

Plasticity of sonal design by *Pipistrellus pygmaeus* in cluttered, edge and open space habitats

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Through echolocation bats utilise active sensing for orientation, avoiding obstacles and prey foraging. Active sensing has shown plasticity for its environment as bats must differentiate between returning echoes from their environment and prey. By measuring pulse duration and intervals of echolocating calls, amongst other sonal design features, it is possible to see changes throughout habitats that soprano pipistrelle (*Pipistrellus pygmaeus*) are found in. A conspecific difference in sonal design of calls can be observed through a direct relationship between the habitats, and it is these differences we aim to observe within *Pipistrellus pygmaeus*. In this experiment we studied the sonal design of the soprano pipistrelle in cluttered (woodland) habitats, edge habitats and open space. These studies were carried out using automated audio recording equipment, SM2BAT and SM4BAT, and took place on the grounds of Orierton house located in Pembrokeshire; south west Wales. The sonal design of calls was found to vary between the environments however did not produce the significant results we had expected.

Key Words: Bandwidth; Diversity; Pulse duration; Pulse interval; Scanning Behavior

Introduction

Approximately 70% of species use larynx derived ultrasonic signals to provide spatial recreations of their environment described by returning echoes (Jones and Teeling, 2006). Typically soprano pipistrelles use broadband calls and, as well as other bat species, have been shown to adjust their calls to localise nearby obstacles in a range-dependent manner (Jones and Holderied, 2007). Bats in open spaces utilise longer pulse durations as well as having longer pulse intervals between calls (Jones and Holderied, 2007). This longer pulse interval is believed to be present to allow for interpretation of information returned in the echoes (Jones and Holderied, 2007). The result of these changes to duration and interval will inherently lead to a difference in bandwidth of calls from broadband to narrowband or vice versa.

Following Jones and Holderied's work (2007) and specifically the work on flight and foraging behavior, excluding feeding behavior, we predict that pulse interval, pulse duration and bandwidth will vary between the three habitats. We will discuss the difference in scanning

behavior amongst habitats and we predict it will change between these. Finally, we will conclude with varying abundance and diversity of bat species between habitats and we predict it will vary between habitats.

Methods

One SM2BAT and one SM4BAT was placed in three defined habitats; there was a minimum of 30 metres between each detector in the same habitat. Habitats were designated as open, edge and cluttered and the specific definitions of these habitats were as follows:

1. Open: At least 20 m from any tree line in any direction from the location of the detector
2. Edge: 5 m (± 1 m) from any tree line at the location of the detector.
3. Cluttered: A minimum of 6 trees within a 10 m² area of the detector

The bat detectors were left out in their designated habitat overnight from approximately 21:30 until the following morning; programmed to record any sounds made. BatSound[®] software was used to analyse any soprano pipistrelle call that recorded; feeding buzz calls were omitted due to not providing a true representation of the *foraging* behavior.. In addition, though the calls were not measured, any other heterospecific call was identified and recorded to observe the biodiversity of the bats and any exigent differences in biodiversity between habitats. Once the data was collated and measured it was entered into SPSS[®] for statistical analyses.

Results

Pulse interval

A Kruskal-Wallis test showed a significant difference in the pulse interval between the three habitats, $\chi^2(2) = 7.528$, $df = 2$, $p = 0.05$, with a mean rank pulse interval score of 69.42 for the open habitat, 88.10 for the edge habitat, and 67.24 for the cluttered habitat. A pairwise post-hoc test with the Bonferroni adjustment was then used to determine that there was no significant difference between the open habitat and the edge habitat, and the open habitat and the edge habitat with $p = 1.000$ and $p = 0.090$ respectively. With the Bonferroni adjustment, none of the values in the pairwise post-hoc test came up as significant, however the comparison between edge and cluttered habitat came close with $p = 0.050$.

