

Investigating the importance of riparian reserves for insectivorous bat species in oil palm and forest estates in Sabah, Malaysia

4th September 2015

Running head: Riparian reserves for insectivorous bats

Keywords: Chiroptera, Southeast Asia, palm oil, riparian reserves, habitat fragmentation, biodiversity loss

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This data will contribute to a peer-reviewed publication - please contact the author, Katherine Mullin on kem36@kent.ac.uk for further information.

Acknowledgements

I am very grateful to M. Struebig for giving me the opportunity to conduct this study and for supervising me throughout. Thank you to S. Mitchell and R. Drinkwater for their guidance in the field and to the field assistants at the SAFE camp. The project would not have been possible without the local collaboration with H. Bernard from the Universiti Malaysia Sabah and the approval from the SAFE Science Committee, the Sabah Biodiversity Council and the Maliau Basin Conservation Area Committee. Thank you for the financial support from the Durrell Institute of Conservation and Ecology (DICE) at the University of Kent and grants awarded to M. Struebig from the Natural Environment Research Council (NERC) under the Human-Modified Tropical Forests programme.

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Abstract

The expansion of oil palm cultivation is a major contributor to biodiversity loss in tropical countries. Riparian reserves, areas of native forest along rivers, offer a way of managing the maintenance of native species and their associated ecological processes within agricultural landscapes. Using acoustic sampling the importance of riparian reserves for insectivorous bats (Chiroptera) in oil palm plantations was investigated by comparing bat activity, feeding activity and species composition in riparian zones in logged forest with that in established riparian reserves within oil palm plantations. I also investigated whether bat activity was associated with riparian habitat covariates to gain an insight into possible optimum characteristics of reserves for bats. The results show that bat activity and feeding activity did not vary between the two riparian types suggesting that for insectivorous bats riparian reserves in oil palm support similar activity to that in logged forest. However, Constant Frequency species composition did vary between the two river types. Fewer of the forest-dwelling species *Rhinolophus trifoliatus*, *Rhinolophus sedulus*, *Rhinolophus borneensis* and *Hipposideros ridleyi* and a higher abundance of edge/open forest species *Hipposideros galeritus* and *Hipposideros cervinus* were found in oil palm riparian reserves. Canopy cover was a key habitat covariate in explaining variation in bat activity. Hence, my results show that riparian reserves sustain bat activity and provide foraging grounds for bats within an oil palm landscape, however the reserves may not provide large enough fragments of forest with sufficient complexity in vegetation structure to sustain the more vulnerable forest-dwelling species. Up to now, the possible benefits of riparian reserves have been poorly studied in Southeast Asia, therefore my results provide an insight into the extent of the ecological benefits these reserves may have in forest-agricultural landscapes.

Introduction

Expanding human populations and rising demand for resources make large areas of agriculture important features of our landscape, contributing to social and economic well-being (Godfray et al. 2010). However, the intensification and expansion of agriculture are two of the major causes of global biodiversity declines (Phalan et al. 2013). Since the tropics support large numbers of species and some of the world's last pristine habitats, the current crisis of biodiversity loss is occurring disproportionately in these areas (Sodhi et al. 2013). In these regions oil palm (*Elaeis guineensis*) plantations are just one example of a commodity agriculture crop undergoing rapid expansion. In the last decade alone palm oil production has more than doubled and demand is likely to rise, due to both its status as the world's primary and cheapest vegetable oil and its use as a biofuel feedstock (Saxon and Roquemore 2011). Plantations typically support less than 40% of the species found in logged or undisturbed forest (Fitzherbert et al. 2008) yet over half of plantation expansion in Malaysia and Indonesia between 1990 and 2005 was estimated to have required forest clearing (Koh & Wilcove 2008). This raises concerns over the unsustainable expansion of oil palm, and associated negative impacts on biodiversity.

To date, bats have been poorly studied in oil palm. However their worldwide distributions, taxonomic stability, and the ease of monitoring their population trends make bats an ideal indicator taxon (Jones et al. 2009). They comprise around 30% of Southeast Asia's mammals (Kingston 2010), an area where deforestation rates are the highest of all the tropics (Sodhi et al. 2010). Fragmentation, the reduction of continuous habitat into smaller and isolated fragments, is known to be a major driver of biodiversity loss (Sodhi et al. 2013), yet habitat loss and fragmentation continue to rise in Southeast Asia, with the expansion of oil palm being a key driver (Fitzherbert et al. 2008). Here, over half of the bat species are of

conservation concern and if deforestation continues, 40% of the species are predicted to be extinct by the end of the century (Lane et al. 2006).

In Borneo high bat diversity is associated with structurally complex, highly heterogeneous and undisturbed habitats (Struebig et al. 2013) however habitat loss affects insectivorous bat families differently. Forest dwelling species that forage and roost in the forest interior are likely to be more sensitive to deforestation due to ecomorphological traits preventing them from moving between forest fragments (Kingston et al. 2003) and the loss of tree cavities and foliage that they use for roosting (Struebig et al. 2008). This group includes the families Hipposideridae and Rhinolophidae. Insectivorous species such as Vespertilionid subfamilies Vespertilioninae and Miniopterinae that forage in forest edges or open spaces outside, or above the forest (referred to as edge/open species hereafter) may be able to adapt to disturbed habitats (Struebig et al. 2010).

The best way to mitigate and manage oil palm's poor diversity value is to maximise natural habitat within plantations which can be done by retaining connected forest fragments (Struebig et al. 2008). Spatial connectivity between fragments is vital for species that cannot migrate between fragments due to an impenetrable matrix (habitat outside the fragment) or physical limitations, as this isolation may cause them to behave as metapopulations (Carroll et al. 2004). Without connectivity these populations risk extinction due to the lack of genetic flow and reduced population size (Frankham et al. 2012). Protecting native forest alongside rivers is one way to retain forest habitat and connect larger fragments. These are called riparian reserves and are mainly retained in agricultural landscapes for their hydrological benefits, which include reducing run-off into streams (Tabacchi et al. 2000), nutrient regulation and pest control (Naiman et al. 2010). Due to these benefits riparian reserves are given protection, and in Malaysia logging and oil palm companies are legally required to set aside 30 metres of forest on either side of rivers 3-20 metres wide (Ewers et al.

2011). This protection provides a feasible option for improving biodiversity within cultivated landscapes. Riparian reserves can serve as dispersal corridors between larger habitat fragments, and provide access to water, food and vegetation for roosting (Gray et al. 2014).

The importance of riparian reserves for bats has not been explicitly studied in Southeast Asia, however in other parts of the world bats have benefitted from them in agricultural landscapes. In the neo-tropics, bats use reserves as stepping stones between patches of vegetation (Peña-Cuéllar et al. 2015) and in England reserves are known to be used for foraging due to the large number of insects supported by rivers (Vaughan et al. 1996). In Mexico, riparian reserves were found to host a higher abundance and diversity of bats compared to other landscape features (Galindo-González et al. 2003), and a study in Swaziland found that as well as high abundance and diversity there was also higher activity and species richness in riparian reserves compared with the surrounding savannah landscape (Monadjem & Reside 2008).

If riparian reserves are to be beneficial for biodiversity conservation and ecosystem functioning it is important to understand which species they support and how they can best be designed to preserve species in disturbed habitats. This study addresses this research gap. Acoustic sampling was used to investigate the differences in bat activity, foraging activity and species composition between riparian reserves in oil palm plantations and riparian zones in logged forest in Sabah, Malaysia. Acoustic survey techniques offer a non-invasive alternative to capture methods, where species can be identified and species that avoid capture can be detected (Struebig et al. 2016). Structural characteristics of riparian reserves were also quantified and associations between these variables and bat activity across the landscape were investigated in order to determine possible optimum features of riparian reserves for bat conservation.

