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Habitat associations of British bat species on lowland farmland within the Upper Thames catchment area

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Summary

1. The habitat associations of vespertilionid bat species were investigated within six lowland farmland sites in relation to the use of three different linear features and a single open area habitat.
2. Overall, bats were found to utilise 'greater' hedgerows, i.e. hedgerows with stands of mature trees, more than any other habitat type sampled. The 45 kHz pipistrelle (*Pipistrellus pipistrellus*), the 55 kHz pipistrelle (*Pipistrellus pygmaeus*) and *Myotis* species all significantly preferred the greater hedge and woodland edge linear features over the lower, mechanically cut hedgerows and open grassland field areas. In addition, both pipistrelle species showed preference toward these two habitats not only as commuting aids, but also as foraging areas.
3. At warmer temperatures bat activity increased at the greater hedgerow, a likely result of increasing insect activity at higher temperatures.
4. Differing plant species richness of the four habitats did not fully explain the preference of bat species towards these habitats. However, vegetative composition of the habitats is more likely to be an influential factor for the higher bat activity rates of the greater hedge and woodland edge, as both types are comprised of similar species, i.e. tree species including Oak (*Quercus robur*), that were otherwise absent from the other, less frequently utilised habitats.
5. These results suggest that careful maintenance, conservation and enhancement of tree-lined hedgerows, could greatly increase the value of linear and hedgerow habitats for British bat species.

Key-words: bats, Microchiroptera, agri-environment, hedgerow management.

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Introduction

Britain is home to 16 species of Microchiroptera with several additional species, such as the Parti-coloured bat (*Vespertilio murinus*) and the Northern bat (*Eptesicus nilssonii*) occurring as vagrant visitors to the country, (JNCC, 2001). British bats are subdivided into two families: the Vespertilionidae (vesper bats), which comprise 14 species; and the Rhinolophidae (horseshoe bats), which comprise 2 species (Altringham, 1996).

Each bat species has specific habitat requirements, but the key factors that influence bat distribution are roost availability and presence of suitable foraging sites (Bihari, 2004). As a result of changing land management practices and agricultural intensification over the past 40 years there has been considerable degradation and destruction of roosting sites and foraging habitats of many british bat species and every one has, at some time, shown some degree of population decline (Rydell, 1992; Defra, 2005). Even Britain's most common bat species, the 'Common' or 45 kHz pipistrelle (*Pipistrellus pipistrellus*) has shown a marked decline since the 1980s (Walsh & Harris, 1996; Stebbings, 1998).

As a measure to halt and reverse the decline of British bat populations, Section 5 of the Wildlife & Countryside Act 1981 (WCA) (as amended) provides protection for all 16 species of bat that occur in the UK and for their roosts, which now have full legal protection in England, Scotland and Wales, with extended protection under the Countryside and Rights of Way (CroW) Act 2000 (JNCC, 2006; Bat Conservation Trust, 2004). In addition, in the UK Biodiversity Action Plans (BAPs) have been produced for several priority species of bat including the 45 kHz Pipistrelle (*Pipistrellus pipistrellus*) and the 55 kHz Pipistrelle (*Pipistrellus pygmaeus*) (JNCC, 2001). Through careful management of agricultural land to increase important habitats for bats, as well as roost and hibernacula conservation, the UK BAP aims to increase bat populations to pre-1970 numbers (JNCC 2006). The 45 pipistrelle also has an unfavourable conservation status in Europe and is listed in Appendix III of the Bern Convention, Annex IV of the EC Habitats Directive and Appendix II of the Bonn Convention.

In comparison to other vertebrate groups such as birds, there have been relatively few studies on bats in agricultural settings (Stebbings, 1988) and as a result the exact effects of agricultural practices on vesper bat populations are often hard to quantify (Defra, 2005). Despite this recent studies based in agricultural settings all agree that the national decline of British bat species is likely to have resulted, at least in part, from increased farm size due to mechanisation and the reduction in connective, linear habitats such as hedgerows used by bats for feeding and commuting (Russ & Montgomery 2002; Altringham, 1996; Wickramasinghe *et al*., 2004).

Furthermore, large-scale use of pesticides causing a decline of the insects consumed by bats (Wickramasinghe *et al*., 2004); habitat degradation and loss of diversity (Robinson & Sutherland 2002); loss of roosting and hibernation sites (Wunder & Carey, 1996); and inappropriate riparian management such as excessive water extraction and pollution (Wickramasinghe *et al*., 2003; Wickramasinghe *et al*., 2004) have all been suggested as potential causes of bat decline.

