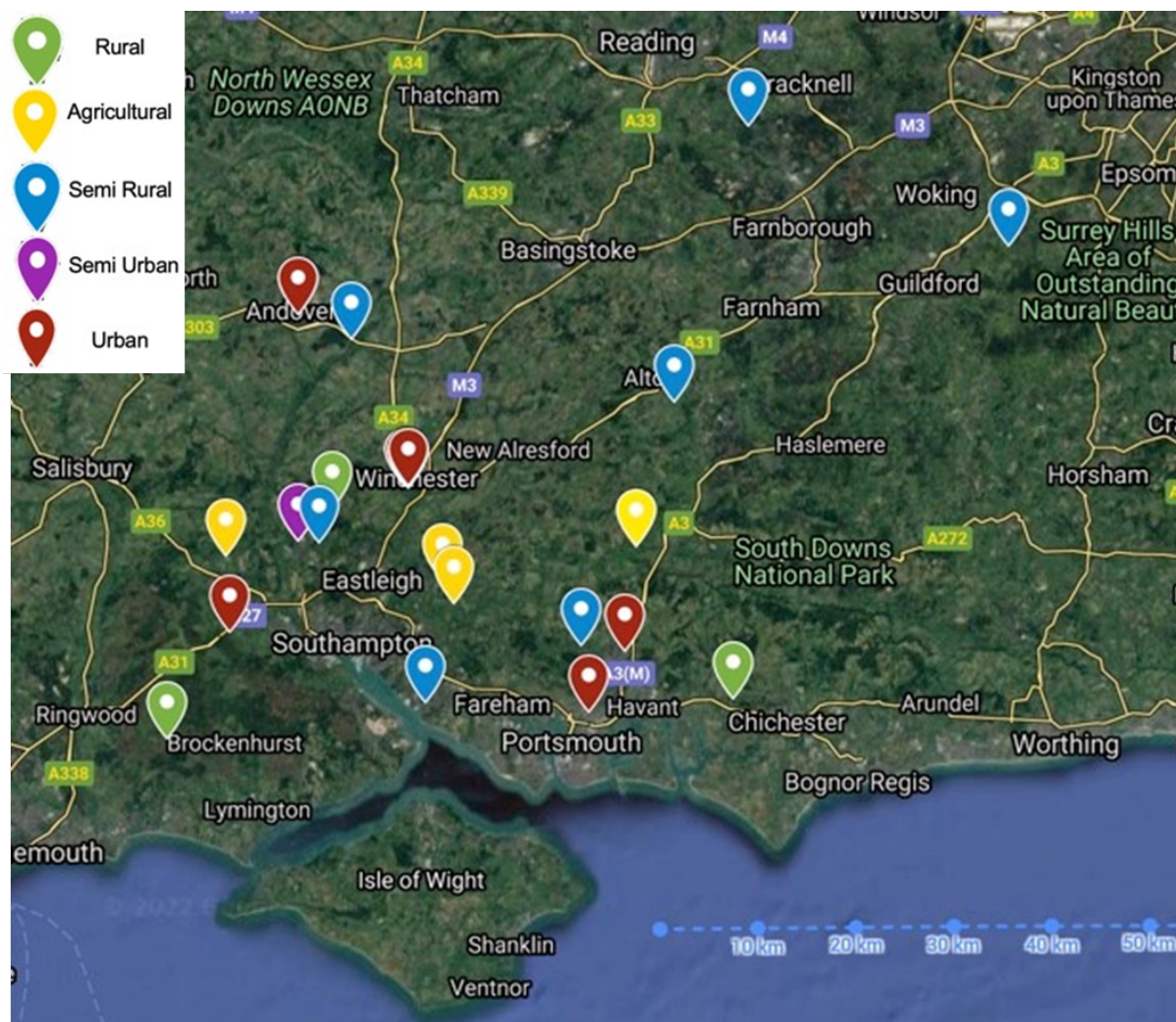


Figure 1: The properties surveyed during this study within Hampshire, Berkshire, and Surrey Base map source: Google Maps Imagery ©2023 Landsat / Copernicus, Data SIO, NOAA, U.S. Navy, NGA, GEBCO, Imagery ©2023 TerraMetrics, Map data ©2023.

Each site ($n = 31$) was surveyed up to three times with a minimum of one survey if no bats were present at the first survey. If low levels of bats were recorded at the first dusk survey, then a dawn survey may not take place. When surveyed three times each location will have two dusk surveys and one dawn survey over a period of six weeks with two-week intervals between each survey.

Acoustic surveys

Surveys at dusk would take place thirty minutes before sunset and would finish up to two hours after sunset depending on bat activity throughout the survey. Dawn surveys would take place up to two hours before dawn and half an hour after sunrise, again depending on bat activity. If no emergences or re-entries were recorded and there was limited bat commuting or foraging, surveys finished a maximum of twenty minutes earlier. Multiple bat detectors and loggers were used throughout the survey period including a magenta bat 5 detector (M5) provided by the University of Plymouth and Elekon Batscanner (EBS) and Elekon Batlogger (EBL) provided by Ecosupport Ltd (Domblides 2021). Automatic recording of GPS

location, bat call frequency and echolocation spectrograms are only recorded by the EBL. The M5 and EBS allow for the bat call frequency can be translated through the device but are recorded manually.

All buildings surveyed had a minimum of two surveyors positioned on each side or corner of the building in order to view potential emergences or re-entries. Larger building or misshapen building required more surveyors with up to fourteen surveyors per site. All surveyors were employed by Ecosupport. All data (even if automatically logged) was recorded in the field under the categories: time of detection, species with recorded frequency (Hz), activity e.g., emergence, re-entry, commuting/transit, foraging and direction of flight. All detectors are programmed to detect frequency's from 10 to 120Hz and for the UK bat species recorded in these surveys it is an estimated 20 to 60Hz, although can vary depending on type of call. All survey data was taken by using ELB or from the Met Office data set (Met Office 2019). Time was also measured at: survey start time, survey finish time, time of sunset or time of sunrise.

Data extraction

Primary survey data was collected between June and September 2021 with secondary data extracted in the time frame of 2015 to 2021. The secondary data has been collected by Ecosupport within the same months using the same methods. These months have the highest levels of bat activity within the year (Fig. 2)

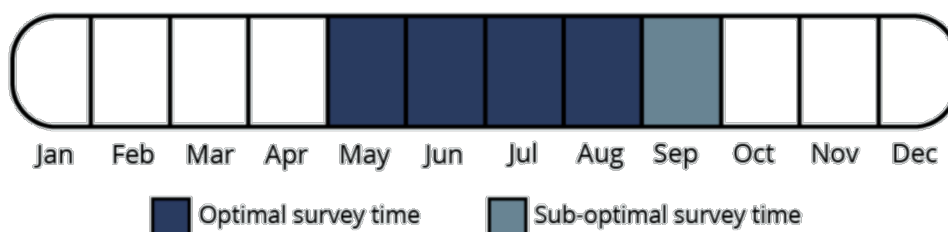


Figure 2: Bat survey calendar used at Ecosupport (n.d.)

Ecosupport provided a selection of their bat survey phase two reports spanning the last six years. Other reports provided by Ecosupport included phase one bat survey reports and mitigation strategies all of which have been used within this dissertation.

Secondary data extraction from these reports allowed for gaining of important characteristics to be used within this study. This included emergences, re-entries, species etc and other abiotic data such as temperature, humidity, and precipitation levels. Each location had its own report with up to three surveys recorded in each and bat activity for all three of the surveys. The secondary data has been collected, recorded and finalised using the same methods as previously mentioned.

All secondary data included within this report has been used with expressed permission from Ecosupport. To maintain Ecosupport's client's confidentiality process all, data used has an estimated location within Fig. 1. With no extract addresses given. No personal data of clients will be shared within this report and any specifically mentioned properties names have been changed.

Data analysis

All variables were tested for normality, in the case where the data is not normally distributed, non-parametric tests were used are; Mann-Whitney U, Kruskal-Wallis Test and a linear regression. Statistical analysis was carried out using Minitab (Minitab 18 2018) with P-values adjusted ties, working with 95% confidence intervals.