Pulse duration

A Kruskal-Wallis test showed a significant difference in the pulse duration between the three habitats, $\chi^2(2) = 14.545$, $df = 2$, $p < 0.05$, with a mean rank pulse interval score of 85.92 for the open habitat, 61.75 for the edge habitat, and 91.99 for the cluttered habitat. A pairwise post-hoc test with the Bonferroni adjustment was then used to determine that there was no significant difference between the open habitat and the edge habitat, $p = 1.000$. A significant difference

was found between the edge habitat and cluttered habitat, and the edge habitat and open habitat, $p < 0.05$ for both.

Call bandwidth

A Kruskal-Wallis test showed a significant difference in the call bandwidth between the three habitats, $\chi^2(2) = 29.223$, $df = 2$, $p < 0.05$, with a mean rank pulse interval score of 106.74 for the open habitat, 64.11 for the edge habitat, and 64.29 for the cluttered habitat. A pairwise post-hoc test with the Bonferroni adjustment was then used to determine that there was no significant difference between the cluttered habitat and the edge habitat, $p = 1.000$. A significant difference was found between the open habitat and cluttered habitat, and the open habitat and edge habitat, $p < 0.001$ for both.

Scanning behavior

A Kruskal-Wallis test showed that there was no statistically significant difference in scanning behaviour between the three habitats: open, edge and cluttered, $\chi^2(2) = 2.150$, $df = 2$, $p = 0.341$ with a mean rank scanning behaviour score of 84.23 for the open habitat, 76.47 for the edge habitat, and 70.27 for the cluttered habitat.

Discussion

Whilst our results were variable between environments we found that either they were not significant as we predicted they would be or, if they were significant, their significance did not represent the habitat's expected sonal design as we anticipated they would. We predict that this is likely due to not restricting the sensitivity of the SM2 and SM4BATs. It is anticipated that they were overly sensitive and picking up calls from their adjacent habitats, i.e. edge habitats picking up woodland calls and this likely substantially confounded our results.

Pulse Interval; **Figure 1**

There was found to be no significant differences between any of the habitats which disproved our prediction that there would be a significant difference between each environment type. It is, however, important to note that in the comparison of cluttered and edge habitats $p = 0.5$.

Pulse Duration; **Figure 2**

Bats commonly reduce their pulse duration, thereby increasing bandwidth, in cluttered and edge environments in response to increased background or environment echoes (Seibert et al., 2013). There was, in this experiment, found to be no significant difference between open and cluttered environments, however there was a significant difference between edge habitats where $p = 0.002$. As we predicted there would be a significant difference between each and every environment our predictions were disproved.

Call bandwidth; **Figure 3**

There was found to be no significant difference between cluttered and edge habitats in our results however open habitats differed significantly from both with $p = 0.000$. As we predicted there would be a significant difference between each and every environment our predictions were disproved.

Edge intermediacy; **Figures 1, 2 and 3.**

The results from these three figures did not represent edge habitats as an intermediate between open and cluttered habitats. This is likely due to the confounding sensitivity settings of the bat detectors. Our hypothesis was not proven.

Scanning behavior; **Figure 4**

There was found to be no significant difference between the habitats when considering scanning behavior. We anticipated there would be increased scanning behavior in edge habitats as they would be performing foraging calls and calls to detect increased background environment (Seibert et al., 2013); this lead us to reject this hypothesis. Whilst this did not fit our predictions it does present interesting results, for further work, that scanning behavior exists in all habitats.

Diversity

For all species that were identified, that were not soprano pipistrelles, the open habitat showed substantially more abundance than in the cluttered or edge habitats as seen in **Figure 5**. Soprano pipistrelles were shown to occur in an even distribution across the three habitats. Not enough samples of other species were collected to accurately accept or reject our hypothesis, however, specifically in terms of soprano pipistrelle, our hypothesis was disproved as they showed an even abundance across all three habitats.