Linear landscape features, such as hedgerows and the edges of woodland, are often cited as important and essential habitat elements for bat as they have been shown to use them as commuting flight paths and as foraging habitats (Racey & Swift, 1985; Limpens & Kapteyn, 1991; Walsh & Harris, 1996a; Walsh & Harris, 1996b; Verboom & Huitema, 1997; Grindal & Brigham, 1998; Verboom & Spoelstra, 1999). However, while the type of woodland edge used by bats has been extensively studied, clear definitions of what constitutes a suitable hedgerow for bats remain poorly characterised.

A lack of appropriate management in recent decades has resulted in the degradation or loss of many hedgerows and many that remain are too low, leggy, gappy or even over-grown to support high levels of biodiversity. Modern mechanical maintenance of hedgerows is also detrimental as is does not allow for new tree growth within the hedgerow, as any saplings are cut off if protruding through the 'line' of the hedge.

In contrast, traditionally managed hedges that are, in some cases, remnants of ancient woodland are extremely rich in both plant and animal species and their structures are able to sustain far more biodiversity. The importance of correctly managed ancient and/or species-rich hedgerows for biodiversity is reflected in their inclusion as a 'priority habitat' in the UK Biodiversity Action Plan (BAP) of 1995.

Thus, it is clear that if conservation intervention for bats is to be successful then the key features of the hedgerows in their habitat that they require must be determined and hedgerows restored accordingly. In this study we have evaluated the activity patterns of different bat species in different habitats and under different environmental conditions.

We have examined the relationships of bats with different types of hedgerow by comparing whether low cut hedgerows without trees or sympathetically managed tree-lined hedgerows significantly influence the activity of different vespertilionid bats in an agricultural landscape. In addition, we have also determined whether bats use hedgerow habitats in preference to woodland edge and have assessed behavioural foraging activities to establish whether any of the studied habitats are also utilised preferentially as foraging grounds by different bat species.

Table 1. Summary of the four broad habitat types that were the subject of this study

Abbreviation	Type	Habitat	Description
LH	Linear	'Low' hedgerow	Intensely managed hedges, less than 4m in height. Trees absent.
GH	Linear	'Greater' hedgerow	'Traditional' hedgerow, with stands of mature trees.
WE	Linear	Deciduous/ mixed woodland edge	Predominantly broad-leaved woodland edge, with few or no Coniferous species.
GF	Open	Unimproved/Improved Grassland	Grassland used for grazing.

Methods

BAT SURVEYS

An acoustic bat monitoring study was undertaken in six farmland sites situated within the Oxfordshire countryside from 30th April to 30th July 2007. All of the six sites surveyed are located in the Upper Thames catchment area, with the majority clustered around or near the town of Witney. Three of the sites – Wytham, Burleigh and Ducklington – were classed as ‘wet’ (containing riparian features such as a stream or river), whilst the other three – Chasewood, Evenlode and Caswell – were classed as ‘dry’ and lacked such features.

Within each farm site a 1x1 km square (as used by Walsh & Harris, 1996; Russ & Montgomery, 2002) was selected that contained all four broad categories of habitat to be studied. These four categories were comprised of three linear landscape features and one open area (Table 1). A single, pre-determined observation point (as used in Wickramasinghe *et al*., 2003; Russ & Montgomery, 2002) was chosen along each linear feature and approximately in the centre of the open area, these points were located in the field with the use of a hand-held Geographic Positioning System (GPS). At each point (four per site), free-flying bats were recorded for a period of 30 minutes.

Surveys were conducted at the rate of one site (1 km square) per night. The first sample commenced half-an-hour after sunset, as this was deemed around the time when most bats had emerged or were emerging from their roosting sites (Jones & Rydell, 1994). All four habitat (point) recordings were completed within a 3-hour period and classed as Visit 1, 2, 3 or 4. BATBOX Duet bat detectors (BATBOX Ltd, England) were used to listen to echolocation calls. Detectors were set to a frequency of 45 kHz and tuned up and down when a bat was heard to establish at which frequency the ‘deepest’ sound occurred. Each 30-minute recording period was recorded directly onto portable minidisk recorders (Sony, M.D. Walkman, MZ-R91) and the exact minute a call was heard and the species/group were marked onto data sheets in the field. As bat detectors lack the ability to differentiate “between the same bat passing several times and single passes by several different bats” (Thomas and West, 1989; Walsh & Harris, 1996), counts of bats represent an index (minute) of activity, and are not related to or a method for proposing population densities. As a result, different species/groups could be recorded within the same minute. Pooling the data sets created a total of 32 samples per site.