Analysis of emergences from different building features

Mann-Whitney U test was used to test the difference between the number of emergences from different building features within the groups: Tiles, and Other Features. Tiles are made up from the observed features; tiles (not specified), hanging tiles, and ridge tiles whereas Other Features but tiles are made up of the observed features; of gable, openings (as in open windows or large gaps in building framework), dormer window, roof (not specified), wooden cladding and soffit. As two surveys occurred at each location, the total emergences for the same building feature at the same location were added together to gain independent samples. A further two Mann-Whitney U tests was then carried out testing the same groups of tiles and Other Features. These were carried out at a species level testing if specific bat species had a preference of emergence location from a building. The species tested were Common Pipistrelles and Soprano Pipistrelles.

Analysis of emergences from different habitat locations

A Kruskal-Wallis test was carried out in order to compare different habitat types and the number of bat emergences from each habitat. This shows if a habitat type has a higher population of bats present. Habitat locations are ranked on ordinal habitat scale from 1-5. A further two Kruskal-Wallis tests was then carried out testing the same habitat ranks (1-5) above. These were carried out at a species level testing if specific bat species had a preference of habitat type in which they emerge from. The species tested were Common Pipistrelles and Soprano Pipistrelles.

Analysis of time of sunset correlating to time of first bat emergence

A linear regression model tested for a correlation between sunset time (response) and time of first bat emergence (predictor) from a building (no specific feature). Time of sunset of each location has been recorded as well as time of first bat emergence.

Analysis of time of sunrise correlating to time of first bat re-entry

A linear regression model tested for a correlation between sunrise time (response) and time of first bat re-entry (predictor) from a building (no specific feature). Sunrise time of each location has been recorded as well as time of first bat emergence.

Results

Emergences from different building features

More bats emerged from Tiles (median =1.00 ± 2.00 IQR) than Other Features (median = 2.00 ± 3.00 IQR; Fig.3). However, there was no significant difference in the number of bat emergences between building features, (Mann-Whitney U; P value =0.245, df=453, N = 454

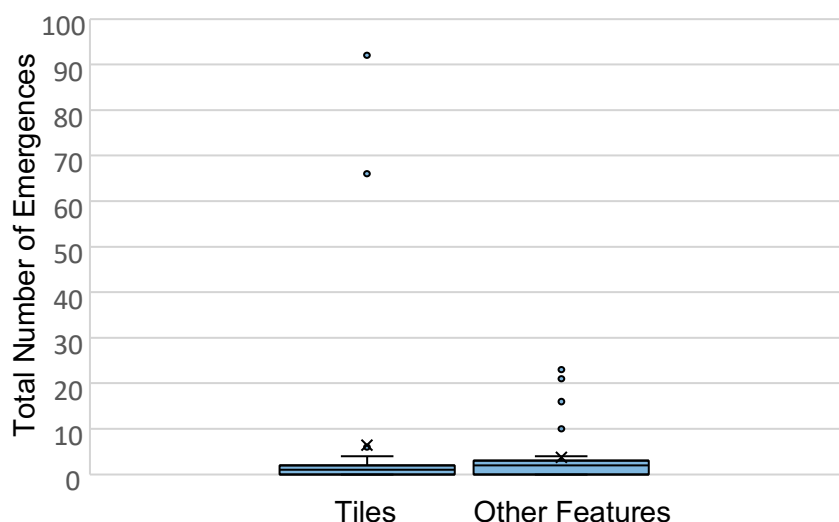


Figure 3: Total emergences recorded from building features: Tiles, and Other Features (x =mean) from August 2015- September 2021

Common Pipistrelle emergences from different building features

More Common Pipistrelles were seen to emerge from Other Features (median =1.00 ± 2.00 IQR) as opposed to Tiles (median =0.00 ± 1.00 IQR; Fig 4). However, there was no significant difference in number of Common Pipistrelle emergences between building features, (Mann-Whitney U; P value =0.057, df=184, N= 185).

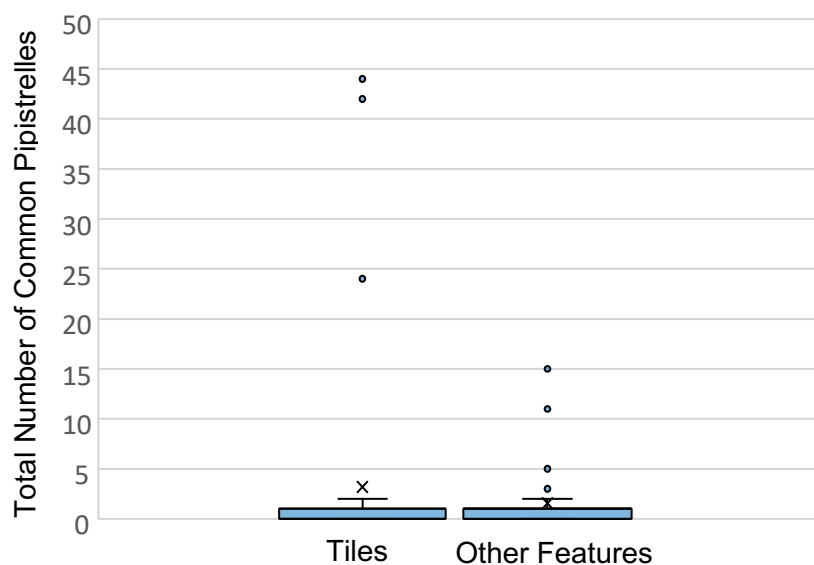


Figure 4: Total Common Pipistrelle emergences recorded from building features: Tiles, and Other Features (x =mean) from August 2015- September 2021

Soprano Pipistrelle emergences from different building features

A similar number of Soprano Pipistrelles emerged from both Tiles (median = 0.00 ± 1.00) and Other Features (median = 1.00 ± 2.00 Fig 5). There was no significant difference in number of Soprano Pipistrelle emergences between building features, (Mann-Whitney U; P value = 0.520, df=169, sample size= 170) Tiles and Other Feature.

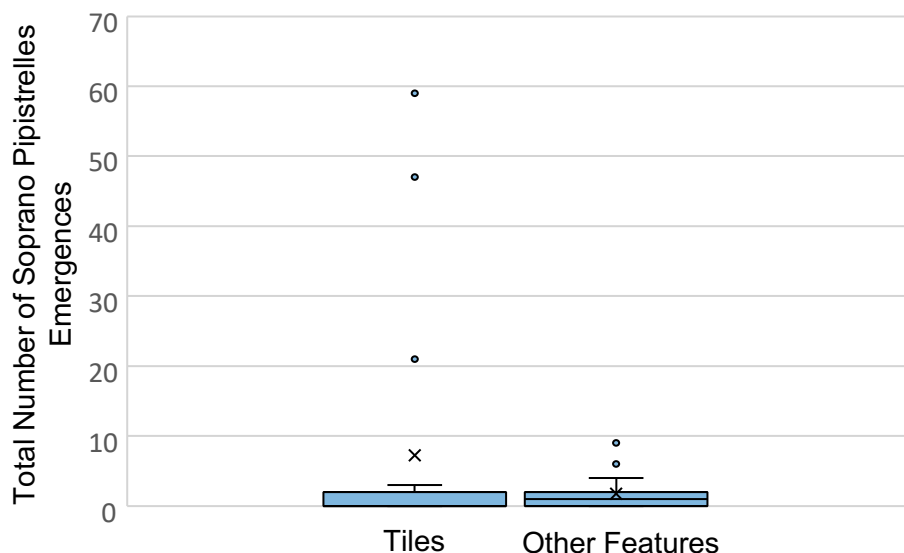


Figure 5: Total Soprano Pipistrelle emergences recorded from building features: tiles, and Other Features (x =mean) from August 2015- September 2021

Total emergences from different habitat locations

A higher number of bats emerged within the habitats agricultural land and semi-rural landscapes (ranks 2 and 3) compared to the other habitats (Fig.6; Kruskal Wallis df =4, P-value 0.083). However even with a larger number of emergences, there is no statistically significant difference between habitat type and number of bat emergences.