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Figures

Figure 1

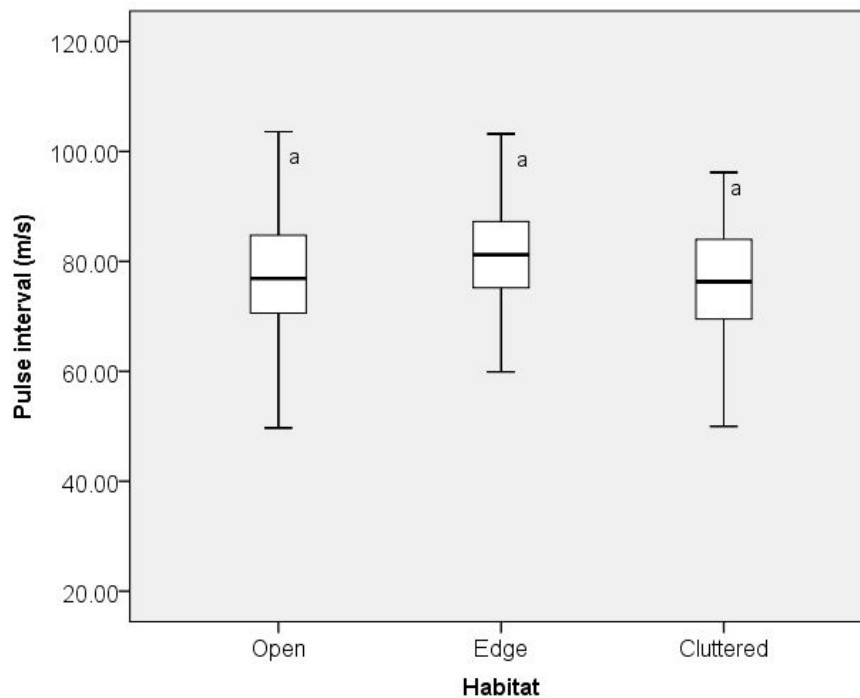


Figure 1 - The mean, interquartile range and full range of the pulse intervals of echolocation calls by *Pipistrellus pygmaeus* in each of three habitats. 'a' denotes data between which there are no significant differences.

Figure 2

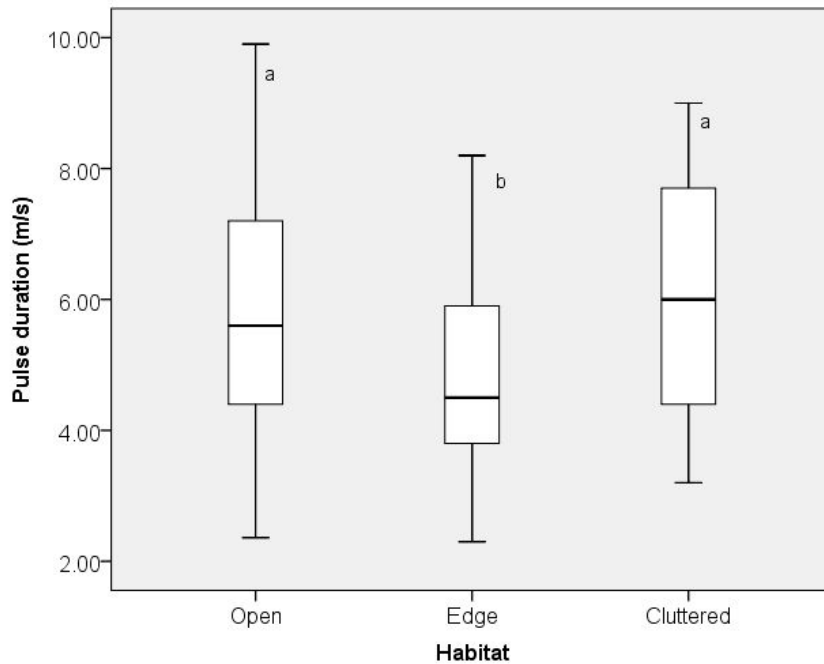


Figure 2 - The mean, interquartile range and full range of the pulse durations of echolocation calls by *Pipistrellus pygmaeus* in each of three habitats. 'a' denotes data between which there are no significant differences, 'b' denotes data that are significantly different from those labelled 'a' and those labelled 'a' are not significantly different from one another.