HABITAT CHARACTERISATION

The three linear habitats were two hedgerow types, low hedge (LH) and greater hedge (GH), and one woodland type; the woodland edge. Hedgerows were selected in accordance with a definition provided by the Department of Food and Rural Affairs (Defra, 2007). Analysis of the species composition of the hedgerows was conducted along a 30-metre section from the sampling point (Defra, 2007); this defined length was also applied to the woodland edge. The height of the habitat was measured for the greater hedgerow and woodland edge. Within the grassland field habitat quadrats were randomly placed to determine the relative species richness of each field.

FORAGING BEHAVIOUR

Behavioural activity, namely the occurrence of feeding activity, was noted both during the field surveys and during the analysis of the recorded data.

ENVIRONMENTAL PARAMETERS

Environmental data recorded during the bat surveys included moon phase, light levels, temperature, cloud cover, time of night and wind speed. All environmental data was recorded onto the data sheets for the bat sample being collected.

DATA MANIPULATION & ANALYSIS

The data from the minidisks were downloaded to a desktop computer and analysed using BatSound (version 3.31 Pettersson Elektronik AB, Sweden). Bats that could not be confidently identified or assigned to a group were labelled ‘Unidentified’, as some calls were often extremely quiet and the image too faint to distinguish which bat species or indeed group, they may belong to.

Microsoft Excel 2000 was used to collate the data and for the production of figures and tables and statistical analyses were carried out in Minitab version 14 for Windows, and SPSS version 12 for Windows, with a significance level of 0.05 unless stated otherwise. Anderson-Darling normality tests were used to identify whether data conformed to a normal distribution. All skewed data ($p < 0.05$) was transformed using a $\log_{10}(x+1)$ transformation. Transformed data sets were analysed using parametric statistical analysis.

Results

OVERALL ACTIVITY

The combined survey results of this study produced a total of 5760 minutes of real-time recordings, of which bats were recorded in 2422 minutes (42%). Of the 13 bat species known to be present within the Oxfordshire district (Linton *unpublished data*, 2007), representatives from six different species were successfully identified during this study. These were the common (45 KHz) pipistrelle (*Pipistrellus pipistrellus*), the soprano (55 KHz) pipistrelle (*P. pygmaeus*), the natterer’s bat (*Myotis nattereri*), the serotine bat (*Eptesicus serotinus*), the noctule bat (*Nyctalus noctula*) and the barbastelle bat (*Barbastella barbastellus*). For the purposes of this study the serotine and noctule bats were grouped together as ‘big bats’.

During this study, the 45 KHz pipistrelle was the most commonly recorded bat species (Figure 1A). The 45 KHz and 55 KHz pipistrelles, *Myotis* species and the large bats were recorded across all six study sites,

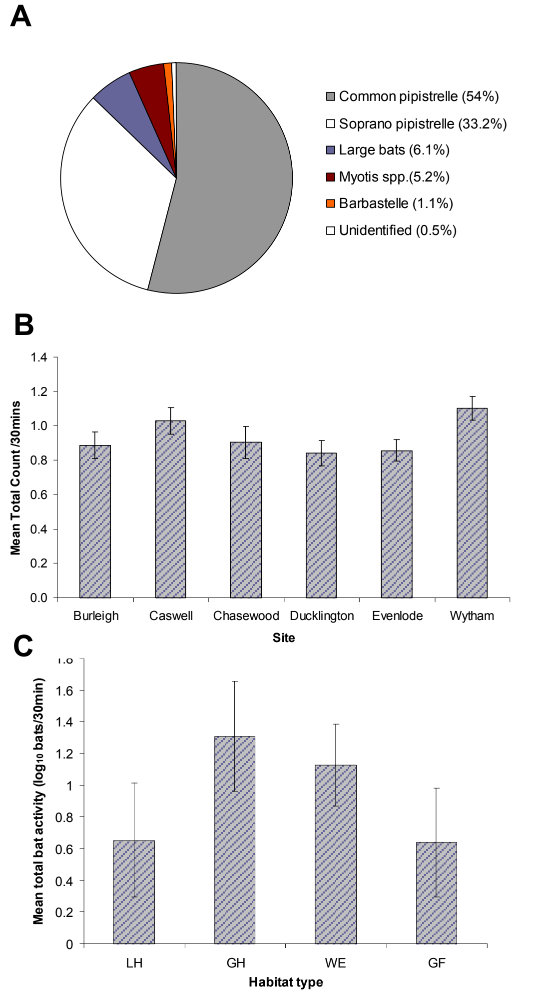

Figure 1. Total recorded bat activity during the study. (**A**) Relative levels of activity (%) recorded for each bat group during the study. (**B**) Mean total bat activity ($\log_{10}$+1) for each site. Error bars represent +/- 1x s.e. mean. (**C**) Mean total bat activity ($\log_{10}$+1) for each habitat type across all 6 sites. Error bars represent +/- 1x s.e. mean.

while the barbastelle bat was confirmed at three of the sites sampled – Chasewood, Burleigh and Evenlode.