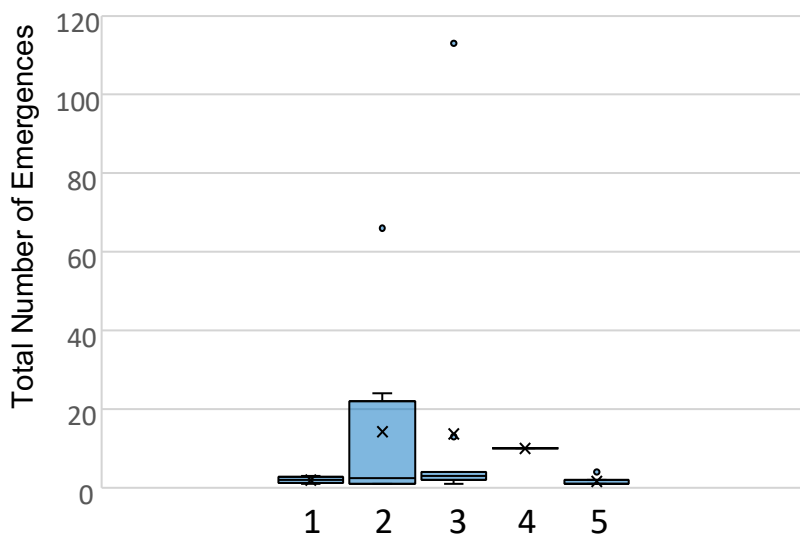


Figure 6: total number of emergences which occurred at each habitat rank: 1. Rural, 2. Agricultural, 3. Semi-Rural, 4. Semi Urban, 5. Urban (x =mean)

Common Pipistrelle emergences from different habitat locations

Significantly more Common Pipistrelle bats emerged within agricultural habitats (rank 2) compared to the other habitats (Fig.7, Kruskal Wallis $df = 4$, P-value 0.031).

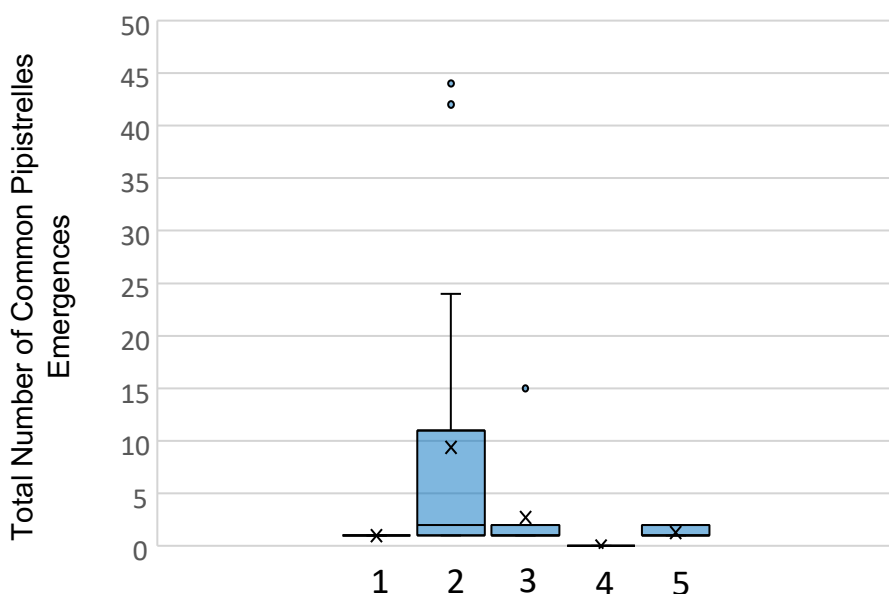


Figure 7: total number of Common Pipistrelle emergences which occurred at each habitat rank: 1. Rural, 2. Agricultural, 3. Semi-Rural, 4. Semi Urban, 5. Urban. (x =mean).

Soprano Pipistrelle emergences from different habitat locations

A higher number of Soprano Pipistrelles emerged from semi-rural habitats (rank 3) compared to the other ranks (Fig 8, Kruskal Wallis $df = 4$, P-value 0.083). However, there is no statistically significant difference between habitat type and number of Soprano Pipistrelle bat emergences.

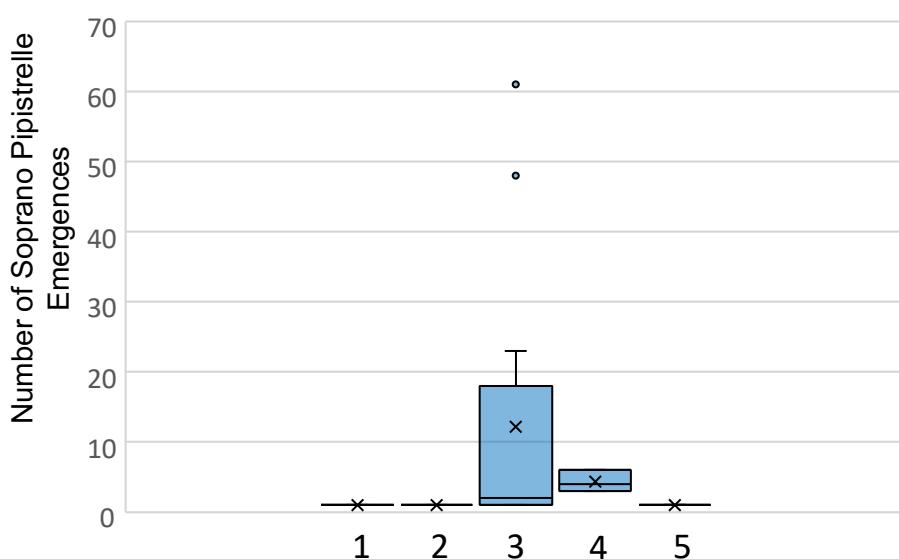


Figure 8: the total number of Soprano Pipistrelle emergences which occurred at each habitat rank: 1. Rural, 2. Agricultural, 3. Semi-Rural, 4. Semi Urban, 5. Urban (x =mean).

Correlation between sunset time and time of first emergence

A significant positive correlation between sunset time and bat emergence time (P value <0.001, Fig. 9). The total bats which emerged after sunset is higher than before sunset which has a peak after 21:00.

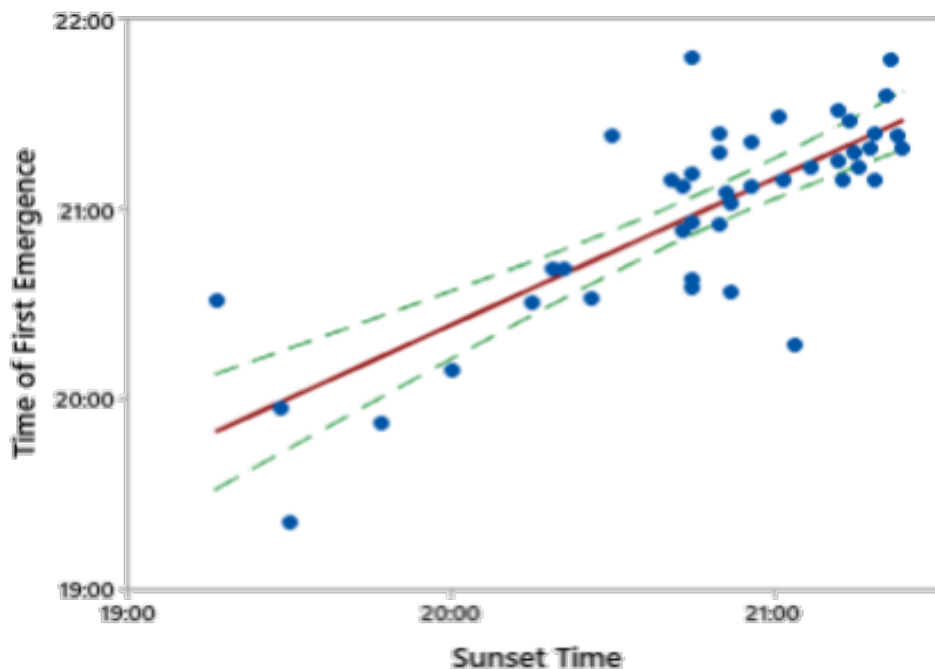


Figure 9: A linear regression between first bat emergence time and sunset time. The linear equation = Time of first bat emergence = 0.2094 + 0.7682 Sunset Time, 61% meaning higher percentage of variation in time of first emergence is explained by the sunset time. The green dashed lines represent the confidence intervals to 95%. There is a higher level of confidence past 21:00 due to a higher number of emergences occurring after 21:00.

