The effect of rainforest modification on two species of South-East Asian terrestrial leeches, *Haemadipsa zeylanica* and *Haemadipsa picta*.

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Abstract

Rainforests around the world are facing increasing pressure from deforestation. Large areas in Sabah, Malaysian Borneo, are being logged and cleared for Oil Palm plantations. The resulting landscape is one of logged forest and forest fragments, and it is important to understand how this modified landscape affects biodiversity. South East Asian rainforests are home to two common sanguivorous terrestrial leeches, *Haemadipsa zeylanica* and *Haemadipsa picta*, which inhabit the forest floor and undergrowth, feeding on mammals. Despite the ubiquitousness of these species, little is known of their ecology or their response to forest modification. This study surveyed for terrestrial leeches in primary forest, logged forest and Oil Palm plantation, and alongside waterways to identify patterns of leech encounter rate, the proportion of the species, and the biomass. As forest is logged, the total leech encounter rate increases due to the increase in abundance of *H. picta; H. zeylanica* declines as forest is logged. These trends are also correlated with other environmental variables. Though encounter rate increases with logging, leech biomass, measured as length, remains the same through different levels of logged forest. No leeches are found in Oil Palm plantations. Riparian reserves around waterways in Oil Palm plantations have leeches present though they are not as populous as those surrounding waterways in logged forest.

Introduction

It is impossible to visit the forests of South East Asia without encountering the charismatic sanguivorous terrestrial leeches *Haemadipsa zeylanica* (Brown Leech) and *Haemadipsa picta* (Tiger Leech). These two leeches occur in forests in many parts of South East Asia and are the only members of The Class Hirudinea found inland over any considerable area in northern Borneo. Their closest relatives in the forest are the Oligochaeate earthworms. There are between 700-1000 species of leech worldwide (Govedich and Bain, 2005), but since the majority of leeches are aquatic, these two species represent the result of a unique evolutionary pathway. They are generalist parasites, feeding from the blood of different species of mammals, birds, fish, reptiles and amphibians (Govedich and Bain, 2005; Schnell et al. 2012), though they spend the majority of their lives detached from their hosts where they inhabit the forest floor and the ground and shrub layer vegetation. They lay eggs solely on vegetation and never on a host. In these respects they have the potential to be seen as good indicators not only of forest quality but of the abundance of prey. Prey detection is accomplished by simple eyes, mechanoreceptors to detect vibration and chemoreceptors to detect CO_2 gradient (Govedich and Bain, 2005).

Fogden and Proctor (1985) found that *H. zeylanica* was found at ground level inhabiting the forest floor and litter layer, and was more abundant than *H.picta*, which inhabits vegetation to 1-2m above the ground. In their various experiments on the leeches, they found that they were long lived in high humidity, lasting several months without a meal and, with repeated meals, lived beyond the lifetime of the experiment (246 days). It was also shown that bigger leeches feed for longer and consume more blood than smaller leeches; but also that although they lose weight faster after feeding, they do so at a slower rate relative to body weight than smaller leeches. Fogden and Proctor (1985) also predict that as leeches are sensitive to low humidity, they would therefore probably be absent from logged forest. If this prediction is correct, we would expect to find no leeches within the logged forest sampled in this study. Although there is work on leeches' physiology and evolutionary history (Dales, 1967; Borda et al. 2008; Siddall et al. 2011) it is clear that a better understanding of leech dispersal and behaviour is needed (Schnell et al. 2012).

Forests in tropical regions are suffering from logging and conversion to agriculture and this can have profound effects on the species within them, though many of the effects are still unknown (Turner et al. 2011). The effect of forest fragmentation on biodiversity and other forest ecosystem properties such as sediment flow in rivers and carbon flux is also an area needing more study. Fragmented forest is increasingly seen as the only realistic option for species conservation within oil palm plantations outside the larger reserves, as fragments can maintain ecosystem services and provide connectivity for species (Turner et al. 2011). Conditions in primary tropical rainforests include high humidity and temperature and sparse ground vegetation due to the dense canopy creating a heavily shaded environment. Logging has the potential of opening up the canopy, causing a surge in ground vegetation in response to the increase in light (Berry et al. 2010). Over a large area, this can have an effect on temperature and humidity. In the Oil Palm plantation, temperature is higher and humidity is lower than in forest, and the 24 hour fluctuation in these variables is also greater (Turner et al. 2011).