Materials and Methods

Study Area

Research was conducted at the Stability of Altered Forest Ecosystems (SAFE) Project (www.safeproject.net) in the Kalabakan Forest Reserve in Sabah, Malaysian Borneo. The SAFE Project is set in lowland dipterocarp rainforest, and takes advantage of a planned conversion of forest to oil palm plantation. Throughout the duration of field research the forest was being salvage logged to make way for more oil palm plantation.

I conducted fieldwork in 6 forested riparian zones in the SAFE project landscape, and 6 established riparian reserves in the surrounding oil palm estates (Fig. 1, Table 1). These estates are managed by one company, Benta Wawasan Sdn. Bhd., which planted oil palm in 2000-2015 (Ewers et al. 2011). All oil palm riparian reserves that were sampled had retained forest-vegetation following the 30 m requirements in Malaysian law. However, the effective width of the forested zone varied substantially along and between individual rivers. Additional sampling was undertaken in three riparian areas designated as controls: one river completely surrounded by mature oil palm with no forest riparian zone (OP2), hence giving an insight into bat activity in oil palm where there is no forest to support the bats, and two rivers surrounded by either once-logged (LFE) or old growth forest (VJR). The latter two were chosen as control sites due to their relatively undisturbed continuous forest. In total I sampled 15 rivers, and all were sampled twice (Table 1).

Acoustic Sampling

I conducted acoustic surveys along rivers and associated riparian zones using a walking-point-transect design. At each site I recorded bats at 8 sampling points positioned approximately 180-220 m apart along a 2 km stretch of river. Surveys were undertaken in the early evening of rain-free nights during peak bat activity, and commenced just before sunset

(May 1823-1827, June 1831-1833 (Time & Date, 2015)). At each point, I recorded bat activity for 10 minutes (80 minutes of recording per night), using a full-spectrum EM3+ ultrasonic recorder (Wildlife Acoustics PLC). The detector was set to record on triggers, with sounds >18 db and >18 kHz triggering a recording. Sampling rate was set at 384 kHz allowing frequencies up to 192 kHz to be recorded. The maximum duration of recordings was set at 10 seconds. One trigger was considered a bat pass of the microphone and this gave an index of bat activity. Triggers and associated data were stored onto an SDHC card as .WAV files.

The EM3+ microphone is omnidirectional, with optimal recordings $\pm 30^\circ$ vertically and 60° horizontally to the microphone. As with all acoustic devices, the detection zone of the microphone varied for different species, and depended on sound attenuation and vegetation clutter around the river. For this reason, if physically possible, I broke up the 10 minutes of recording into 4 in the centre of the river, and 3 on either bank approximately 5 m from the river's edge. This minimised bias to river-species whilst also maximising detection of forest interior species. All rivers were sampled on two occasions, visiting sites sequentially from one end of the river to the other. The first samples of the six forested riparian zones were conducted in 2014 by Simon Mitchell and Dr Struebig using the same data points, however I analysed the recordings from those samples in the same way as the rivers sampled by me in 2015. When logistically possible I sampled the rivers starting at the opposite end of the transect on the second sample in order to control for differing levels of bat activity over the period of the evening. For example, I expected higher bat activity earlier in the evening, around and just after dusk, with declining activity as the evening progressed.

Processing bat calls

Data from each night was attributed using the SonoBat SM2 Batch Attributer, and then scrubbed using the SonoBat Batch Scrubber 5.2 to remove noise files and other ultrasonic activity (e.g. from insects or frogs). The remaining 7,751 calls were processed using SonoBat 3.2p batch processor, and each manually accepted or rejected as a genuine bat trigger. An independent trigger file was accepted as a genuine bat call if there was a minimum of three pulses. To quantify bat activity at each river I used the number of genuine bat microphone triggers, noting that this could represent a single bat responsible for multiple triggers. When the calls were processed I identified feeding buzzes through visual interpretation of the call and also through auditory identification. When bats are in the final stages of prey capture the durations of the pulses in the call become shorter and the number of pulses increase making identification possible (Figure S1).

I used SonoBat to automatically extract the following call parameters, which were exported into a database for each sound file to facilitate subsequent identification: pulse duration (length of a single pulse), highest frequency (of dominant harmonic) and lowest frequency (of dominant harmonic) (Struebig et al. 2016). All genuine bat calls were manually viewed alongside the call parameters, and were subsequently classified into the following call-types adopting the definitions of Struebig et al. (2016): constant frequency (CF), frequency modulating-quasi constant frequency (FM-QFC), broad band frequency modulated (FMb), multi-harmonic frequency modulated (MHFM) and multi-harmonic QFC bats (Figure S2). As the echolocation calls of many bat species from the study landscape were unknown it was not feasible to identify all bats to the species level. However, horseshoe and leaf-nosed bats (Rhinolophidae and Hipposideridae respectively) could be confidently identified due to the species-specific peak parameters of their constant frequency (CF) tone (Table 2). These call parameters were taken from Payne and Francis (1998) and from a self-made library of

recordings from bats caught in harp traps in the forest interior. Analysis was therefore restricted to the level of call-type for most bats, with the addition of species-based analysis for CF bats.

Environmental characteristics of riparian zones

During the acoustic surveys river width and canopy cover were recorded at each point on every river, giving 48 data points in both riparian types. The width of the river was measured from bank to bank at the highest water mark point using a measuring tape. Canopy cover directly above each point was recorded as an estimate between 0 and 100%. In order to measure the widths of the riparian reserve at each point I used satellite imagery (SPOT, 2011) together with the measuring tool in ArcMap version 10.2.2. At each point the river width was then subtracted to yield the total width of forest. Riparian width was only measured for the oil palm rivers due to the forest being continuous in places along the forested rivers.

The rest of the vegetation data came from 25 x 25 m plots conducted by other researchers at the SAFE project. Plots were implemented in forested riparian zones only, totalling 32 data points across the 6 rivers. The diameter at breast height (DBH) was recorded and this measurement was converted into Basal Area (BA) in m²/ha using the following equation:

$$BA = DBH^2 \times 0.00007854 \text{ (x4 to scale up to 1 ha from the 25 x 25 m plot)}$$

Tree density was recorded as the number of trees within the plot of DBH >10 cm. Canopy height was the mean height of all trees within the plot. These habitat variables were chosen due to Struebig et al. (2013) studying their associations with bats in the SAFE landscape.

Statistical analysis

For all analysis (bat activity, feeding activity and call-type analysis), counts of each parameter from both visits to a river were summed at each point, to give each point a total

count for all three activity types. I tested activity and feeding activity data from the 6 riparian zones in either forest (48 points) or oil palm (48 points) for normality using the Shapiro-Wilk tests in IBM SPSS Statistics Version 22. Because neither river type had normal distributions for activity (forested riparian zones: $W = 0.902$, $p < 0.001$; oil palm riparian reserves: $W = 0.878$, $p < 0.000$), and feeding activity (forested riparian zones: $W = 0.786$, $p < 0.000$; oil palm riparian reserves: $W = 0.681$, $p < 0.000$) I used the non-parametric Mann-Whitney U test to compare general activity and feeding activity between rivers in forest and oil palm. Additional Mann-Whitney U comparisons were made between activity and feeding activity in forested or oil palm riparian reserves with their respective controls, noting the unbalanced design from limited samples of control rivers.

I compared the number of FM-QCF and CF triggers between the two river types, and also within the river types using Mann-Whitney U tests. Due to the overlapping calls of *Rhinolophus trifolius* and *Rhinolophus francisi*, and the rarity of *R. francisi*, the two species calls were grouped together. This was the most abundant taxon and so I ran a Mann-Whitney U test to compare the numbers between oil palm riparian reserves and forested riparian zones.