Figure 1B shows that there were no significant differences between the mean total bat activities recorded at each of the different sites during the study. This was also to be the case for the individual bat groups when studied singly, with the exception of the 55 KHz pipistrelles, which exhibited significantly greater activity at the Wytham study site when compared to the other sites ($F_{185, 5} = 2.67$, $p < 0.05$) (data not shown).

As Figure 1C shows, the mean total bat activities recorded for the different habitats were significantly different ($F_{188, 3} = 50.50$, $p < 0.001$). In linear habitat types, the 'greater hedge' (GH) had the highest total level of bat activity recorded at 1201 minutes, while the woodland edge (WE) was the second most frequented habitat with 710 minutes of activity recoded during the study.

In contrast the low hedge (LH) and grass field (GF) habitats had relatively low overall activity levels with 247 minutes and 253 minutes of respectively.

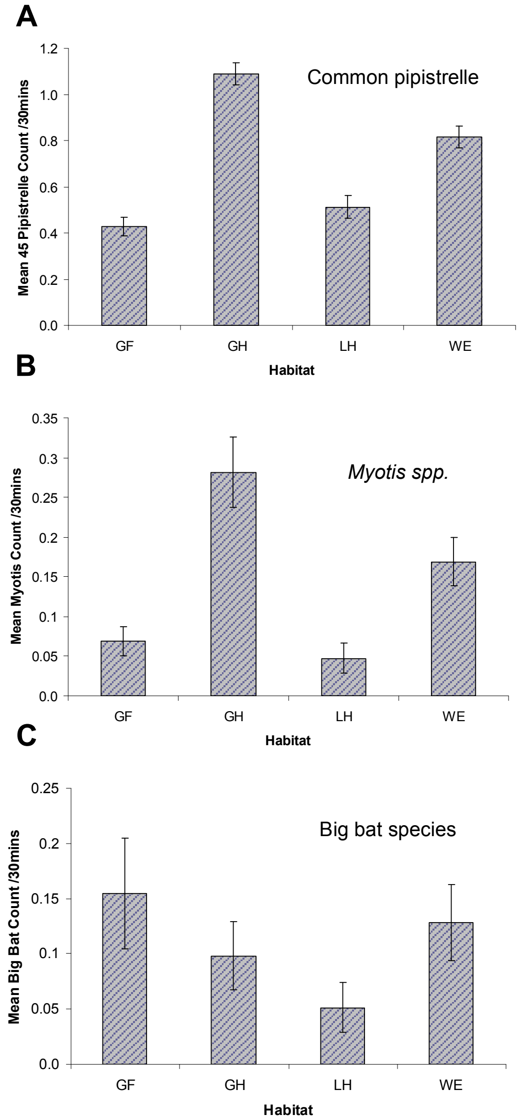

Figure 2. Mean bat activity recorded for different bat groups in different habitats during the study. (**A**) Mean counts recorded for common (45 KHz) pipistrelle in each of the 4 habitat types during the study. Error bars represent +/- 1x s.e. mean. (**B**) Mean counts recorded for *Myotis spp.* in each of the 4 habitat types during the study. Error bars represent +/- 1x s.e. mean. (**C**) Mean counts recorded for 'big bats' in each of the 4 habitat types during the study. Error bars represent +/- 1x s.e. mean.

HABITAT USE

Figure 2A shows that the 45 KHz pipistrelle bat was strongly associated with the GH and WE habitats ($F_{188, 3} = 42.69$, $p < 0.001$) and between these two habitats they significantly favour the hedgerow habitat. A similar pattern of activity is also seen in the 55 KHz pipistrelles (data not shown) and in the *Myotis spp.* bats (Figure 2B), which exhibited the greatest levels of activity in the GH habitat and significantly greater levels of activity in the GH and WE habitats compared to the GF and LH habitats. As can be seen in Figure 2B the *Myotis spp.* bats actually showed an even greater affinity for these habitats than the two pipistrelle species. Neither pipistrelle bat species nor the *Myotis spp.* showed any significant difference in their usage of the LH and GF habitats.