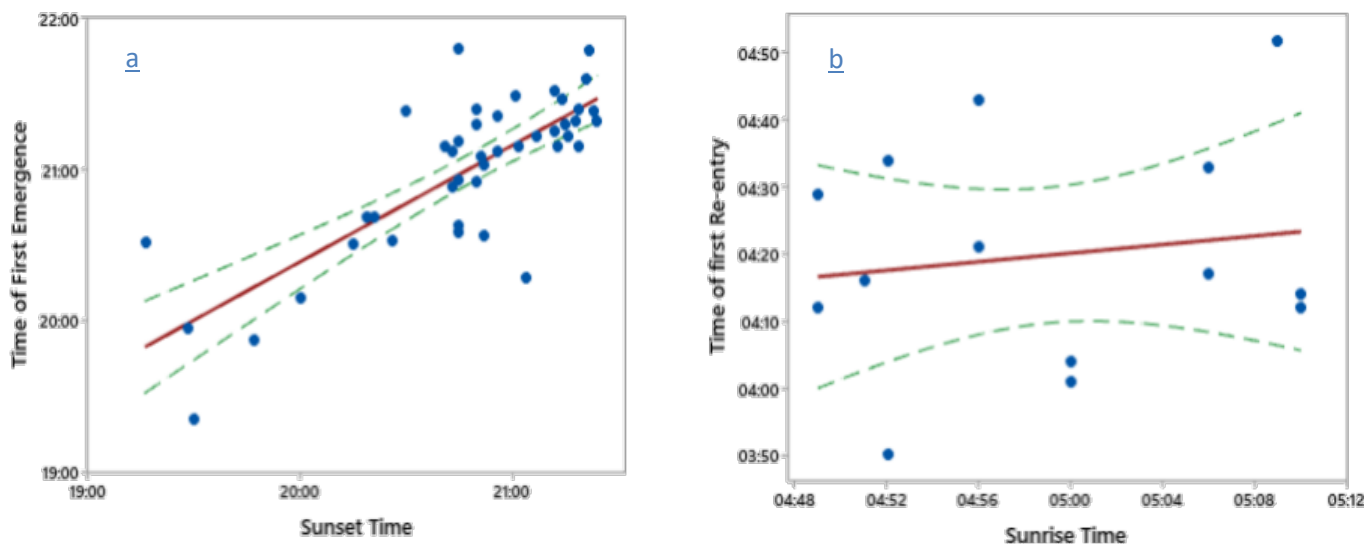


Figure 10 a: a linear regression model testing if there's a correlation between time of first re-entry and sunrise time. The included outlier drives the positive relationship between the two variables **b:** a linear regression model testing if there's a correlation between time of first re-entry and sunrise time with the outlier removed. This shows that there is no relationship between the two variables.

Discussion

Is there a preferred emergence location from different building features for UK bat species?

The results of this study can go towards developing bat friendly habitats and spaces such as bat boxes, and identifying qualities of bat boxes which can be developed going forwards to be species specific or generalised. This gives a higher chance of bats taking up roosts within specially designed bat boxes or habitats allowing them to have the best chance of survival.

The results may also show the best habitats to place these bat boxes in for conservation depending on the species within that habitat. Direction the roost is facing, and temperature may also affect the two species studied (Common Pipistrelle and Soprano Pipistrelle) as well as all bat populations within the United Kingdom. Sunset and sunrise data may be used to monitor emergence and re-entry times within conservation areas. If these areas have a higher urban population these results may help with identifying light at night and knowing when to reduce or adapt streetlights and domestic lights e.g., flood lights. Across all bat species no preference between tiles and other building features were found, neither was there a preference when testing this on a species-specific level for Common pipistrelles and Soprano pipistrelles.

However, a limitation to this study is not all buildings had every feature which was analysed e.g., not all buildings had wooden cladding. This leads to a wider range of buildings needing to be examined with all the features listed, to gain a higher level of accuracy within the results. Also, when examining the secondary data from Ecosupport, the reports did not always specify material types e.g., types of tiles or roof material. New categories had to be created to make up for this. Higher specificity would be needed in order to progress to another study on bat emergences from building feature.

Tiles overall had a higher number of total emergences recorded this however did not show significance within the results. An unsubstantial amount of previous research has been carried out on emergence location from a building, Collins *et al.*, (2020) concluded that bat species in the United Kingdom do not have a preference. Collins *et al.*, (2020) study aligns with the results from this study. When provided with multiple access points to a series of British bat maternity roosts only 8% of the total were used with 94% of bats (within the 8%) only using a single access point even when more were provided (Collins *et al.*, 2020). Collins *et al.*, (2020) concluded however that bats most frequented access points were between 13-22mm when given ranges from 10-35mm. This provides information to the sizing of the entrances to bat boxes and other man-made bat habitats with specifically sized access points but not a specific shape or material. Bats which frequented these bat boxes at 10-35mm mainly included both the Common Pipistrelle and the Soprano Pipistrelle and due to their small size and fast flying these boxes are easily accessible to them (Collins *et al.*, 2020; Jones and Rydell 1994).

Neither Common or Soprano Pipistrelle had a preferred emergence location, this is in line with a previous study (Collins *et al.*, 2020). This however is unusual as both the pipistrelle species are crevice dwelling bats (Bat Conservation Trust 2021), which are usually found between tiles or slates on roofs and the internal structure of a loft

or a ceiling (Jenkins *et al.*, 1998). However according to a study also by Jenkins *et al.*, (1998) all pipistrelle bats did not select roosts with specific structural attributes, even though they are known to select roosts based on internal structure. With Jenkins *et al.*, conclusion when looking back at the data analysis the P value for Common Pipistrelles is 0.057 which is on the margin of being statistically significant, matching up with previous literature. This may have been limited by a smaller sample size in both pipistrelle data sets compared to total bat species with a difference of 284 bats. A larger Common Pipistrelle and Soprano Pipistrelle data set would be required to re-test this hypothesis and confirm a statistical significance in pipistrelle emergences.

Looking into the wider literature on bat boxes specifically it can be seen that bats still prefer different internal structures at a species level, with pipistrelles preferring crevices and Brown Long-eareds preferring void-dwelling locations. (Garland *et al.*, 2017). However, Garland *et al.*, (2017) only looked at one series of maternity roosts which re-established itself over the course of three years, within a specifically designed bat building. Both this study and Garland *et al.*, (2017) can be taken into consideration when creating bat boxes or incorporating bat friendly spaces into already functional buildings, as they can be structured to species specific conditions. When comparing Garland *et al.*, (2017) to this study, Garland *et al.*, (2017) presents both Common Pipistrelle and Soprano Pipistrelle to be crevice dweller bats. The data gained from this study may not have been statistically significant due to the vastly different number of emergences from each property.

The least number of emergences being one for both and the most being forty-four for the Common Pipistrelle data and sixty-one for the Soprano Pipistrelle data. To counter act this more properties would need to be surveyed in order to conclude if the data is statistically significant when similar emergence numbers are compared. Then a higher chance of obtaining a significant result can provide more information on which to base a conclusion, and have a better comparison to Garland *et al.*, (2017). The wider literature (Lourenço, and Palmeirim 2004, Licht and Leitner's 1967, Mering and Chamber 2014) also confirms that specific temperatures are required within bat boxes and bat friendly spaces for bats to be able to preserve energy while resting for bats not to overheat. The most common bat found within all the surveys within this study was the Soprano Pipistrelle, which has a higher heat tolerance than most other British bat species. They can survive within roosts or bat boxes up to 40°C therefore requiring black bat boxes to absorb more wavelengths of light in order to reach higher temperatures (Lourenço, and Palmeirim 2004). However, it was seen in Collins *et al.*, (2020) when temperatures were reaching temperatures higher than 40°C overheating within bat species was taking place. Twenty-two bats from that study were seen to fall out of the bat boxes when trying to emerge and all were dehydrated when brought into care (Collins *et al.*, 2020).