In order to model bat activity against habitat variables I used Generalized Linear models (GLMs) with quasi-poisson error terms in R (R Development Core Team version x64 3.2.1). In order to avoid collinearity in the GLMs, only non-correlated variables were included ($r_s < 0.5$) (Table S3). As basal area and tree density were correlated ($r_s = 0.981$, $p < 0.000$) I included basal area due to its relevance in carbon stock research conducted in the SAFE landscape. The model with the lowest residual deviance was identified as the best model. Activity data partitioned to call type and feeding buzz data led to overinflated models and so are not reported.

Results

Over 30 survey nights I recorded 14,572 sound files, however only 7,751 sound files were recognised as bat calls. Of these, I manually identified 2,830 as being genuine bat triggers. The forested riparian reserves had 44.1% of the recordings whilst the oil palm riparian reserves had 39.8%. The control rivers made up the remaining recordings. FM-QCF bats were more active than any other echo-type, making up 73.2% of total bat activity. Six CF taxa were identified which made up 22.0% of all bats, hence this was the amount I identified to species level. Other echo-types made up the final 4.8% of which 83.9% were five species of FMB bats (Table 1).

Variation in bat activity and feeding activity

There was slightly more activity in the forested riparian zones compared with oil palm riparian reserves, although this difference was not significant ($U_{48,48} = 1146.0$, $Z = -0.044$, $p = 0.965$), similarly for feeding activity ($U_{48,48} = 1018.5$, $Z = -1.004$, $p = 0.316$) (Fig. 2). Activity ($U_{48,16} = 226.0$, $Z = -2.452$, $p = 0.014$) and feeding activity ($U_{48,16} = 231.5$, $Z = -2.445$, $p = 0.014$) did significantly differ between the forested riparian zones and the control forest rivers with the former having greater activity and feeding activity. Activity ($U_{48,8} = 155.5$, $Z = -0.855$, $p = 0.400$) and feeding activity ($U_{48,8} = 140.0$, $Z = -1.278$, $p = 0.233$) did not differ significantly between the oil palm riparian reserves and the oil palm control.

Call type and species-level responses

FM-QCF bat activity did not significantly differ between the forested riparian zones and the oil palm riparian reserves ($U_{48,48} = 1034.0$, $Z = -0.865$, $p = 0.387$). Although there was an apparent difference overall between CF activity in forested riparian zones and oil palm riparian reserves there was no significant difference ($U_{48,48} = 929.5$, $Z = -1.686$, $p = 0.092$) (Fig. 2). There was more FM-QCF bat activity than CF bat activity in both the forested

riparian zones ($U_{48,48} = 718.5$, $Z = -3.20$, $p < 0.001$) and the oil palm riparian reserves ($U_{48,48} = 298.5$, $Z = -6.297$, $p < 0.000$).

Six CF taxa were recorded over the study period and all were found at least once in both forested riparian zones and oil palm riparian reserves. *R. trivoliatus*/*R. francisi* was the most abundant taxa in both river types, representing 78.9% of CF bats in forested riparian zones and 83.8% of those in oil palm riparian reserves; however their activity was lower in oil palm riparian reserves (Table 2). Although a difference in their activity between forested riparian zones and oil palm riparian reserves was apparent, it was not significant ($U_{48,48} = 1020.0$, $Z = -1.045$, $p = 0.296$).

The least common CF species overall was *Rhinolophus borneensis* and all Rhinolophidae species had lower activity in the oil palm riparian reserves (Table 2). *Hipposideros galeritus* and *Hipposideros cervinus* were the only 2 species to have a greater abundance in oil palm riparian reserves compared with forested riparian zones. Despite the increases in these two Hipposideridae species, the vulnerable species *Hipposideros ridleyi* was recorded 10 times in the forested riparian zones and just once in the oil palm reserves.

Relationships between bat activity and vegetation covariates

When activity data from both river types was pooled into the GLM, river type had no effect on activity, supporting the Mann-Whitney U results that activity is comparable across all rivers. The model that best predicted activity was the one that included both canopy cover and river width (Table 3), concluding that over all of the study sites, wider rivers with denser canopies had fewer bats. Despite investigating models including canopy cover, river width, canopy height and basal area in the forested riparian zones, and canopy cover, river width and riparian width in the oil palm riparian reserves, the model of best fit for activity in both river types was the one with just canopy cover (Table 3). Canopy cover was greater in the forested

riparian zones (mean (SD)= 56.24 (30.29)) compared to the oil palm riparian reserves (mean (SD)= 44.38 (32.41)), albeit not significantly (Table S4).

When the two river types were combined, feeding buzzes were significantly negatively correlated with canopy cover ($r_s = -0.268$, $p = 0.008$, $df = 94$) and river width ($r_s = -0.211$, $p = 0.039$, $df = 94$). In the forested riparian zones feeding buzzes were negatively correlated with river width ($r_s = -0.317$, $p = 0.028$, $df = 46$) and in the oil palm riparian reserves they were negatively correlated with canopy cover ($r_s = -0.303$, $p = 0.036$, $df = 46$) (Figure S5).

Discussion

Trends in activity and feeding activity

This study indicates that riparian reserves support bat populations within an oil palm landscape as levels of activity and feeding activity were comparable between forested riparian zones and oil palm riparian reserves. Similar results are reported for other taxa such as leaf litter ants (Gray et al. 2015) and dung beetles (Gray et al. 2014) where riparian reserves were found to have similar species richness and community composition as nearby continuous logged forest.

The relatively low activity and feeding activity in the forested controls compared to the forested riparian zones might be unexpected, but this result supports the use of riparian reserves as foraging grounds for bats. The comparable levels of bat activity and feeding activity in the oil palm control and the oil palm riparian reserves were also interesting. Although studies are far from conclusive oil palm plantations typically have negative consequences on the arthropod community (Turner & Foster 2009), including the reduction in moth diversity (VunKhen 2006) and mosquito numbers (Chang et al. 1997) both of which are prey for insectivorous bats. These results contradict studies that have found higher bat activity in riparian reserves compared to the surrounding matrix (Galindo-González et al.

2003; Monadjem & Reside 2008). The quality of the matrix influences within and between-fragment dynamics (Jules & Shahani 2003), therefore the comparable levels of bat activity raises the question about whether oil palm is a fairly sustainable matrix for species to persist in, buffering the habitat change. However, Fukuda et al. (2009) found that compared to other habitat types, including orchards, oil palm had the lowest capture rates of insectivorous bats. It is evident that this area requires more research. My control sites were limited, and the lack of power in the control tests may have affected the validity of the results. Future work requires more control sites, and in the oil palm controls the distance from forest should be recorded in order to assess whether they are within commuting distance for bats.

Call-type and species responses

Despite comparable levels of activity and feeding activity between the river types, species composition varied. In both river types FM-QCF bats were more active than bats of any other call-type. The forested riparian reserves were within logged forest and so their high activity across the landscape may suggest that these species are more tolerant to disturbance than FMb and CF bats. Struebig et al. (2013) studied changes in bat assemblages across a forest disturbance gradient in the SAFE landscape and found that 85% of edge/open species were captured in repeatedly logged forest. Hence, an example of FM-QCF species recorded in my study could be the edge/open *Miniopterus* genus in the *Vespertilionidae* family.