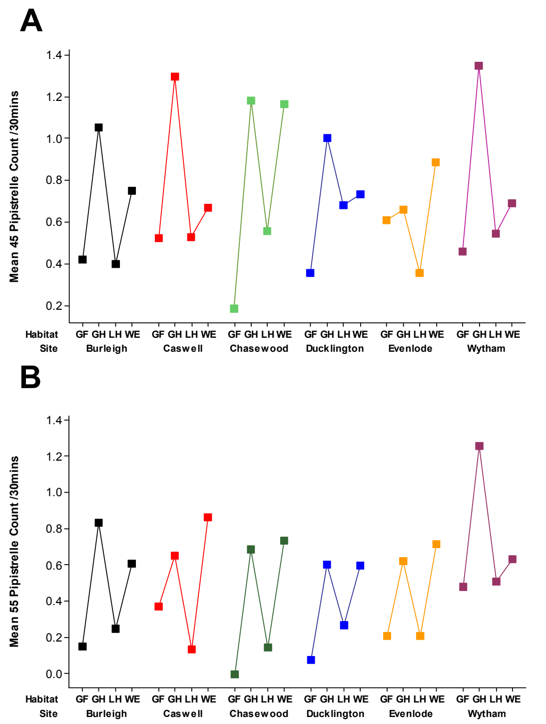

Figure 3. Mean activity of common (45 KHz) and soprano (55 KHz) pipistrelle bats recorded in different habitats at different sites during the study. (**A**) Mean counts recorded for common (45 KHz) pipistrelle in each of the 4 habitat types at each site during the study. (**B**) Mean counts recorded for soprano (55 KHz) pipistrelle in each of the 4 habitat types at each site during the study.

In contrast to these findings, the 'big bats' exhibited greater activity in the GF habitat when compared to the GH and WE habitats and their lowest affinity appeared to be for the LH habitat. These differences, however, proved not to be significant.

Barbastelle bats were recorded in only two of the four habitats (GH and WE), which indicated that they may have similar habitat associations to the other study groups. The low numbers of this species recorded, however, meant that the differences seen were not significant.

Analyses revealed that the distribution of total bat activity across the different habitats was different depending on which study site was examined ($F_{168,\ 15} = 3.7$, $p < 0.001$) and this was also true in two of the individual study groups; the common (45 KHz) pipistrelle bats ($F_{168,\ 15} = 3.76$, $p < 0.001$) (Figure 3A) and the *Myotis* bat species ($F_{168,\ 15} = 3.73$, $p < 0.001$) (data not shown).

In contrast, the soprano (55 KHz) pipistrelle bats exhibited habitat usage patterns that were not significantly different between the different sites (Figure 3B) and this was also found to be the case for the barbastelle bats and for the 'big bats' (data not shown).

FORAGING ACTIVITY

Figure 4A shows the mean total bat foraging activity for each of the habitat types in the study and shows that significantly more foraging occurred in the GH habitat ($p < 0.05$) than any of the others, while the WE habitat had significantly more foraging activity recorded in it than both the LH ($p < 0.005$) and the GF ($p < 0.001$) habitats. No significant differences in the mean total foraging activity in the GF and LH habitats were found.

Sufficient foraging activity to perform meaningful analyses was only recorded in the pipistrelle bat species and both showed significant foraging differences between habitats ($p < 0.001$ and $p < 0.001$ respectively) (data not shown). Both species exhibited the greatest foraging activity in the GH habitat ($p < 0.01$), with the WE habitat also showing significantly greater levels of activity ($p < 0.005$) than the other two habitats. Neither species showed a significant preference for either the LH or GF habitat for foraging.

To determine whether bats actually preferred to forage in certain habitats, the proportion of the total bat activity recorded in each habitat that was taken up with foraging activity was calculated (Figure 4B).

As Figure 4B shows, bats spent, on average, a significantly greater proportion of their time foraging while in the GH (71%) and WE (52%) habitats when these values are compared to the GF (16%) and LH (23%) habitats ($F_{87,\ 3} = 15.81$, $p < 0.001$). This indicates that bats not only exhibit greater levels of activity in these habitats, but that they also spend a greater proportion of their time foraging when they are in them.