Figure 3

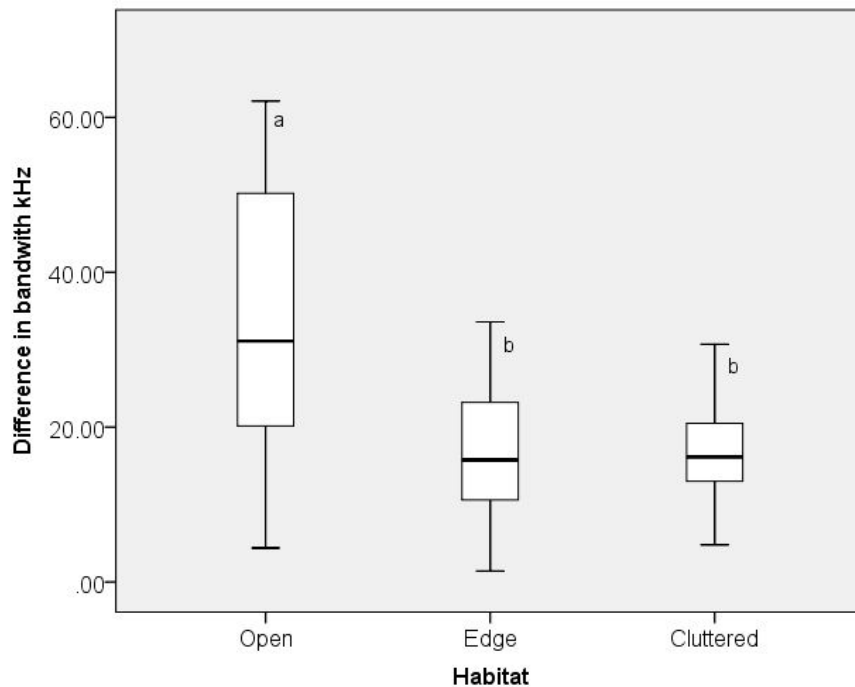


Figure 3 - The mean, interquartile range and full range of the bandwidths of echolocation calls by *Pipistrellus pygmaeus* in each of three habitats. 'a' denotes data between which there are no significant differences, 'b' denotes data that are significantly different from those labelled 'a' and those labelled 'a' are not significantly different from one another.