All 6 CF taxa were found at least once in both forested riparian zones and oil palm riparian reserves. Peña-Cuéllar et al. (2015) also found that riparian zones in mature forest and riparian reserves in open pasture had similar numbers of species. However they found that some species were exclusive to just one riparian type, a result which was not seen in my study. The activity of the different species did however vary between the river types. Four of the 6 taxa were less active in the oil palm riparian reserves, *R. trifoliatus*/*R. francisi*, *R. sedulus*, *R. borneensis* and *H. ridleyi*, all of which are forest-dwelling species (Kingston

2010). These species have low wing loading and aspect ratios associated with flight suited to clutter and are poorly adapted to flying long distances which is energetically expensive (Kingston et al. 2003). In the same landscape Struebig et al. (2013) found that twice logged and repeatedly logged forests have fewer, smaller trees with significantly less cavities. The riparian reserves were degraded patches of forest and so this reduced availability of roosting trees may limit the number of bats that can be supported. Additionally, their narrow width may mean that movement and hence genetic flow of these forest-dwelling species is limited. Both of these factors will affect their long term survival in riparian reserves.

Two species, *Hipposideros galeritus* and *Hipposideros cervinus* were more active in the oil palm riparian reserves. These species are cave-roosting and are less susceptible to habitat fragmentation (Struebig et al. 2008) due to their ability to commute from roosting to foraging sites. For example, *H. cervinus* have been recaptured in sites up to 12.5 km apart in Peninsula Malaysia (Struebig et al. 2008). They have fast energy-efficient flight due to small, long and narrow wings (Kingston et al. 2003) contrasting with forest-dwelling species. These results suggest that these species may be able to persist in oil palm plantations if riparian reserves are maintained.

Trends in vegetation covariates

Bat activity was best predicted by canopy cover in both river types and a negative correlation was observed. A study in European woodlands also found that there was a negative correlation between bat activity and closed canopy (Kusch et al. 2004). However, when activity was partitioned by species, some species (*Pipistrelle* and *Myotis*) preferred areas with open canopy, whilst others (*Nyctalus* species) were more active in closed canopy areas. In the disturbed SAFE landscape Struebig et al. (2013) found that bat assemblage structure was associated with canopy height, canopy openness and densities of cavities. After logging, forests typically have a lower and more broken canopy and their study found that in these

more open canopied forests there were more edge/open species. This could explain the results of greater activity of FM-QCF species across this disturbed landscape, and the increase in cave-roosting species and decrease in forest-dwelling species in oil palm reserves where on average there was a lower canopy cover. However, the species-specific response in the riparian reserves could not be investigated fully due to the zero-inflated nature of the activity data and the lack of FM-QCF and FMb species identification. Further investigation using zero-inflated GLMs could elucidate this pattern as could occupancy analysis. Repetitions of the rivers would also help to reduce the zeros in the count data and thereby reduce possible statistical zero skewing.

Canopy height, tree density and basal area did not correlate with activity or feeding buzzes in any of the river types. Peña-Cuéllar et al. (2015) found that bat species composition was positively correlated with tree basal area. This could be explained by the close relationship between the number of natural cavities for roosting and the size of the tree (Evelyn & Stiles 2003). A lower tree density or basal area in the oil palm riparian reserves may help to explain the reduction in forest-dwelling species, albeit non-significant, however vegetation plot data was not available so unfortunately this could not be investigated. Bat activity did increase with riparian width, potentially due to a greater tree density in wider reserves. This result supports the maintenance of riparian reserves, suggesting that wider reserves are better for bats, and due to their role as bio-indicators, most probably for other taxa.

Long term view

Riparian reserves certainly have benefits for biodiversity in agricultural landscapes, however their long term effectiveness as a mitigation strategy is unclear. Fragmented habitats are subject to edge effects, changes in the microhabitat of the forest at the edge of the fragment (Laurance et al. 2011), and it is assumed that these will occur at the edges of the riparian reserves. This may further change the suitability of roost sites (Struebig et al. 2008) reducing

the quality of the forest needed for these species. *H. ridleyi* is listed as vulnerable on the International Union for Conservation of Nature (IUCN) Red List due to habitat loss (Francis et al. 2008), and the single recording in oil palm riparian reserves raises concerns over the future of this species even with the provision of riparian reserves. Vertical structural complexity of vegetation is ecologically important (Struebig et al. 2013), and this should be maintained within these reserves in order to support forest-dwelling species. However as selective logging of large trees in the reserves was observed during this study, strict protection is crucial if the reserves are to fulfil their true potential.

Identifying land management practices that can mitigate the devastating loss of biodiversity that results from forest conversion to oil palm is critical. This study indicates that riparian reserves in oil palm maintain similar levels of bat activity and feeding activity as in logged forest riparian zones, suggesting there is a role for riparian reserves in the maintenance of ecosystem functioning that is associated with insectivorous bats. However, despite maintaining the number of bats, riparian reserves within oil palm may not provide substantial enough patches of forest to maintain the more sensitive forest-dwelling species. In order to conserve these bats, the best practice may be to maintain larger forest fragments with complex vegetation structures and riparian reserves could be used to connect them. More research on this topic is necessary, and a repeat of this study once the forested riparian zones are fully isolated would allow greater understanding of the effects of these reserves on insectivorous bats.

Supplementary information

Examples of feeding buzzes (Appendix S1) and call-types (Appendix S2), correlation matrices (Appendix S3), river characteristics (Appendix S4) and habitat covariate scatterplots

(Appendix S5) are available at the end of this document. The author is solely responsible for the content and functionality of these materials and queries should be directed to them.

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Table 1. Rivers sampled with their sample dates, overall bat activity, feeding activity, and activity broken down into call-type, all showing the two site repetitions.

Riparian type	Survey month		Bat Activity ^a		Foraging Activity ^b		CF Activity		CF Species Present ^c		FM-QCF Activity		FMb Activity	
			1 st	2 nd	1 st	2 nd	1 st	2 nd	1 st	2 nd	1 st	2 nd	1 st	2 nd
Forested Sites														
0m	May 2014	May 2015	56	65	6	8	14	4	<i>Rhtr/Rhfr, Hice</i>	<i>Rhtr/Rhfr</i>	42	60	0	1
5m	May 2014	May 2015	43	52	2	19	25	6	<i>Rhtr/Rhfr, Rhse</i>	<i>Rhtr/Rhfr</i>	16	44	2	1
15m	April 2014	May 2015	153	155	15	38	38	49	<i>Rhtr/Rhfr, Rhse</i>	<i>Rhtr/Rhfr</i>	114	98	0	8
30m	July 2014	May 2015	198	115	15	10	53	63	<i>Rhtr/Rhfr, Rhse</i>	<i>Rhtr/Rhfr</i>	145	52	0	0
60m	July 2014	May 2015	71	118	5	23	7	5	<i>Rhtr/Rhfr, Hiri</i>	<i>Hiri, Higa, Rhse</i>	64	102	0	11
120m	July 2014	May 2015	65	157	4	19	36	74	<i>Rhtr/Rhfr</i>	<i>Rhtr/Rhfr, Hiri, Rhbo</i>	29	77	0	5
Forested Control														
RLFE	March 2015	May 2015	73	51	6	2	4	0	<i>Rhtr/Rhfr, Higa</i>	-	65	48	4	3
VJR	June 2015	June 2015	78	74	4	11	49	10	<i>Rhtr/Rhfr, Hiri, Higa</i>	<i>Rhtr/Rhfr, Higa, Rhse, Hice</i>	28	62	1	2
Oil palm riparian reserves														
RR2 Kapur	June 2015	June 2015	55	44	10	2	19	17	<i>Rhtr/Rhfr, Higa, Hice</i>	<i>Rhtr/Rhfr, Rhbo, Higa, Hice</i>	31	17	5	10
RR3 Belian	May 2015	June 2015	207	94	31	3	14	13	<i>Rhtr/Rhfr</i>	<i>Rhtr/Rhfr, Hiri</i>	191	77	2	4
RR7 Menggaris	May 2015	June 2015	122	119	10	4	0	1	-	<i>Rhtr/Rhfr</i>	99	98	23	20
RR12 Keruing	May 2015	June 2015	123	90	21	16	8	8	<i>Rhtr/Rhfr</i>	<i>Rhtr/Rhfr, Higa, Hice</i>	108	79	0	3
RR14 Merbau	May 2015	June 2015	107	73	27	1	14	4	<i>Rhtr/Rhfr</i>	<i>Rhtr/Rhfr, Higa</i>	92	69	1	0
RR16 Selendang Batu	June 2015	June 2015	44	49	4	8	26	12	<i>Rhtr/Rhfr, Rhse, Hice</i>	<i>Rhtr/Rhfr, Higa</i>	16	24	2	4
Oil palm control														
OP2	June 2015	June 2015	95	85	3	9	7	42	<i>Rhtr/Rhfr</i>	<i>Rhtr/Rhfr, Hiri Rhbo</i>	83	41	1	2