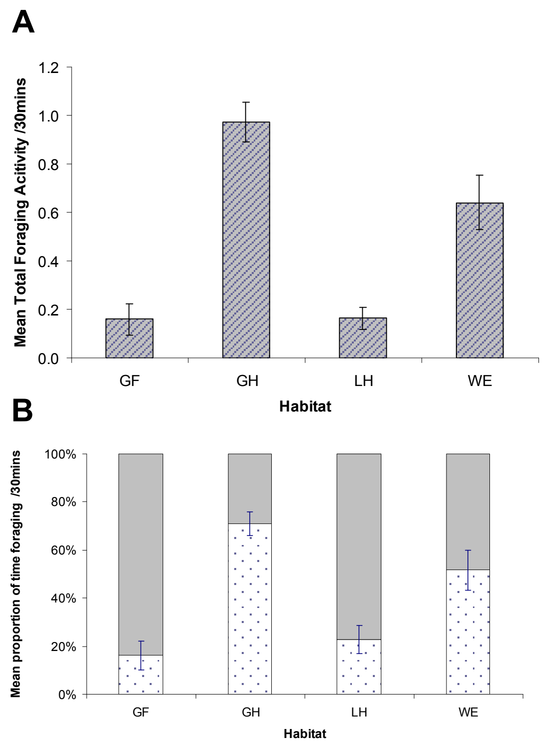

Figure 4. Foraging activity of bats recorded in different habitats during the study. (**A**) Mean total bat foraging counts recorded in each of the 4 habitat types during the study. Error bars represent +/- 1x s.e. mean. (**B**) Mean proportion of activity in each habitat counted as foraging in each of the 4 habitat types during the study. Error bars represent +/- 1x s.e. mean.

HABITAT CHARACTERISTICS

It was speculated that the preferences of bats for the GH and WE habitats may because of their physical or biological characteristics. Analysis revealed that the height of the habitat and the number of species that occurred in the different habitats varied significantly between the sites and so the total bat activity in each sample was correlated with the height of the habitat and the number of species in it irrespective of the broad habitat classification. The results, shown in Figure 5, revealed that bat activity was significantly correlated with both the height of the habitat (Figure 5A) and with the number of species in the habitat (Figure 5B). Multivariate analysis revealed that the height of the habitat was a better predictor of bat activity than species richness ($F_{189, 2} = 58.88$, $p < 0.001$)

CLIMATIC EFFECTS ON BAT ACTIVITY

Multivariate analyses of the bat activity data and the climatic variables measured revealed that average temperature on a particular day was significantly positively correlated with the mean total bat activity ($F_{189, 2} = 14.7$, $p < 0.001$) (Figure 6) and that when the variation due to temperature was taken into account the degree of cloud cover was also a significantly negatively correlated with mean total bat activity ($F_{189, 2} = 14.7$, $p < 0.001$). Temperature, however, did not explain the differences between the variations in activity between sites or habitats.

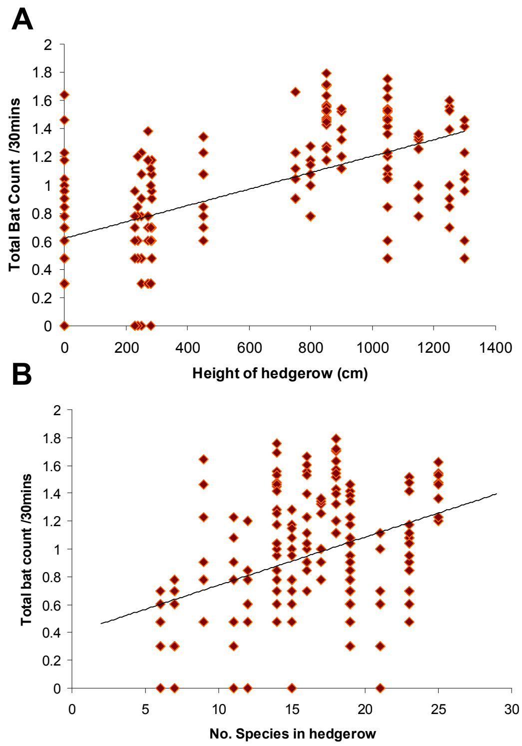

Figure 5. The effect of habitat characteristics on total bat activity. (**A**) Relationship between the height of a hedgerow and the total recorded bat activity during the study. Regression line is shown. (**B**) Relationship between the number of species in a hedgerow and the total recorded bat activity during the study. Regression line is shown.

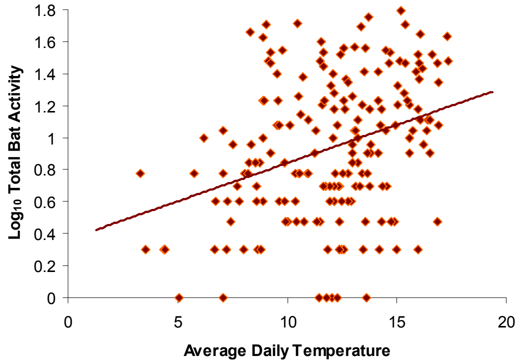

Figure 6. The effect of average temperature on total bat activity. Regression line is shown.

The effects of temperature and cloud cover that were observed in total bat activity were also found in the 45 KHz pipistrelle ($p < 0.001$), but not in the 55 KHz pipistrelle or the ‘big bats’, in which only temperature had a significant effect on activity, nor in the *Myotis spp.* or barbastelle bats, in which neither had any significant effect.