Roosts are important for *Microchiroptera* as this is where the majority of their lives are spent (Lausen and Barclay 2002), they are important for socialisation, mating, hibernation, and rearing young (Kunz 1982). To be able to adapt structures such as buildings or create bat boxes more research would have to take place to identify specific roost features. This would include internal roost searches (with licences) with known bat species to conclude specific bat box features.

Is there a preferred habitat type in which species of UK bats dwell and emerge?

The identified hypothesis that total bat species favour rural habitats to emerge and dwell in can be rejected, as there is no significant difference between habitat types and emergences. Although a large proportion of the bats can be seen within agricultural land and semi-rural. This is also seen in the hypothesis that Soprano Pipistrelles prefer rural habitats as the data analysis concluded no significant difference in habitat type. Although again a large proportion of the emergence habitat data is found within semi-rural habitats. However, the Common Pipistrelle hypothesis (same above) although also rejected, concluded that there was a significant preference for agricultural land.

As no significant difference was found between total species emergences and habitat type, this resulted in a deeper look into the data set. Upon further investigation a pattern can be seen within agricultural land and semi-rural having over three quarters of emergences overall (420). When comparing results to other studies it has been found that bats can benefit from these habitats on a species-to-species level. Organic agriculture is highly beneficial to bat populations providing many characteristics of semi-natural habitats (Wickramasinghe *et al.*, 2003) (such as seen in rank 3). Higher levels of dipterans can be found within agroecosystems (Fuentes-Montemayor *et al.*, 2013) and they also provide habitats such as hedgerows which bats are known to use as flight paths (Zeale *et al.*, 2018). Agroecosystems and hedgerows are particularly beneficial to *myotis* bats such as Natterers allowing cover from predators and increased dipterans levels. However, relating to this study, it is unknown whether the agricultural land surrounding the bat emergences is organic or inorganic, this would be an important factor which to obtain when concluding emergences from agricultural land and would require further research.

The highest emergence count of a single survey was within semi-rural habitats with a property having eighty-four emergences in a single night. This semi-rural site had a large housing network surrounding it, the wider ecosystem consisting of several nature reserves and water sources such as ponds. This surrounding woodland allows for a high population of bats to survive as it offers feeding and additional roosting opportunities for all bat species (Lacki *et al.*, 2007). Woodlands found within semi-natural habitats benefit *myotis* bats such as Barbastelles. This is due to its specialised feeding by gleaning invertebrates from vegetation (Fuentes-Montemayor *et al.*, 2013) so they are able to forage in 'cluttered environments' (Brigham *et al.*, 1997; Schofield *et al.*, 2004). As the bats at Property O live amongst a human neighbourhood, particular species have used human presence to their advantage. Low levels of light (below 25 lux) have been seen to benefit Soprano Pipistrelles because of the dipteran attraction to light (Michaelsen *et al.*, 2018). However high light levels have been found to disrupt flight paths and deter bat species (such as *myotis*) from urbanised areas (Mathews *et al.*, 2015).

However, when looking at a species level at Soprano Pipistrelles, the data analysis concluded there was no significant difference between habitat type and Soprano Pipistrelle emergences. Significantly more Soprano Pipistrelles emerged within semi-rural habitats than any other habitat. But because of this the data was uneven with over half the data set falling into semi-rural habitats, which may have led to the

insignificant outcome, as the data analysis does not match the wider context, and more secondary data is required to investigate this further.

Urban habitats have resulted with the lowest emergence data results for all data measured within this study. Urban habitats cannot provide characteristics seen within British bat species natural habitats such as woodlands. There is little canopy and vegetation cover from predators (Meyer *et al.*, 2008), and less reliable foraging opportunities (Lacki *et al.*, 2007). However similar emergence numbers were recorded within the rural habitats which could be seen as the most beneficial habitat towards bat species. Although low numbers of emergences were recorded within these areas, bats were still seen to be present, and this could be because bats are favouring other roost sites rather than buildings. Trees are one example as they give slow flying bats (*Myotis*) the opportunity to not travel far from their roost site to forage.

The main species at the property on all three surveys was Soprano Pipistrelles with an estimated eighty-six numbered maternity roost. With the benefits of both the anthropogenic and natural environment it can be assumed that the high numbers of Soprano Pipistrelles found there are benefiting from both aspects of the habitat (Lourenco *et al.*, 2004). This is because of their urban adapter evolutionary advantage to survive alongside humans (McKinney 2006) and potentially provide a pest control symbiotic relationship. Because of this however, over half of the Soprano Pipistrelles ended up emerging from semi-urban habitats (majority from Property O) making the data set highly uneven. An increased number of emergences with a data set with a larger variety of habitat emergences would be able to conclude a reliable data set. To conclude this statement, further investigation would have to take place on specific Soprano Pipistrelle foraging activity within the natural and un-natural areas of the ecosystem.

However, when looking at the species level for Common Pipistrelles the results lead to the conclusion that there is a statistical significance in emergences from within agricultural land. This can be seen when looking that the data with agricultural land having the highest Common Pipistrelle emergence count. When looking at the wider literature bats are seen as valuable aspects of pest control (Kalda *et al.*, 2015) as mentioned previously when discussing all bat species. Because of their value within agroecosystems the United Kingdom has a number of agri-environmental schemes to adapt less intensive environmental practices, in order to protect bat species such as the Common Pipistrelle (Fuentes-Montemayor *et al.*, 2013). When looking at the difference between agricultural habitats compared to rural and semi-rural habitats and the wider literature it is seen that Common Pipistrelles prefer to forage in 'uncluttered' environments such as in sparsely wooded landscapes and open areas (Fuentes-Montemayor *et al.*, 2013; Klingbeil and Willig 2009). This can be seen in agroecosystems as they have less woodland environment thus benefiting Common Pipistrelles fast foraging technique and similar if not more dipterans available. This makes agricultural land the ideal habitat for Common Pipistrelles.

Limitations for the overall hypothesis suggest that more data would need to be collected from rural, semi-urban and urban habitats due to an unequal sample size which may be driving the statistically insignificant data. This would allow for an equal sample size to conclude results with higher accuracy.

Is there a correlation between time of first emergence and sunset time?

Sunset and sunrise timings are crucial to bats as this allows them to emerge at peak dipteran activity at dusk and then return to a roost just before dawn. These primal instincts can be shifted off balance when high levels of artificial light are used at night causing a change in emergence or re-entry time making them vulnerable to predators. These results promote the importance of light within a twenty-four hour cycle for bats showing their exact emergence and re-entry times and how it benefits their hunting pattern.

The identified hypothesis that sunset time has an effect on the time of first bat emergence (for total bat species) is accepted, as there is a strong positive correlation between the two variables that was significant. A higher confidence level can be seen past 21:00, this is because the majority of sunset times happened past 21:00 when the data set was collected, with the average emergence time being 20:59 with the average sunset time being 20:47. This pattern of high correlation between sunset time and time of first emergence can be seen across the wider literature. The wider literature provides the insight that bat emergences are 'controlled by the endogenous rhythm, synchronised with the external 24-h light-dark cycle' (Erkert, 1982) which is controlled primarily by sunset and sunrise time.

The latest sunset time was found to be at 21:24 with the first emergence occurring at 21:19 for that property. This emergence was a Common Pipistrelle which is slightly earlier than the wider reading suggests. Swift (1980) shows that Common Pipistrelles emerge an estimated thirty-five minutes after sunset with little flexibility. When looking at the wider environment this property is situated within a rural habitat with high tree density and overhead cover. This aligns with Rydell and Speakman's (1995) data that bats will emerge earlier before sunset to take advantage of peak dipteran activity to increase their feeding time.