^aBat activity is defined as the number of genuine bat microphone triggers (one trigger consists of at least 3 pulses) along each river on one night of sampling.

^bForaging activity is defined as the number of feeding buzzes along each river on one night of sampling.

^cAbbreviations: *Rhtr/Rhfr*, *Rhinolophus trifolius/Rhinolophus francisi*; *Hice*, *Hipposideros cervinus*; *Rhse*, *Rhinolophus sedulus*; *Hiri*, *Hipposideros ridleyi*; *Higa*, *Hipposideros galeritus*; *Rhbo*, *Rhinolophus borneensis*.

Table 2. Constant frequency (CF) bats identified in this study with the call parameters used to identify them along with their activity in the two river types and the habitat type they are usually found in.

Species	Low frequency ^a (Payne & Francis 1998)	High frequency ^b	Activity ^c in forested riparian zones	Activity in oil palm riparian reserves	Ensemble
<i>Rhinolophus trifolius</i>	47	52	295	114	forest-dwelling
<i>Rhinolophus francisi</i>	49	50			
<i>Rhinolophus sedulus</i>	59	62	62	1	forest-dwelling
<i>Rhinolophus borneensis</i>	79	84	3	1	cave-roosting
<i>Hipposideros galeritus</i>	108	114	1	14	cave-roosting
<i>Hipposideros ridleyi</i>	61	63	10	1	forest-dwelling
<i>Hipposideros cervinus</i>	115	126	3	5	cave-roosting

^a Lowest frequency of the dominant harmonic in kHz

^b Highest frequency of dominant harmonic in kHz

^c Number of genuine bat microphone triggers

Table 3. Results from the Quasi-Poisson Generalised Linear Model of habitat variables and overall bat activity.

Parameter		Est/coefficient \pm SE	t value	p value	Value*
<i>Total activity</i>	intercept	2.0296 \pm 0.150	13.510	2.00E-16	***
	canopy cover	-0.00612 \pm 0.00153	-4.002	0.000130	***
	river width	-0.0281 \pm 0.0138	-2.044	0.0438	*
Residual deviance: 99.548 on 93 degrees of freedom					
<i>Forested activity</i>	intercept	1.853 \pm 0.148	12.558	<2.00E-16	***
	canopy cover	-0.00658 \pm 0.00251	-2.623		*
				0.0118	
Residual deviance: 67.218 on 46 degrees of freedom					
<i>Oil palm activity</i>	intercept		18.273	2.00E-16	***
	canopy cover	1.712 \pm 0.0937	-2.742	0.00868	**
		-0.00513 \pm 0.00187			
Residual deviance: 35.648 on 46 degrees of freedom					

Significance values, where ‘’ is $p < 0.05$, ‘**’ is $p < 0.01$ and ‘***’ is $p < 0.0005$

Figure 1. Location of the study site in Sabah, Malaysian Borneo showing the Stability of Altered Forest Ecosystems (SAFE) landscape and the surrounding oil palm estates with the sampled rivers labelled.

Figure 2. Boxplots showing a) Total bat activity counts across the oil palm riparian reserves and the forested riparian zones b) The variation in bat activity counts across all rivers c) Total feeding activity counts across the oil palm riparian reserves and the forested riparian zones d) The variation in feeding activity across all rivers e) Total CF activity counts across the oil palm riparian reserves and the forested riparian zones f) The variation in CF activity across all rivers.

Figure 1.