Figure 4

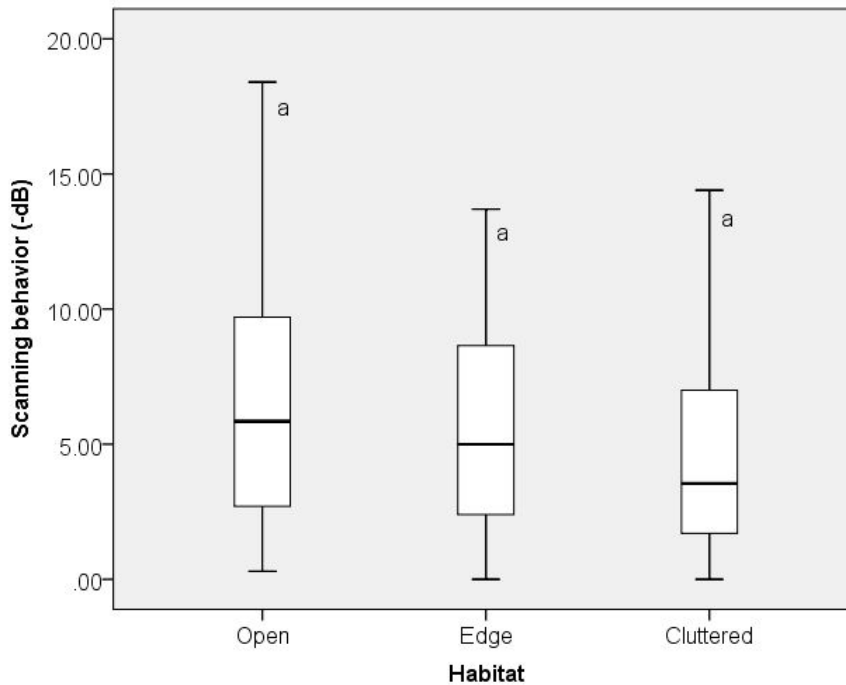


Figure 4 - The mean, interquartile range and full range of the scanning behaviour of echolocation calls by *Pipistrellus pygmaeus* in each of three habitats. 'a' denotes data between which there are no significant differences, 'b' denotes data that are significantly different from those labelled 'a' and those labelled 'a' are not significantly different from one another.

Figure 5

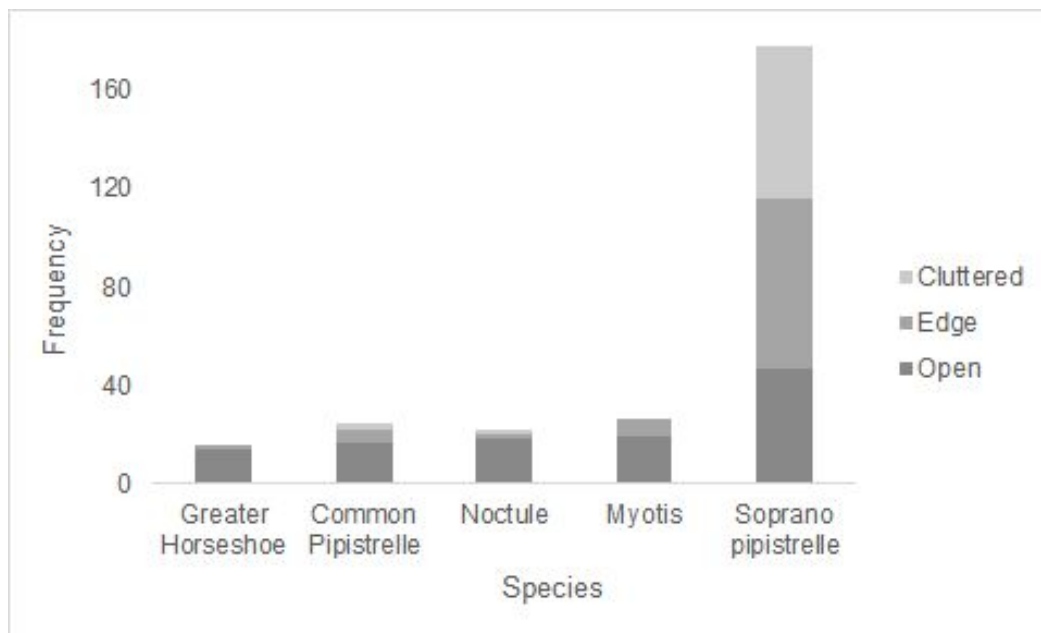


Figure 5 - Diversity of bat species across habitats. Green represents open habitats, blue represents edge and finally, yellow represents cluttered habitats.

EFFECTIVE WORD COUNT: 1500.

How echolocation call structure and wing morphology relate to the ecology of the European myotis bats.

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Introduction

The European myotis bats, *Myotis. nattereri*, *M. emarginatus*, *M. mystacinus*, *M. daubentonii* and *M. dasycneme*, which I will refer to generally as myotis, exhibit specific adaptations in wing morphology and the sonal structure of their echolocating calls (Siemers and Schnitzler. 2004). In this case they belong to the edge space aerial and trawling foragers guild of bats (Schnitzler, Moss and Denzinger, 2003) feeding on flying insects and spiders on foliage. These prey are found along edge habitats and amongst clutter and as a result the myotis faces the difficulty of differentiating between obstacles in their environment and prey items in the returning echoes of their calls. In addition, two species of these myotis bats that alternatively feed off of the water surface and they contend with floating debris complicating their returning echoes from prey items. Wing morphology is also vital to provide maneuverability to these myotis bats as a low aspect ratio and low wing loading afford slow flight imperative for capturing prey amongst clutter or on vegetation (Norberg and Rayner, 1987).