Different bat species have different emergence times which depend on environmental factors such as predators and light intensity and biological factors such as pregnancy and age. This is seen in Duvergé *et al.*, (2000) when measuring emergence times within Greater Horseshoe bats and Lesser Horseshoe bats. Observation included pregnant females of both species emerging later as lactation occurred, and energy demands increased (Duvergé *et al.*, 2000). Serotine bats also have a strong correlation between time-of-day roost, emergence and sunset time (Catto *et al.*, 1995)

Limitations would include when bats for reasons such as pregnancy, injuries, or environmental factors e.g., temperature choose to emerge later than predicted. This may happen after surveys finish or when surveys cannot continue, because of the lack of visibility or unpredicted weather conditions. To be able to counteract this, surveys would need to be extended and other equipment such as infrared or temperature cameras can be used to increase viability without using light. The results were also limited at the species level due to the small volume of first emergences being either Common or Soprano Pipistrelles leaving the data inconclusive. A specialised series of surveys would have to be carried out in order to gain conclusive results to discuss at a species level.

Is there a correlation between time of first re-entry and sunrise time?

The identified hypothesis that sunrise time has an effect on time of first bat re-entry for total bat species is rejected as the data analysis, concluded no significant correlation between the two variables. However, this conclusion is only made apparent when an outlier is removed from the data set. This outlier was driving the positive relationship between the two variables causing the positive correlation.

When examining the outlier, a Soprano Pipistrelle is seen re-entering a property thirty-five minutes before sunrise. Although there is a lack of research into bats returning to roosts within Britain, one study suggests that Soprano Pipistrelles returned to roosts an average of four hours after their original emergence (Stone 2015). This would require the original emergence to be an estimated 01:06am which would have been roughly four hours before sunset. This is not a typical emergence time of a Soprano Pipistrelle as they emerge an estimated twenty minutes after sunset (University of Bristol 2005) to take advantage of peak dipteran activity at dusk (Jones and Rydell 1994). With limited wider reading available to conclude a reliable result other factors are taken into consideration when presented with an outlier.

There is very little wider literature studying the effect of sunrise time on re-entries within British bat species but there are still factors affecting re-entry time. The main factor affecting bat activity and returning to roosts is pregnancy, as energy demands are higher and reserves are lower impacting their flight durability and hunting quality (Duvergé *et al.*, 2000). This would lead to subsequently later emergences and earlier re-entries. Environmental factors can also affect earlier returns to roosts which can be seen within Watkins (1971) study with high winds causing an earlier return to roosts. Fenton (1969) also saw earlier roost returns with high periods of rainfall affecting bat activity.

Limitations are mainly down to a small dataset. The re-entry data set is less than half the size of the emergence data set, as the majority of the data required for a phase 2 bat surveys can be carried out at emergence surveys which are at more sociable hours. Also, according to bat survey guidelines (Collins *et al.*, 2016) only one re-entry survey (dawn) was required on all survey sites (where the secondary data was collected from Ecosupport) whereas all sites required two or more emergence surveys (dusks). Additional re-entry surveys would need to take place in order to build up a sufficient data set. This is also a similar limitation to species level results with the last re-entry to a roost rarely being a Common Pipistrelle or Soprano Pipistrelle. A specialised series of surveys would have to be carried out in order to gain conclusive results to discuss at a species level.

Conclusions

British bats did not have a preference for any specific habitat type, building feature or re-entry time. However, there was a preference in emergence time with it being after 21:00. When looking at building features it is seen that for each species studied (total species, Common Pipistrelles, and Soprano Pipistrelles) that there is no significant difference of emergence location from Tiles and Other Features. This however does not align with related literature as both Common Pipistrelles and Soprano Pipistrelles are known to choose emergence location based on slates, tiles and inner cavities of buildings. Overall total species emergences are limited by vague descriptions for building features gained within secondary data sets.

Habitat type also has the same conclusions that there is no preference for emergence within a specific habitat type for all species of bats (total species and Soprano Pipistrelles). However, a large proportion of the data set has found within agricultural land and semi-rural habitats. When looking at species level is seen that Common Pipistrelles have a preference to agricultural land to emerge within. This may have been because of agricultural land having high levels of dipteran activity allowing for a reliable food resource for Common Pipistrelles to acquire. A statistically significant result was not seen within Soprano Pipistrelle populations however but, a large number of emergences occurred within semi-rural habitats. This may have been because of their urban adapter evolutionary advantage to use both urban and rural aspects of their habitat.

When looking at sunset data it is seen that total bat species studied had a high positive correlation of time of first emergence and sunset time, with the average emergence time being 20:47. This is backed up by the literature which suggests a primal instinct allowing bats to emerge at peak dipteran activity at dusk, to allow for a reliable feeding timeframe. Sunrise data on the other hand did not conclude any statistically significant results once an outlier was removed from the data set. This may have been because of earlier returns to roosts which were not picked up within the survey timeframe. The wider literature however is limited on this subject with the only literature describing the effects on pregnancy and re-entry back into roosts. There was also not enough data to conclude specific species level data on re-entries and sunrise times. Therefore a larger data set would be required to obtain those results.

Future work

To be able to continue this study to conclude any statistically significant results an even distribution of survey data between building features and habitat ranks would need to be obtained.

A study into specific building features would have a higher level of specificity within each feature to gain a better understanding of locations of emergences. Also recording a higher variety of species would make it possible to conclude if other species of bats such as Brown Long-eared have preferences of emergence locations. When species are discovered within a property (under the supervision of a licenced bat expert) to investigate lofts and wall cavities to describe each species preferred roost location and roost conditions such as temperature, humidity, materials used etc. This would allow for a higher level of knowledge to conclude from results for ideal conditions for bat box creation, studying both outer and inner materials as well as inner box conditions for bat roosts.

An examination of different habitat locations with a focus on agricultural land and semi-rural habitats. Considering the difference between organic and inorganic farming and noting how the population of bats changes between each using both transect surveys and emergence surveys where required. An exploration into different bat species which occupy feeding niches within organic and inorganic agriculture and if one habitat benefits a specific species. Carrying out a transect survey within an entire semi-urban habitat (such as a town), to evaluate if there are any advantages for bats at a species level. This would be able to conclude hotspots

for bat activity within a semi-rural habitat and what makes them favourable to bats such as building type, light levels, dipteran activity etc.

A higher variety of species could be surveyed looking at sunset times and times of first emergence. This would conclude different emergence times for specific species and then broadening it out into different variables for different emergence times such as habitat type, dipteran activity temperature etc. A larger set of results would need to be collected for sunrise data as this data set was 2/3 smaller than the emergence data sets. This would then indicate if there was a correlation between sunrise time and time of first re-entry overall before looking into it at a species level. To conclude any re-entries which happen outside of the timeframe of the survey a longer survey time would be required to properly assess this.

Overall, this study can allow for an understanding of different activity levels of bats within Hampshire, Berkshire and Surrey and conclusively may be able to be applied to the United Kingdom. With further studies indicating roost activity within bat boxes, buildings and different habitat types.

Acknowledgements

Throughout my research for this dissertation including my field work and my desk-based research, I would like to thank my advisor Dr Catherine (Catie) Gutmann Roberts for her extensive help and support throughout. Even without any prior knowledge on my chosen subject her overall professionalism and enthusiasm is outstanding, always pushing me to look deeper into what my results show. I cannot express enough gratitude towards her for all of her help throughout the last year.

I would also like to acknowledge the help of Ecosupport, an ecological consultancy who has allowed me to use their data in order to work on my project. For that I would like to acknowledge the CEO and principal ecologist Dean Swensson. Foremost I would also like to thank project ecologist Aaron Domblides for the hours of phone calls and emails he has set up to transfer me all the data sets required and to discuss my project at length. Finally, from Ecosupport I would like to extend my appreciation towards assistant ecologists Leah Murphy and Lewis Lakudzala for always being available questions and advice. All these ecologists are exceptional work colleagues.

My gratefulness is extended to my friends who throughout this have had to endure my constant bat knowledge entering every conversation for the last three years. Thank you for (half) taking in what I have to say and looking at all the images of the bats that I show you.