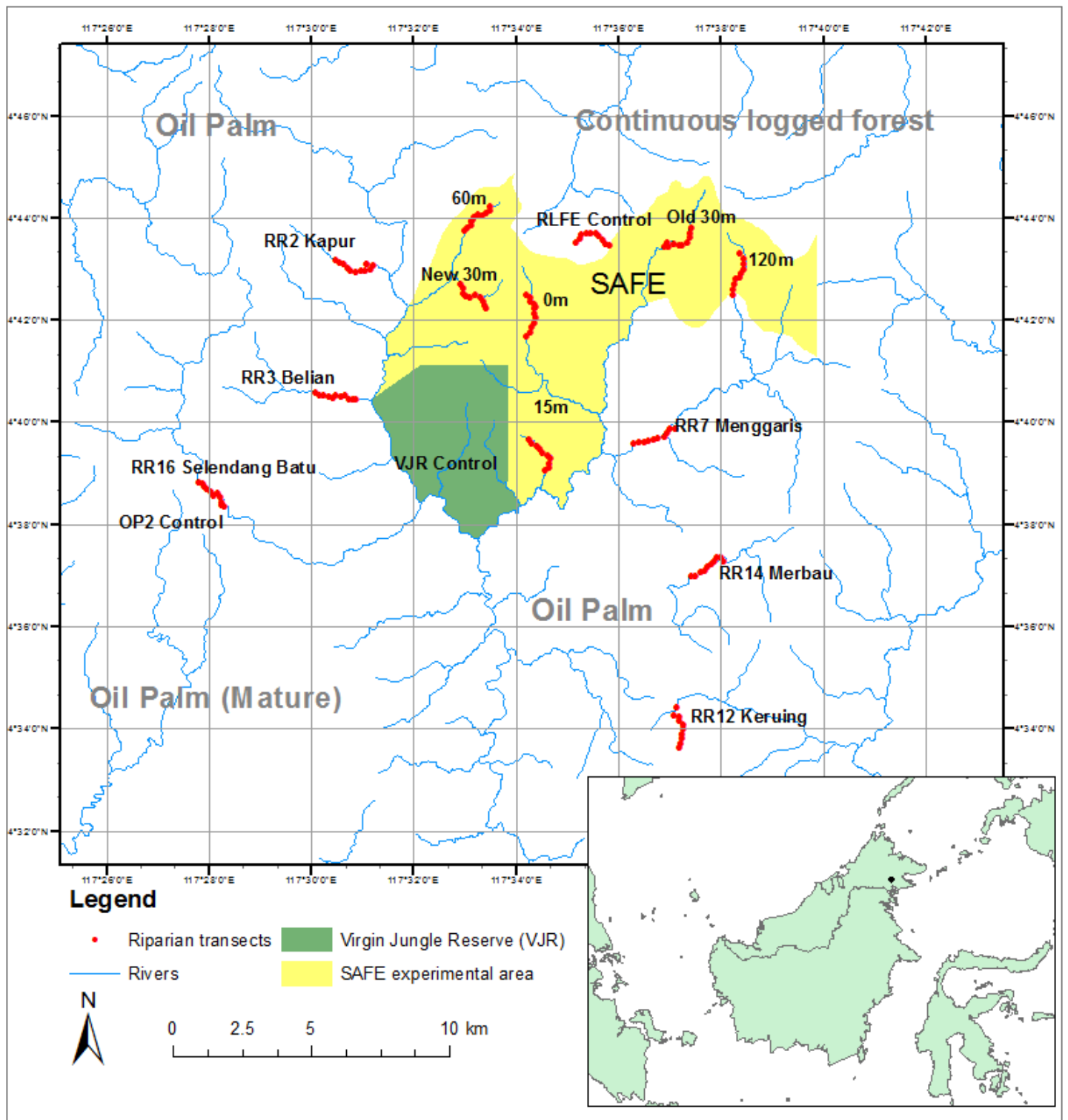
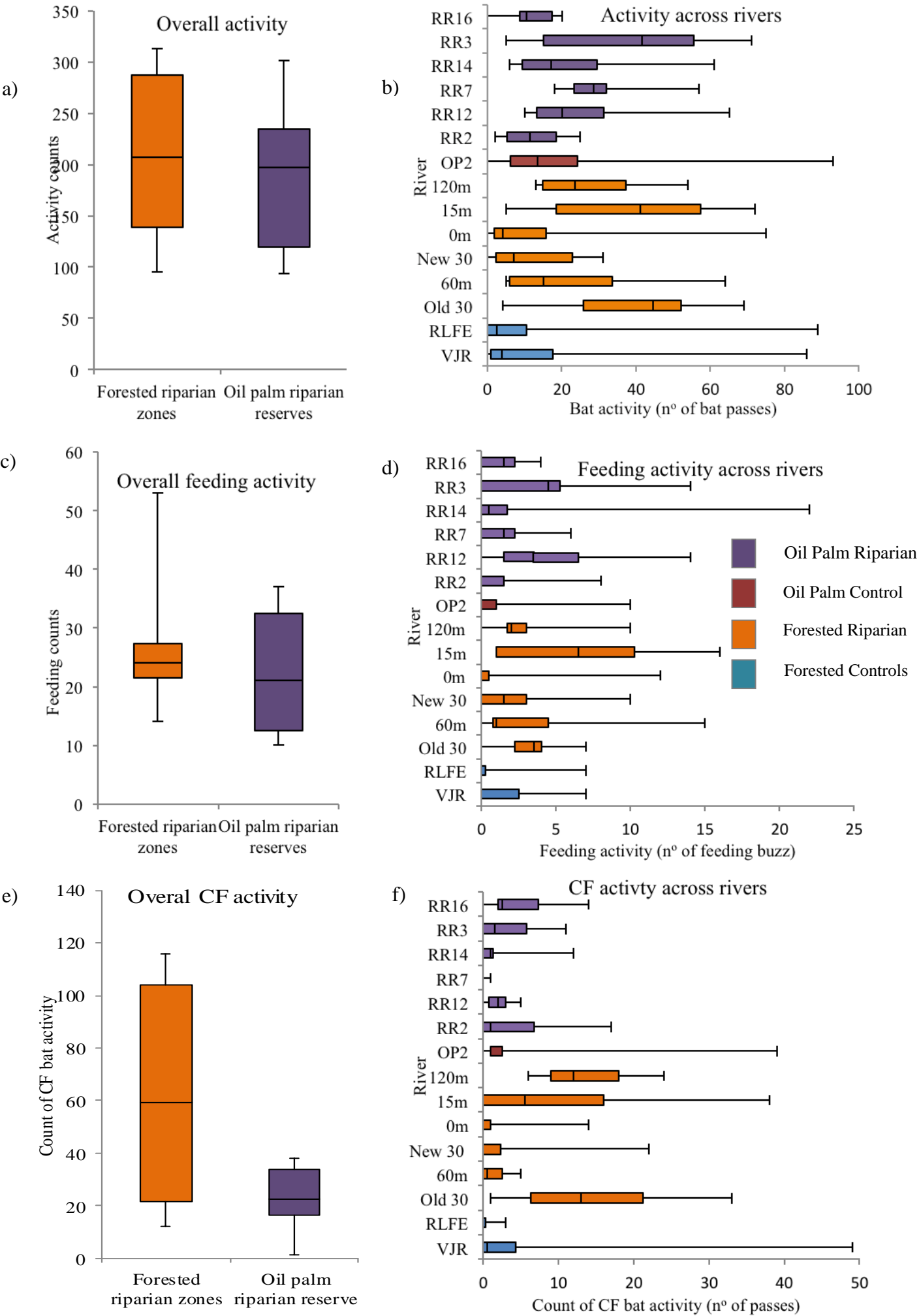


Figure 2



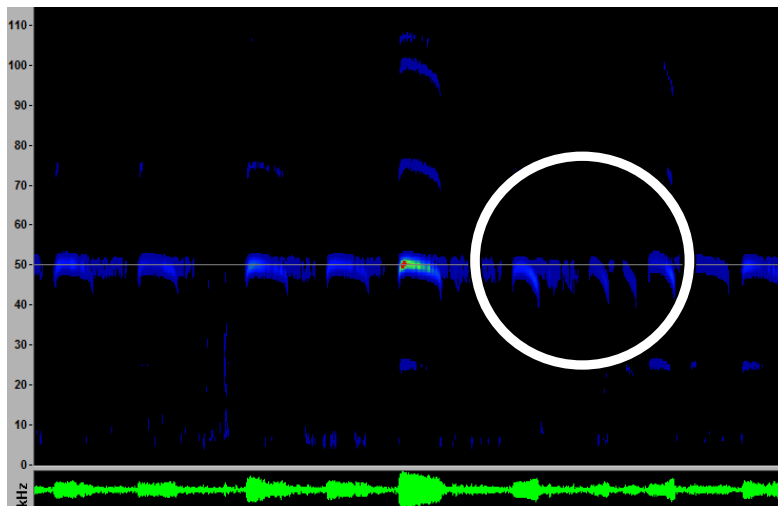
Supplementary Information

Visual examples of feeding buzzes (Appendix S1) and call-types (Appendix S2), correlation matrices (Appendix S3), river characteristics (Appendix S4) and scatterplots showing habitat covariates against bat activity (Appendix S5).

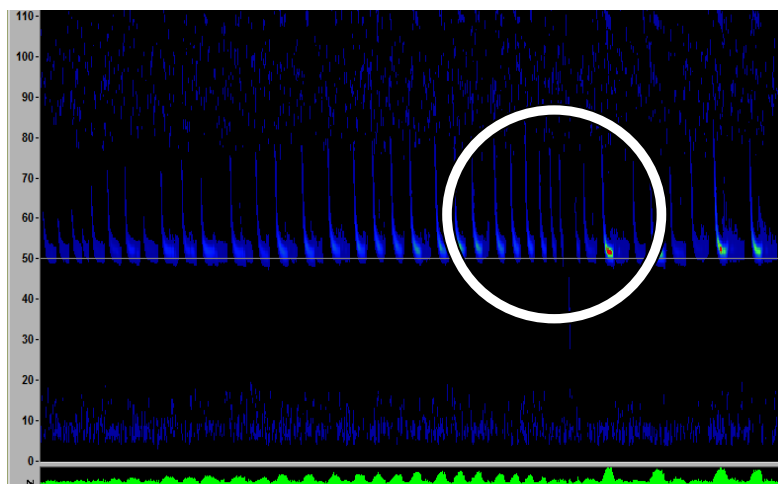
Appendix S1- Examples of feeding buzzes

Variation in the number and duration of pulses within a call can be used to identify when a bat is feeding and these ‘feeding buzzes’ are highlighted in the figures below.