Echolocation calls

Jones and Holderied (2007) states echolocation calls of bats as “remarkable examples” of natural selection leading to good design of a species. In this case, they go on to explain that bandwidth of calls, pulse duration and pulse intervals of calls are perfectly adapted to reflect the needs of their ecological niche(s). In order to avoid any confusion caused by acoustic clutter in edge habitats, as well as in any cluttered habitats they might use, myotis bats will not use long pulse duration calls and will reduce its pulse interval length so provide more rapid updates to its surroundings.

Suga and Jen (1975) describe that certain bat species can contract a muscle in their middle ear whilst they are calling to avoid deafening themselves. During this period, any echoes that return whilst the bats are calling, especially in frequency modulated (FM), or broadband, bats such as these myotis bats are masked and not heard. This masking is also known as a signal overlap zone (SOZ). SOZ, more specifically, can be described the area around a bat where returning echoes overlap with the emitted call they're from. As sound travels at 340 ms^{-1} and the bat has a period between calls it must listen for echoes every additional 1 ms of call adds 17 cm to the

bat's SOZ. Because of this myotis bats generally tend to call at low duty cycles, meaning they have their calls active for a short period of time and therefore broadband. When foraging in cluttered spaces and approaching prey they shorten their SOZ.

Wing Morphology

This guild of bats, as previously described as forage in confined or cluttered spaces, require a high level of turning performance. This can be measured by two variables: maneuverability, described by the minimum space in which a bat can initiate a turn, and agility, the rate at which a turn can be initiated. In order to confer this turning performance these European myotis bats require a particular short and broad wing morphology. Firstly, a low aspect ratio of their wings worked out as $\text{span}^2/\text{area}$. In addition to this, they require a low amount of wing loading; determined by $\text{mass}/\text{area nm}^{-2}$ (Schunk, Swartz and Breuer, 2016). This is an inefficient type of flight not suited to long distances and has a high metabolic demand. Conversely, larger species of bats that hunt in open space habitats have high wing loading and high aspect ratios are better suited to faster and more efficient flight.

A large proportion of flying animals have their wings made of non-living materials such as chitin in insecta and feather in aves. By contrast, wings of bats are made of a living skin which is elongated by specialised arms and fingers (Hendenström and Johansson, 2015). This allows the wing to contain intrinsic muscles allowing control camber and curvature of the wing in flight conferring additional maneuverability in the niche fulfilled by this guild (Hendenström and Johansson, 2015). Furthermore, as a result of having their skin stretched over these specialised fingers it allows the bat to morph the shape and in turn the area of the wing and convex the shape to control the wings camber allowing the bat to have control over the lift coefficient; the ability to generate lift. Wings also have a tail membrane which has been studied to provide additional maneuverability for the bat. This tail membrane further changes the camber of the wing and also increases the angle of attack in flight (Gardiner et al., 2011).

Most bats in the northern hemisphere adopt hibernating strategies as opposed to migrating. Migratory bats require wings better suited to long and efficient flight. This guild of myotis bats are hibernating bats and as such are able to maintain their wing morphology best suited to their ecological niche (Hendenström and Johansson, 2015).

Conclusion

This guild of bats European myotis bats are defined by the ecological niche they fulfill, the edgeland. In order to be able fulfill this niche they inherently use broadband calls with short pulse duration and intervals. This allows them to reduce their SOZ and more rapidly update themselves on surroundings and approach prey in confined spaces. In addition, short broad wings confer slow and maneuverable flight further enabling living amongst edge habitats.

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