In Sabah, Malaysian Borneo, the logging of primary forest and conversion to Oil Palm plantation has been going on for many decades (Berry et al. 2010; Reynolds et al. 2011). Although legislation now asks for a 30m riparian reserve around permanent waterways and inaccessible steep areas are left as forest islands, this conversion is continuing. All the evidence collected to far suggests that conversion to Oil Palm is detrimental to biodiversity. Turner et al. (2011) collate a table from other studies showing that all taxa except bees show decreased diversity and most taxa show decreased abundance in Oil Palm when compared to primary forest. Schultze et al. (2004) also show this effect for several different taxa. However, logged forest does maintain a large proportion of its biodiversity and so the maintenance of this, though somewhat damaged forest, does have its positives (Berry et al. 2010). For example, ants are more abundant and have higher diversity in logged secondary forest whereas termites do better in primary (Luke, 2010). Dung beetles, which are analogous to leeches in their dependence on vegetation and mammalian hosts, showed a 34% reduction in species when forest was fragmented (Diaz et al. 2009); and Slade et al (2011) showed a reduction in dung beetle species richness between primary and logged forest. There are many reasons to want to preserve biodiversity, from the innate value in species' existence, to their enhancement of tourism, to the provision of ecosystem services

such as water purification and pollination (Hector et al. 2011). Understanding the effect of logging on forest species and the effect of different sized fragments of forest on species which formerly lived in continuous forest is important for all these reasons. There is a growing literature on the effects of logging and Oil Palm conversion on species richness within various taxa (Turner et al. 2011).

Endo- and ectoparasites are an important factor in the web of life, which can undergo various changes during forest modification. Despite the importance of parasites to ecosystems, little is known about the community structure of ectoparasites and their interaction with host animals (Wells et al. 2001), and surveys are only just beginning in South East Asia (Mariana et al. 2005). Wells et al. (2007) have shown differences between helminth assemblages in small mammals between logged and unlogged forest in Sabah, Borneo. Nematode species richness and parasite load per mammal is higher in logged forest in the tree shrew *Tupaia longipes* but lower in logged forest in the tree shrew *Tupaia tana* and the rat *Leopoldamys sabanus*. Cestode infestation of *L.sabanus* was also found to be lower in logged forest. The terrestrial leeches of Borneo are two important species in their own right, but little is known about their ecology or response to forest modification. There is also a new technique emerging to use leeches to detect rare and data-deficient mammals, and estimate mammal abundance, since the blood they ingest can still be identified up to four months later (Schnell et al. 2012). The working hypothesis is that leech abundance should be reduced in logged forest and further reduced in Oil Palm; this is because of the higher temperature and lower humidity, and also because in general, their mammalian hosts have reduced diversity and abundance in logged forest and in Oil Palm (Berry et al. 2010; Turner et al. 2011), though Slade et al. (2011) notices an increase in abundance for some mammal species.

This study looks at the density and biomass of both species of terrestrial leech, as well as the species ratio, along a continuum of 6 levels of forest quality within logged forest, Oil Palm plantation and intact primary forest. The species data is also compared with canopy openness, temperature, humidity and a soil moisture score. Through this the responses of the terrestrial leech species to logging and conversion to Oil Palm plantation can be determined.