a) Constant Frequency (CF) feeding buzz



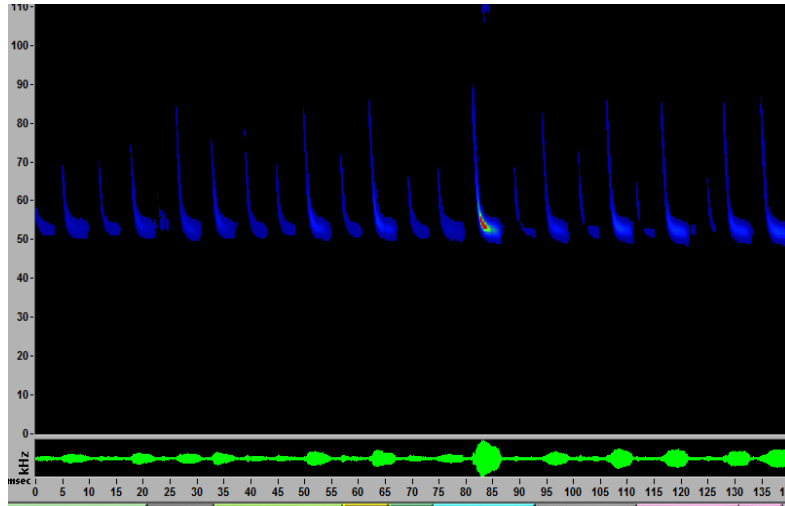
b) Frequency modulating- quasi constant frequency (FM-QFC) feeding buzz



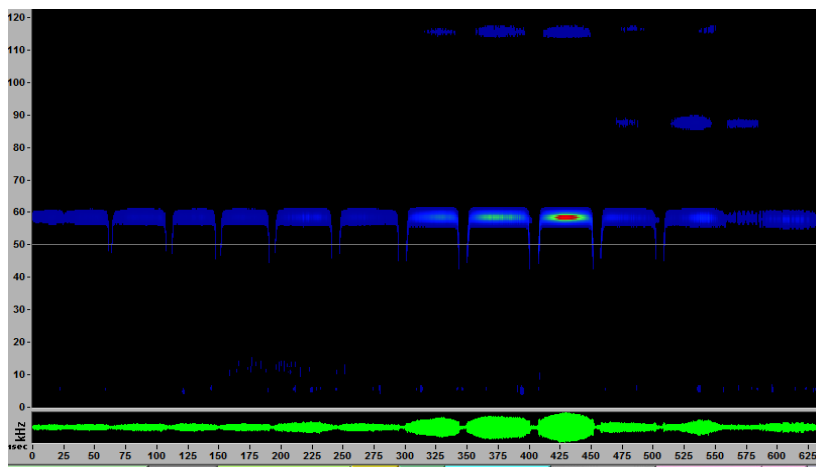
Appendix S2- Examples of the five call types

Spectrograms from the SonoBat software of the different call types found in this study. Along the x axis is time in ms (scale varies between calls) and along the y axis is the frequency of the call in kHz.

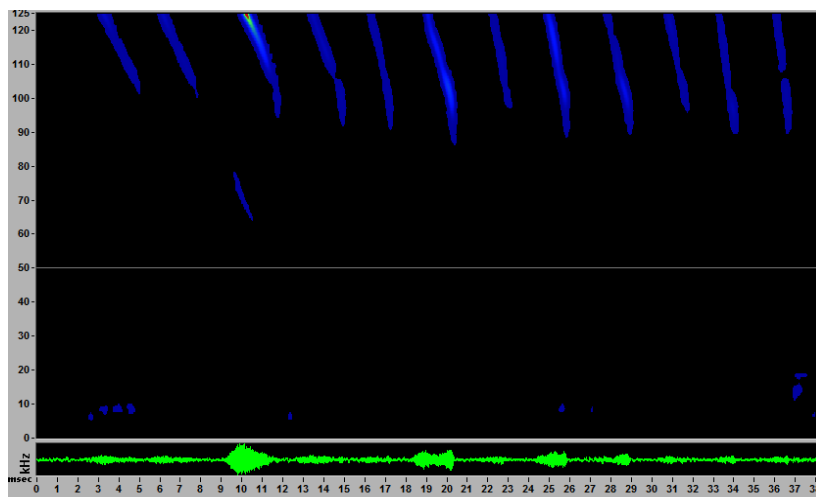
Frequency modulating-quasi constant frequency (FM-QFC) call



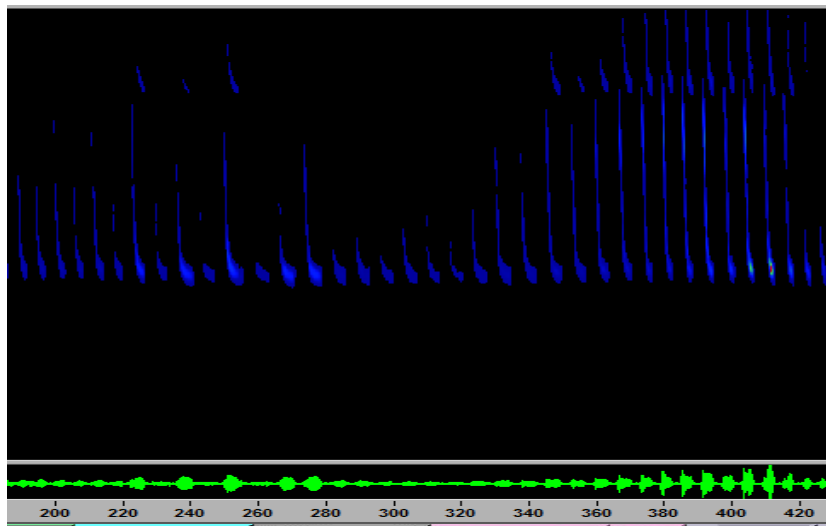
Constant Frequency (CF) call



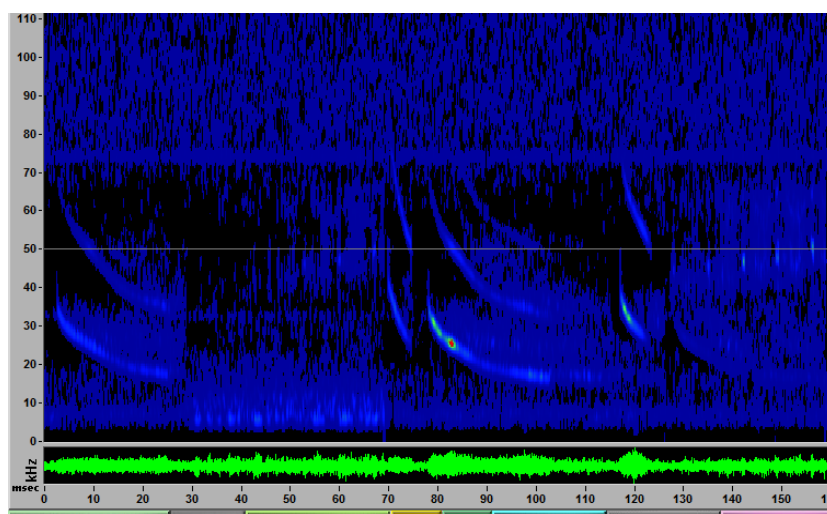
Broad band frequency modulated (FMb) call



Multi-harmonic frequency modulated (MHFM) call



Multi-harmonic QFC bats (MHQFC) call



Appendix S3- Correlation matrices

a) Correlation matrix combining the oil palm riparian reserves and forested riparian zones habitat variables alongside bat activity and feeding activity. The level of significance of the correlations is marked by the number of *, where * is significant at the 0.05 level and ** is significant at the 0.01 level.