Discussion

LEVELS OF BAT ACTIVITY

The two species of pipistrelle, the common 45 KHz pipistrelle (*P. pipistrellus*) and the soprano 55 KHz pipistrelle (*P. pygmaeus*) were the most recorded bat species during this investigation. The common 45 KHz pipistrelle, despite having undergone dramatic population declines within the past 30 years, is still Britain’s most common bat species (Altringham, 2003), and this is reflected in the findings of this study. While the soprano 55 KHz pipistrelle shows considerable geographical overlap with that of the 45 pip within the UK, higher numbers of 55 pips are found in the north of the country (Altringham 2003). Thus, the results determined in this investigation, concur with these north/south trends of the two species, whereby soprano 55 KHz pipistrelles were recorded less frequently than common 45 KHz pipistrelles.

Myotis bat species were found to occur over all the farmland sites sampled, but overall this group did not contribute a large proportion of activity to the study. The natterer’s bat (*Myotis nattereri*) bat was recorded only at Wytham over the grass field, which could be explained by the presence of sheep, and less frequently cows, in this habitat. In two studies based on dietary analysis, Swift and Racey (2002) and Shiel *et al*. (1991) both found that natterer’s bats forage and glean insects from foliage and the ground and, Entwistle *et al*. (2001) found natterer’s to be the most dependent of the myotid bats on grassland habitats.

Numerous studies have reported Myotis species as particularly reliant and restricted to riparian habitats and some species within this group, such as the Daubenton’s bat (*Myotis daubentonii*), feed almost exclusively over water (Warren *et al*., 2000). As no riparian habitats were actively sampled for this investigation, it is perhaps not surprising that Myotis recordings were infrequent.

The 'big bats' group, which is comprised of noctule, serotine and potentially Leisler's species, were also recorded less frequently compared to the pipistrelles. Noctule and serotine bats are relatively widespread across Britain and are known to use open pastures, but as the ratio of open habitats to linear features in the sites of this study was 1:3, this could explain the relatively low activity recorded for this group.

The barbastelle bat (*Brabastellus barbastella*) was recorded very infrequently throughout this investigation. The Barbastelle is a very elusive bat and is so rarely recorded that its distribution across Britain is uncertain (Altringham, 2003).

HABITAT SELECTION

This study has demonstrated that bats significantly selected those linear features that included tree species (GH and WE) over any other habitat. For all species of bats combined, and for several individual species, the GH habitat was the dominant habitat in terms of bat activity. This finding is in accordance with other studies that have included hedgerows when determining bat habitat preferences and which also show high activity at hedges (e.g. Walsh & Harris, 1996b). However, our findings appear to contradict the findings of another study, which found that tree lines and woodland edges in general were selected in favour of hedgerows and that, overall, hedgerows were actually avoided by bats (Russ & Montgomery, 2002). This discrepancy could be explained by the fact that, in many of these studies, detailed descriptions of the hedgerows studied are not given and whether or not they were tree-lined or low, mechanically cut hedges was not specified. The low levels of bat activity levels at hedgerows observed in these studies could therefore have resulted from the amalgamation of data from low-cut intensely managed hedges and species-rich or tree-lined hedgerows, and this possibility is even suggested by the authors (Russ & Montgomery, 2002). This emphasises and highlights the importance of this study in determining whether tree-lined hedges are in fact preferable.

Previous studies have shown common 45 KHz pipistrelles to be generalist foragers, thus explaining its dominant presence in all four habitats (Vaughan *et al*., 1997; Russ & Montgomery, 2002; Davidson-Watts *et al*., 2006). Soprano 55 KHz pipistrelles, however, are often described as preferring riparian habitats and deciduous woodland (Davidson-Watts et al. 2006). In this study, the common 45 KHz pipistrelles significantly preferred the GH habitat to all other habitat and soprano 55 KHz pipistrelles were similarly closely associated with the GH and WE habitats. The proportion of time spent foraging by pipistrelles was also higher at the GH and WE habitats, which suggests that these species utilise the habitat not just for possible commuting behaviour but also as optimum foraging areas. The finding that 55 KHz pipistrelles equally prefer the GH and WE habitats has not been previously been reported.

The *Myotis* bat species also significantly preferred the GH and WE habitats to the LH and GF habitats, while the potential association of the barbastelle bats with the two tree-line habitats is in accordance with previous studies that have suggested that this species is reliant upon these habitats due to the presence of trees (Sierro, 1998; JNCC, 2006).