Methods and Materials

The study was carried out at the Stability of Altered Forest Ecosystems (SAFE) Project in Sabah, Malaysian Borneo (Figure 1). SAFE is set up in twice-logged forest to monitor the changes in multiple biodiversity and physical indicators as the land surrounding six fixed plots undergoes the conversion to Oil Palm plantation (Ewers et al. 2011). Each plot is divided up into one 100ha, two 10ha and four 1ha fragments, with a transect running through each of these, as well as a fourth transect running through the 'Matrix', which will eventually retain no forest cover (Figure 1). Currently, there is logged forest connecting the fragments and the plots, so the effect of fragment size on leeches cannot yet be determined. As well as the six fixed plots, SAFE also has access to forest that will remain logged and will not be converted to Oil Palm, the Virgin Jungle Reserve which has been logged variably and retains 61% forest cover, land that is already used for Oil Palm plantation, and old growth primary forest in Maliau Basin. For this study, all six fixed plots were used as they are logged to different levels. The Virgin Jungle Reserve, Oil Palm plantation and Old Growth forest were also used to compare with the logged forest.
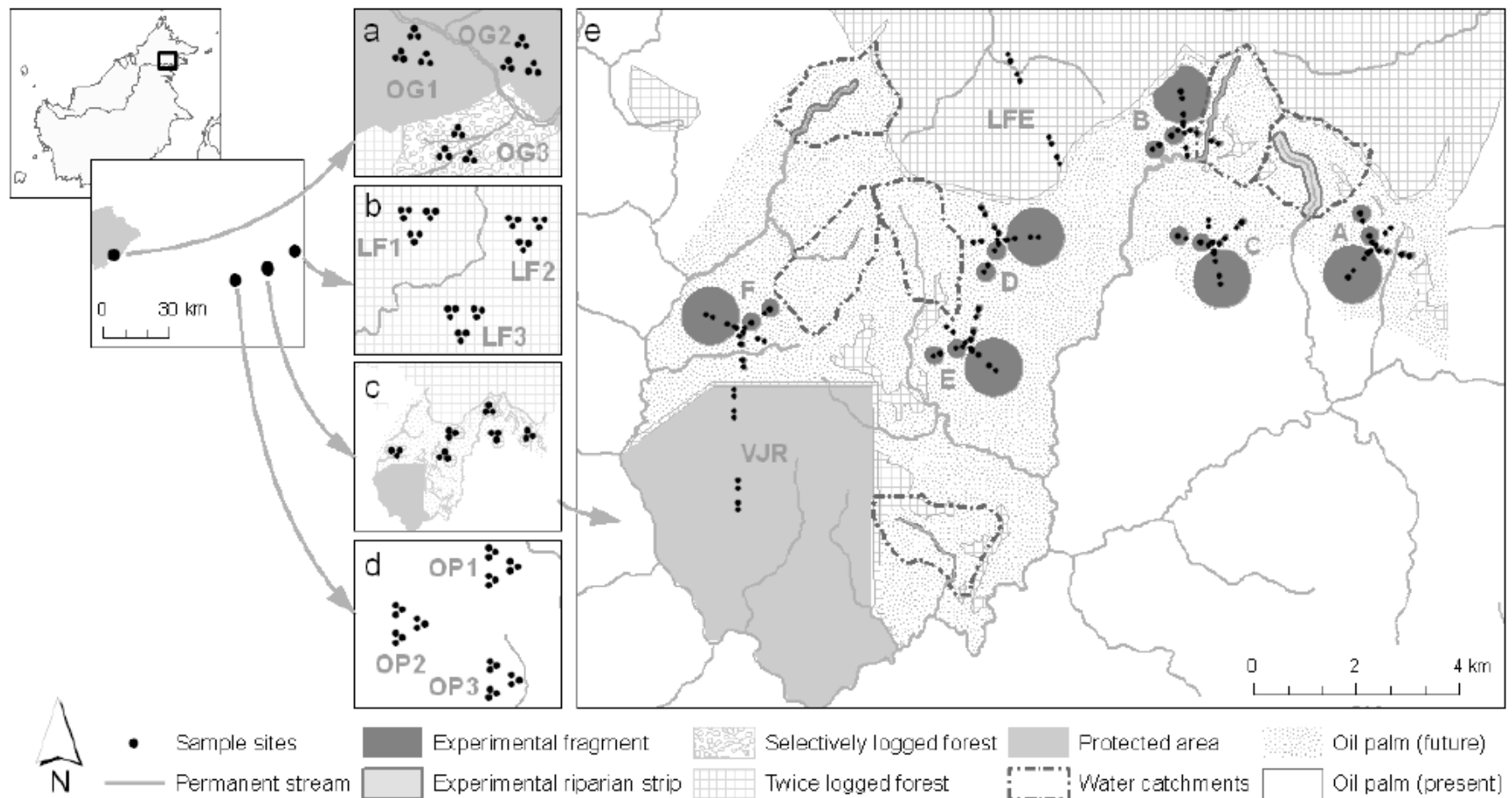
Figure 1. The SAFE Project area (7089ha in total) showing the location of the logged forest plots and the Virgin Jungle Reserve. The black dots are the second order points which were sampled in this study. The dark circles are the future sites of the fragments, though at the time of the study there was logged forest covering the whole area.

In each plot, sampling sites are laid out in a fractal pattern so that results taken at any level can be compared. This study sampled at each of the 2nd order points since this produces 16 repeats for each logged forest plot and is also where vegetation data had previously been collected and the 'forest quality' assessed and given a number between 0 and 5 (Table 1). This SAFE forest quality score has previously been successful in correlating with other taxa such as termites (Luke, 2010).