		<i>Activity</i>	<i>Feeding buzz</i>	<i>River width</i>	<i>Canopy cover</i>
<i>Activity</i>	correlation coefficient	1.000	0.783**	-0.119	-0.381**
	significance		0.000	0.247	0.000
	N	96	96	96	96
<i>Feeding buzz</i>	correlation coefficient	0.783	1.000	-0.211*	-0.268**
	significance	0.000		0.039	0.008
	N	96	96	96	96
<i>River width</i>	correlation coefficient	0.119	-0.211	1.000	-0.125
	significance	0.247	0.039		0.225
	N	96	96	96	96
<i>Canopy cover</i>	correlation coefficient	-0.381	-0.268	-0.125	1.000
	significance	0.000	0.008	0.225	
	N	96	96	96	96

b) Correlation matrix of the forested riparian zones habitat covariates along with bat activity and feeding activity. The highlighted relationship shows the highly significant correlation between tree density and basal area, where tree density was removed from further analysis.

		<i>Activity</i>	<i>Feeding</i>	<i>River</i>	<i>Canopy</i>	<i>Canopy</i>	<i>Basal</i>	<i>Tree</i>
			<i>buzz</i>	<i>width</i>	<i>cover</i>	<i>height</i>	<i>area</i>	<i>density</i>
<i>Activity</i>	correlation coefficient	1.000	0.851**	-0.252	-0.364*	-0.146	0.250	0.318
	significance		0.000	0.084	0.011	0.426	0.168	0.076
	N	48	48	48	48	32	32	32
<i>Feeding</i> <i>buzz</i>	correlation coefficient	0.851	1.000	-	-0.225	-0.020	0.177	0.217
	significance	0.000		0.317*	0.125	0.914	0.333	0.233
	N	48	48	0.028	48	32	32	32
<i>River</i> <i>width</i>	correlation coefficient	-0.252	-0.317	1.000	0.121	-0.177	-0.129	-0.134
	significance	0.084	0.028		0.413	0.332	0.483	0.464
	N	48	48	48	48	32	32	32
<i>Canopy</i> <i>cover</i>	correlation coefficient	-0.364	-0.225	0.121	1.000	0.438*	0.209	0.152
	significance	0.011	0.125	0.413		0.012	0.251	0.405
	N	48	48	48	48	32	32	32
<i>Canopy</i> <i>height</i>	correlation coefficient	-0.146	-0.020	-0.177	0.438	1.000	0.323	0.269
	significance	0.426	0.914	0.332	0.012		0.071	0.136
	N	32	32	32	32	32	32	32
<i>Basal</i> <i>area</i>	correlation coefficient	0.250	0.177	-0.129	0.209	0.323	1.000	0.981**
	significance	0.168	0.333	0.483	0.251	0.071		0.000
	N	32	32	32	32	32	32	32
<i>Tree</i> <i>density</i>	correlation coefficient	0.318	0.217	-0.134	0.152	0.269	0.981	1.000
	significance	0.076	0.233	0.464	0.405	0.136	0.000	
	N	32	32	32	32	32	32	32

c) Correlation matrix of the oil palm riparian reserves habitat covariates along with bat activity and feeding activity.

		<i>Activity</i>	<i>Feeding</i>	<i>River width</i>	<i>Canopy</i>	<i>Riparian</i>
			<i>buzz</i>		<i>cover</i>	<i>width</i>
<i>Activity</i>	correlation coefficient	1.000	0.719**	-0.033	-0.430**	0.341*
	significance		0.000	0.823	0.002	0.018
	N	48	48	48	48	48
<i>Feeding</i> <i>buzz</i>	correlation coefficient	0.719	1.000	-0.069	-0.303*	0.098
	significance	0.000		0.639	0.036	0.510
	N	48	48	48	48	48
<i>River</i> <i>width</i>	correlation coefficient	-0.033	-0.069	1.000	-0.183	0.213
	significance	0.823	0.639		0.214	0.147
	N	48	48	48	48	48
<i>Canopy</i> <i>cover</i>	correlation coefficient	-0.430	-0.303	-0.183	1.000	-0.201
	significance	0.002	0.036	0.214		0.171
	N	48	48	48	48	48
<i>Riparian</i> <i>width</i>	correlation coefficient	0.341	0.098	0.213	-0.201	1.000
	significance	0.018	0.510	0.147	0.171	
	N	48	48	48	48	48

Appendix S4- Summaries of the riparian site's characteristics used in the GLMs, means are used due to the models accounting for the non-normal structure of the data.

Riparian type	River Width ^a (m)	Canopy cover (%) ^b	Canopy Height (m) ^c	Tree density ^d	Basal Area ^e	Reserve Width ^f (m)
	Mean \pm SD	Mean \pm SD	Mean \pm SD	Mean \pm SD	Mean \pm SD	Mean \pm SD
<i>Forested Sites</i>						
0m	9.96 \pm 4.24	66.25 \pm 19.96	12.56 \pm 2.59	27.50 \pm 13.61	103.99 \pm 78.69	
5m	8.1 \pm 2.90	86.25 \pm 21.34	14.46 \pm 2.41	51.2 \pm 26.45	452.36 \pm 557.83	
15m	5.96 \pm 1.72	35.25 \pm 24.46	13.11 \pm 3.05	32.33 \pm 17.31	125.07 \pm 109.80	
30m	8.53 \pm 1.47	33.75 \pm 31.59	11.69 \pm 1.41	50.67 \pm 26.92	377.00 \pm 375.18	
60m	5.68 \pm 1.74	72.5 \pm 23.75	13.90 \pm 3.40	38.0 \pm 20.24	169.40 \pm 135.52	
120m	6.21 \pm 1.35	42.50 \pm 21.21	11.91 \pm 2.86	28.5 \pm 16.94	92.83 \pm 80.04	
<i>Forested Control</i>						
RLFE	8.93 \pm 3.08	72.50 \pm 18.32	10.60 \pm 1.26	33.75 \pm 3.77	135.15 \pm 55.00	
VJR	8.03 \pm 2.80	71.25 \pm 22.95				
<i>Oil palm riparian reserves</i>						
RR2 Kapur	8.24 \pm 3.87	72.5 \pm 42.34				35.60 \pm 5.93
RR3 Belian	12.67 \pm 2.71	32.5 \pm 26.59				91.94 \pm 15.84
RR7 Menggaris	11.73 \pm 2.93	21.25 \pm 16.42				88.48 \pm 22.80
RR12 Keruing	5.60 \pm 0.80	32.50 \pm 15.81				72.48 \pm 15.72
RR14 Merbau	7.06 \pm 0.67	76.25 \pm 15.06				89.93 \pm 39.82
RR16 Selendang Batu	13.70 \pm 2.53	31.25 \pm 24.75				72.54 \pm 16.46
<i>Oil palm control</i>						
OP2	5.44 \pm 1.80	23.75 \pm 26.15				0

^aWidth of the river at each sampling point from bank to bank at the highest water mark point

^b Canopy cover through estimates between 0 and 100%

^c Mean height of all the trees within the 25 x 25 m vegetation plot

^d The number of trees within the 25 x 25 m plot that had a diameter at breast height (DBH) >10 cm

^e The area of land in the 25 x 25 m plot that was occupied by the cross-section of tree trunks

^f The distance from one side of the oil palm riparian reserve to the other, minus the river width

Appendix S5 – Correlations between bat characteristics and habitat covariates

5) Scatterplots showing a) the relationship between activity and canopy cover in the forested riparian zones b) the relationship between the number of feeding buzzes and river width in the forested riparian zones c) the relationship between bat activity and canopy cover in the oil palm riparian reserves and d) the relationship between bat activity and riparian reserve width in the oil palm riparian reserves.