To both my Environmental Science and Environmental Management classmates of 2019-2022 thank you for your encouragement and support especially through the Covid-19 pandemic. It has been a hard few years but we've done it!

Finally, I credit the bats I have had the pleasure of working with over the last year, especially: Crispin, Sherlock, Holly, Dani and Jemima, you are the real stars here.

References

- Ancillotto, L. and Russo, D., (2020) Brown Long-Eared Bat *Plecotus auritus* (Linnaeus, 1758). *Handbook of the Mammals of Europe*, pp.1-18.
- Bat Conservation Trust (2021) *Bats in Buildings - Buildings, planning and development*. [online] Bat Conservation Trust. Available at: <https://www.bats.org.uk/our-work/buildings-planning-and-development/bats-inbuildings>. [Accessed 16 Dec 2021]
- Bats and Climate Change (2020) *About – ClimBats – COST Action CA18107*. [online] COST Action CA18107 - Description of Project Climate change and bats: from science to conservation. Available at: <https://climbats.eu/about/> [Accessed 16 Dec. 2021]
- Berthinussen, A. and Altringham, J. (2012) Do Bat Gantries and Underpasses Help Bats Cross Roads Safely? *PLoS ONE*, 7(6), p.e38775.
- Bonato, V., Facure, K.G. and Uieda, W., (2004) Food habits of bats of subfamily Vampyrinae in Brazil. *Journal of Mammalogy*, 85(4), pp.708-713.
- Boyd, I.L. and Stebbings, R.E. (1989)., Population Changes of Brown Long-Eared Bats (*Plecotus auritus*) in Bat Boxes at Thetford Forest. *The Journal of Applied Ecology*, 26(1), p.101.
- Brigham, R.M., Grindal, S.D., Firman, M.C. and Morissette, J.L. (1997) The influence of structural clutter on activity patterns of insectivorous bats. *Canadian Journal of Zoology*, 75(1), pp.131–136.
- Brittingham, M.C. and Williams, L.M., (2000) Bat boxes as alternative roosts for displaced bat maternity colonies. *Wildlife Society Bulletin*, pp.197-207.
- Burger, J., Gochfeld, M., Powers, C.W., Clarke, J.H., Brown, K., Kosson, D., Niles, L., Dey, A., Jeitner, C. and Pittfield, T. (2013) Determining Environmental Impacts for Sensitive Species: Using Iconic Species as Bioindicators for Management and Policy. *Journal of Environmental Protection*, 04(08), pp.87–95.
- Carlier, J., Moran, J., Aughney, T. and Roche, N. (2019) Effects of greenway development on functional connectivity for bats. *Global Ecology and Conservation*, 18, p.e00613.
- Catto, C.M.C., Racey, P.A. and Stephenson, P.J. (1995) Activity patterns of the serotine bat (*Eptesicus serotinus*) at a roost in southern England. *Journal of Zoology*, 235(4), pp.635–644.
- Collins, J. and Bat Conservation Trust (2016) *Bat surveys for professional ecologists: good practice guidelines*. London: Bat Conservation Trust.

Collins, J.H., Ross, A.J., Ferguson, J.A., Williams, C.A. and Langton, S.D., (2020) The implementation and effectiveness of bat roost mitigation and compensation measures for *Pipistrellus* and *Myotis* spp. and brown long-eared bat (*Plecotus auritus*) included in building development projects completed between 2006 and 2014 in England and Wales. *Conservation Evidence*, *17*, pp.19-26

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.

Davies, T.W. and Smyth, T. (2017) Why artificial light at night should be a focus for global change research in the 21st century. *Global Change Biology*, *24*(3), pp.872–882.

De Conno, C., Nardone, V., Ancillotto, L., De Bonis, S., Guida, M., Jorge, I., Scarpa, U. and Russo, D., (2018) Testing the performance of bats as indicators of riverine ecosystem quality. *Ecological Indicators*, *95*, pp.741-750.

Dodds, M. and Bilston, H., (2013) A comparison of different bat box types by bat occupancy in deciduous woodland, Buckinghamshire, UK. *Conservation Evidence*, *10*(2), pp.24-28.

Domblides, A. (2021) Email to Hannah McCabe, 21 July.

Duvergé, P.L., Jones, G., Rydell, J. and Ransome, R.D. (2000) Functional significance of emergence timing in bats. *Ecography*, *23*(1), pp.32–40.

Ecosupport. (n.d.). *Ecosupport | Ecological Consultancy - Southern England*. [online] Available at: <https://ecosupport.co.uk/>.

Entwistle, A.C., Racey, P.A. and Speakman, J.R., (1996) Habitat exploitation by a gleaning bat, *Plecotus auritus*. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences*, *351*(1342), pp.921-931.

Entwistle, A.C., Racey, P.A. and Speakman, J.R., (1997) Roost selection by the brown long-eared bat *Plecotus auritus*. *Journal of Applied Ecology*, pp.399-408.

Erkert, H.G., (1982) Ecological aspects of bat activity rhythms. In *Ecology of bats* (pp. 201-242).

Falchi, F., Cinzano, P., Duriscoe, D., Kyba, C.C., Elvidge, C.D., Baugh, K., Portnov, B.A., Rybnikova, N.A. and Furgoni, R., (2016) The new world atlas of artificial night sky brightness. *Science advances*, *2*(6), p.e1600377.

Fenton, B.M. and Simmons, N.B., (2015) A world of science and mystery. *Chicago: University of Chicago*. 303pp.

Fenton, M.B., (1969) Summer activity of *Myotis lucifugus* (*Chiroptera: Vespertilionidae*) at hibernacula in Ontario and Quebec. *Canadian Journal of Zoology*, *47*(4), pp.597-602.

Fuentes-Montemayor, E., Goulson, D., Cavin, L., Wallace, J.M. and Park, K.J., (2013) Fragmented woodlands in agricultural landscapes: The influence of woodland character and landscape context on bats and their insect prey. *Agriculture, ecosystems & environment*, *172*, pp.6-15

Fuhrmann, M. and Seitz, A., (1992) Nocturnal activity of the brown long-eared bat (*Plecotus auritus* L., 1758): data from radio-tracking in the Lenneberg forest near Mainz (Germany). *Wildlife telemetry. Remote monitoring and tracking of animals*, pp.538-548.

Garland, L., Wells, M. and Markham, S., (2017) Performance of artificial maternity bat roost structures near Bath, UK. *Conservation Evidence*, *14*, pp.44-51.

Google Maps Imagery ©2023 Landsat / Copernicus, Data SIO, NOAA, U.S. Navy, NGA, GEBCO, Imagery ©2023 TerraMetrics, Map data ©2023

Häussler, U., Nagel, A., Braun, M. and Arnold, A., (2000) External characters discriminating sibling species of European pipistrelles, *Pipistrellus pipistrellus* (Schreber, 1774) and *P. pygmaeus* (Leach, 1825). *Myotis*, *37*, pp.27-40.

Jenkins, E.V., Laine, T., Morgan, S.E., Cole, K.R. and Speakman, J.R., (1998) Roost selection in the pipistrelle bat, *Pipistrellus pipistrellus* (Chiroptera: Vespertilionidae), in northeast Scotland. *Animal behaviour*, *56*(4), pp.909-917.

Jones, G. and Rydell, J., (1994) Foraging strategy and predation risk as factors influencing emergence time in echolocating bats. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences*, *346*(1318), pp.445-455.

Kalda, O., Kalda, R. and Liira, J., (2015) Multi-scale ecology of insectivorous bats in agricultural landscapes. *Agriculture, Ecosystems & Environment*, *199*, pp.105-113.

Kalka, M.B., Smith, A.R. and Kalko, E.K., (2008) Bats limit arthropods and herbivory in a tropical forest. *Science*, *320*(5872), pp.71-71.

Kasso, M. and Balakrishnan, M., (2013) Ecological and economic importance of bats (Order Chiroptera). *International Scholarly Research Notices*, *2013*.

Klingbeil, B.T. and Willig, M.R., (2009) Guild-specific responses of bats to landscape composition and configuration in fragmented Amazonian rainforest. *Journal of applied ecology*, pp.203-213.