This study found that the larger ('big') bat species, such as the noctule and the serotine, exhibited no significant preference towards any of the habitat types. A possible reason for this could be that the noctule, known to feed on smaller insects as well as larger beetles and moths, can exhibit aerial hawking (capturing insects in flight) and that their prey of large beetles and moths are said not to require wind protection from linear features and are therefore found more commonly in open area habitats (Verboom & Huitema, 1997). As a result, noctule's are likely to feed at hedgerows for weaker flying insects and open fields for larger insects and not show a preference toward one habitat type over another.

The finding of this study that the selection of different habitats by some bats, but not others, varied between different sites is indicative that additional factors are influencing their behaviour. These factors could be variations in the management, topography, 'wetness' or food availability of the sites and have not been analysed in this study. One possible suggestion is that livestock, such as cattle, can have a positive influence on the number of foraging bats by increasing the presence of nocturnal insects such as dung-flies and beetles. In accordance with this, it was noted that three sites; Wytham, Evenlode and Caswell, had cows or sheep present in the field during periods of recording and that, possibly as a result, all had higher bat activity at their grass field habitats.

CLIMATIC EFFECTS

Throughout the summer of 2007, the period in which this study was conducted, very unusual weather conditions were experienced with extremely high levels of rainfall recorded (Smith, 2007). As flying is an energetically expensive activity and taller landscape features provide protection from buffeting winds, it was speculated that the association of bats with taller linear habitat features could have been a behavioural response to reduce impact of negative weather conditions (Verboom & Spoelstra, 1999).

In this study bat activity was positively correlated with the height of the habitat, but there was no significant association between wind speed and bat activity or habitat selection. In addition, if bats were selecting for taller habitats because of the shelter they offered, then the taller WE habitat might have been expected to show higher levels of activity to that of the GH habitat, but this was not the case for any of the bat species recorded.

Although Swift (1980) found that the emergence of 45 KHz pipistrelles from their roosting sites was not affected by cloud cover, we have demonstrated that, increasing temperature and cloud cover did combine to have a significant positive and negative impact respectively on both total bat activity and common 45 KHz pipistrelle activity. Furthermore, the activities of soprano 55 KHz pipistrelles and 'big bats', were also found to be significantly positively correlated with average temperature. These findings are in accordance with those of other studies that have demonstrated that noctule bats select roosts in the warmest available tree cavities and at the edge of woodlands for thermoregulatory reasons (Boonman, 2000) and that the serotine is also reliant on temperature to an even higher degree than that of the noctule (Altringham, 2003).

The positive correlation between the activity of certain bats and temperature may be because there is a positive correlation between insect activity and temperature, particularly over hedgerows (Abdullah 1961; Wickramasinghe *et al*., 2004). This means that on warmer nights there is greater food availability for bats and their foraging activity is correspondingly increased.

HEDGEROW CHARACTERISTICS

The GH and LH habitats did not exhibit significantly different levels of plant species richness and therefore cannot explain the preference bats exhibited towards the GH habitat over the LH habitat. However, there was a strong correlation between plant species richness and bat activity when broad habitat classification was removed. Multivariate analysis revealed that when the effect of hedgerow height was removed the significance of plant species richness was reduced, but it still had a strong effect.

This finding may indicate that the overall structure of the habitat is more important or that the bats are not influenced by the number of different species within the habitat, but more by the type of plants present. The fact that higher numbers of insects are associated with certain plant species may suggest this to be the case. For example, when comparing the bat activity in the GH habitats between sites it was observed that, while all had trees present, those at Evenlode uniquely lacked the native penndunculate oak trees (*Quercus robur*) found at Wytham, Chasewood, and Caswell. Interestingly all of the GH habitats at these latter sites had significantly higher levels of recorded bat activity than those at Evenlode, which suggests that the trees may act not only as windbreaks, but also as an important habitat for many invertebrates on which bats feed.

SUMMARY

The degradation, destruction and fragmentation of ancient woodland habitats has meant tree lined, species-rich and ancient hedgerows have become increasingly important landscape features for many wildlife species, including bats. In this study we have demonstrated the importance of tree-lined, species rich hedgerows to common 45 KHz pipistrelles, soprano 55 KHz pipistrelles and *Myotis* bats. We have also demonstrated that many bat species, especially common 45 KHz pipistrelles and soprano 55 KHz pipistrelles, use these habitats not just for commuting, but also as foraging habitats.

This finding; that hedgerows themselves can act as important feeding habitats, further highlights their importance in developing conservation strategies for British vespertilionid bats. For biodiversity action plans to be successful in conserving bats it is essential that species rich, tree-lined hedgerows are managed sympathetically by trimming them less severely, protecting existing trees and promoting new standard growth.

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