Kunz, T.H., Braun de Torrez, E., Bauer, D., Lobova, T. and Fleming, T.H., (2011) Ecosystem services provided by bats. *Annals of the New York academy of sciences*, *1223*(1), pp.1-38.

Lacki, M.J., Amelon, S.K. and Baker, M.D., (2007) Foraging ecology of bats in forests. *Bats in forests: conservation and management* (MJ LACKI, JP HAYES, and A. KURTA, eds.). Johns Hopkins University Press, Baltimore, Maryland, pp.83-127.

Lakudzala, L. (2019) The effect of urbanisation on African bat community composition and diversity (unpublished).

Lausen, CL and Barclay, RM, (2002) *Roosting behavior and roost selection of female big brown bats (Eptesicus fuscus) roosting in rock crevices in southeastern Alberta. Canadian Journal of Zoology*, 80 (6), pp.1069-1076.

Lewanzik, D., Straka, T.M., Lorenz, J., Marggraf, L., Voigt-Heucke, S., Schumann, A., Brandt, M. and Voigt, C.C. (2022). *Evaluating the potential of urban areas for bat conservation with citizen science data. Environmental Pollution*, 297, p.118785. doi:<https://doi.org/10.1016/j.envpol.2021.118785>.

Licht, P. and Leitner, P., (1967) Behavioural responses to high temperatures in three species of California bats. *Journal of Mammalogy*, 48(1), pp.52-61.

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.

Makanya, A.N. and Mortola, J.P., (2007) The structural design of the bat wing web and its possible role in gas exchange. *Journal of anatomy*, 211(6), pp.687-697.

Mathews, F., Roche, N., Aughney, T., Jones, N., Day, J., Baker, J. and Langton, S., (2015) Barriers and benefits: implications of artificial night-lighting for the distribution of common bats in Britain and Ireland. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 370(1667), p.20140124.

Mayr, E., (1970) *Populations, species, and evolution: an abridgment of animal species and evolution* (Vol. 19). Harvard University Press.

McKinney, M. L. (2006) Urbanization as a major cause of biotic homogenization, *Biological conservation*, Vol. 1 (27), 247-260.

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. doi:<https://doi.org/10.1002/wsb.461>.

MET Office (2019) *Weather and climate change - Met Office*. [online] Met Office. Available at: <https://www.metoffice.gov.uk/>.

Meyer, C.F., Fründ, J., Lizano, W.P. and Kalko, E.K., (2008) Ecological correlates of vulnerability to fragmentation in Neotropical bats. *Journal of Applied Ecology*, 45(1), pp.381-391.

Michaelsen, T.C., Jensen, K.H. and Högstedt, G., (2018) Does light condition affect the habitat use of soprano pipistrelles *Pipistrellus pygmaeus* at the species northern extreme? *Acta Chiropterologica*, 20(2), pp.377-385.

Mickleburgh, S.P., Hutson, A.M. and Racey, P.A. (2002). *A review of the global conservation status of bats*. *Oryx*, 36(1), pp.18–34.
doi:<https://doi.org/10.1017/s0030605302000054>.

Minitab18, (2018) *MINITAB*, Available at: <https://www.minitab.com/en-us/> (Accessed: 6/10/2023).

Norberg, U.M. and Rayner, J.M., (1987) Ecological morphology and flight in bats (Mammalia; Chiroptera): wing adaptations, flight performance, foraging strategy and echolocation. *Philosophical Transactions of the Royal Society of London. B, Biological Sciences*, 316(1179), pp.335-427.

Perry, R.W. (2012). A review of fire effects on bats and bat habitat in the eastern oaks region. pp.170–191.

Riccucci, M. and Lanza, B., (2014) Bats and insect pest control: a review. *Vespertilio*, 17, pp.161-169.

Rowse, E.G., Lewanzik, D., Stone, E.L., Harris, S., and Jones, G. (2016) Dark Matters: The Effects of Artificial Lighting on Bats. In: Voigt, C., Kingston, T. (eds) *Bats in the Anthropocene: Conservation of Bats in a Changing World*. Springer, Cham. https://doi.org/10.1007/978-3-319-25220-9_7

Russo, D. and Jones, G., (2015) Bats as bioindicators. *Mammalian Biology*, 80(3), pp.157-246.

Russo, D., Cistrone, L., Jones, G. and Mazzoleni, S., (2004) Roost selection by barbastelle bats (*Barbastella barbastellus*, *Chiroptera: Vespertilionidae*) in beech woodlands of central Italy: consequences for conservation. *Biological Conservation*, 117(1), pp.73-81.

Russo, D., Salinas-Ramos, V.B., Cistrone, L., Smeraldo, S., Bosso, L. and Ancillotto, L., (2021) Do We Need to Use Bats as Bioindicators? *Biology*, 10(8), p.693.

Rydell, J. and Speakman, J.R., (1995) Evolution of nocturnality in bats: potential competitors and predators during their early history. *Biological Journal of the Linnean Society*, 54(2), pp.183-191.

Schaub, A., Ostwald, J. and Siemers, B.M., (2008) Foraging bats avoid noise. *Journal of Experimental Biology*, 211(19), pp.3174-3180.

Schoeman, M.C. (2015). Light pollution at stadiums favors urban exploiter bats. *Animal Conservation*, 19(2), pp.120–130.

Schofield, H. and Fitzsimmons, P., (2004) The importance of woodlands for bats. *Managing Woodlands and their Mammals*, p.41.

Seto, K.C., Fragkias, M., Güneralp, B. and Reilly, M.K., (2011) A meta-analysis of global urban land expansion. *PloS one*, 6(8), p.e23777.

Smith, G.C. and Agnew, G., (2002) The value of 'bat boxes' for attracting hollow dependent fauna to farm forestry plantations in southeast Queensland. *Ecological Management & Restoration*, 3(1), pp.37-46.

Speakman, J.R., Thomas, D.W., Kunz, T.H. and Fenton, M.B., (2003) Physiological ecology and energetics of bats. *Bat ecology*, pp.430-490.

Stone, E., Zeale, M.R., Newson, S.E., Browne, W.J., Harris, S. and Jones, G., (2015) Managing conflict between bats and humans: the response of soprano pipistrelles (*Pipistrellus pygmaeus*) to exclusion from roosts in houses. *PLoS One*, 10(8), p.e0131825.

Stone, E.L., Jones, G. and Harris, S., (2009) Street lighting disturbs commuting bats. *Current biology*, 19(13), pp.1123-1127.

Swift, S.M., (1980) Activity patterns of pipistrelle bats (*Pipistrellus pipistrellus*) in north-east Scotland. *Journal of Zoology*, 190(3), pp.285-295.

University of Bristol (2005) *Soprano Pipistrelle Bat*. [online] www.bio.bris.ac.uk. Available at: <http://www.bio.bris.ac.uk/research/bats/britishbats/batpages/sopranopipi.htm#topofpage>

Vaughan, N., Jones, G. and Harris, S. (1996). *Effects of sewage effluent on the activity of bats (Chiroptera: Vespertilionidae) foraging along rivers*. *Biological Conservation*, 78(3), pp.337–343.

Watkins, L.C., (1971) A technique for monitoring the nocturnal activity of bats, with comments on the activity patterns of the evening bat, *Nycticeius humeralis*. *Transactions of the Kansas Academy of Science (1903-)*, 74(3/4), pp.261-268

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

Wildlife and Countryside act (1981), United Kingdom, [online] Available at: <http://www.legislation.gov.uk/ukpga/1981/69/contents> [Accessed 16 December 2021].

Zeale, M.R., Stone, E.L., Zeale, E., Browne, W.J., Harris, S. and Jones, G., (2018) Experimentally manipulating light spectra reveals the importance of dark corridors for commuting bats. *Global change biology*, 24(12), pp.5909-5918

Zukal, J., Pikula, J. and Bandouchova, H., (2015) Bats as bioindicators of heavy metal pollution: history and prospect. *Mammalian Biology*, 80(3), pp.220-227.

Appendices are provided separately as supplementary files (see additional downloads for this article).