Each sampling site was surveyed for leeches. To do this, any leeches attached to the body at the start were removed and discarded. Then, the person would walk around in the vicinity of the centre of the 2nd order sampling point dragging a 1mx1m white cloth for 5 minutes. The white cloth dragging method is recommended by Mariana et al. (2005) for tick sampling and 5 minutes was determined to be enough to get an accurate measure of leech encounter rate at a particular site after several trials. Although ectoparasites can also be sampled by catching the hosts (Mariana et al. 2005), this is unsuitable for leeches because of their short feeding time on their hosts, with a mean of 79 minutes (Fogden and Proctor, 1985).

At the end of the 5 minute survey, leeches were removed from the cloth and from the person and placed in 70% alcohol in a plastic tube. The leeches from each sampling point were placed in separate tubes. All leeches caught at each sampling point were identified to species and had their length measured as a proxy for biomass. For each sampling point a measure of total leech length, average leech length and ratio of *Haemadipsa picta* to *H.zeylanica* was then determined.

At each 2nd order sampling point, the temperature, humidity and a soil moisture score (Table 1) were noted. Data was also available at each point for forest quality (Table 1).

Forest type	Quality	Description - vegetation in the area immediately around sample point
0	Oil Palm	Oil Palm
1	Very poor	No trees - open canopy with ginger/vines or low scrub
2	Poor	Open with occasional small trees over ginger/vine layer
3	Okay	Small trees fairly abundant/canopy at least partially closed
4	Good	Lots of trees, some large, canopy closed
5	Very Good	No evidence of logging at all, closed canopy with large trees
Soil Moisture Score		**Soil Condition**
1		Dry, with dust
2		Moisture in soil but hard under foot
3		Soil wet under foot (mud)
4		Water visible on soil surface
5		Standing water over majority of site

Table 1. The Forest quality scale used by SAFE. A value is given to each second order point, the same points used in this study. Also, the soil moisture score table used for the study. Sampling points were also given half marks if they fell between two of the descriptions or if parts of the site varied widely.

As well as the forest plots, SAFE also has access to riparian reserves around permanent waterways within reach of the main camp; these reserves vary in their width and quality and are bordered by Oil Palm plantation. Surveys were carried out in six riparian reserves as well as in three control waterways surrounded by continuous logged forest, and three waterways in Oil Palm plantations without riparian reserves. At each site, four 5 minute surveys were conducted at 150m intervals along the river, within 20m of the bank. For the riparian reserves, values were obtained for the width of the reserve at the sampling points. Temperature and humidity were also measured and a soil moisture score determined. Leeches were also kept, identified to species and had their length measured.

Statistical Analysis

The response variables collected were the encounter rate of leeches during the 5 minute survey time, the numbers of each species that were encountered, and the length of each individual leech. These were compared to environmental variables collected at the time and previously as part of the core SAFE data. These explanatory variables are temperature, humidity, soil moisture, canopy openness and forest quality. Canopy openness is a direct

measurement for each sampling point. All analysis was done using the statistical package R 2.15.1.

The encounter rate, as a count compared to continuous and categorical environmental variables, was analysed using a general linear model with Poisson errors. The species ratio between *H.picta* and *H.zeylanica* was analysed using a general linear model with binomial errors and compared to the environmental variables. The total length of leeches encountered in a 5 minute survey and the average length of those leeches were compared to the explanatory variables using an ANOVA, a different analysis being performed for each species.

Results

Confounding variables

It is clear from common sense and from the analysis in (Table 2) that all of the explanatory variables are also somewhat correlated. This was to be expected as many of the environmental variables are dependent upon each other (forest quality and canopy openness being a good example). The discussion will highlight how several environmental conditions must be optimum for leeches to survive. They are impossible without detailed experimental and physiological work to tease apart from each other completely.

Though they are all correlated, the later analysis still identifies which of these variables are significant in explaining the leech data and which are not. Instead of presenting several graphs, the study has concentrated on forest quality indicating a general forest condition, humidity as an indicator of microclimate and soil moisture as the most independent variable with the smallest correlation coefficient to the other variables.

Leech encounter rate

A brief summary of the differences in encounter rate between the old growth forest, virgin jungle reserve, logged forest and oil palm plantation is shown in Figure 2. This shows the overall general trend. The general linear model shows that temperature ($p<0.001$), humidity ($p<0.001$), canopy openness ($p<0.001$), forest quality ($p<0.001$) and soil moisture ($p<0.001$) were all significant factors. Humidity, forest quality and soil moisture are shown in Figure 3.

Leech species ratio

Canopy openness ($p<0.001$), humidity ($p<0.01$) and forest quality ($p<0.001$) were all significant (Figure 4). Temperature and soil moisture were not found to be significant.
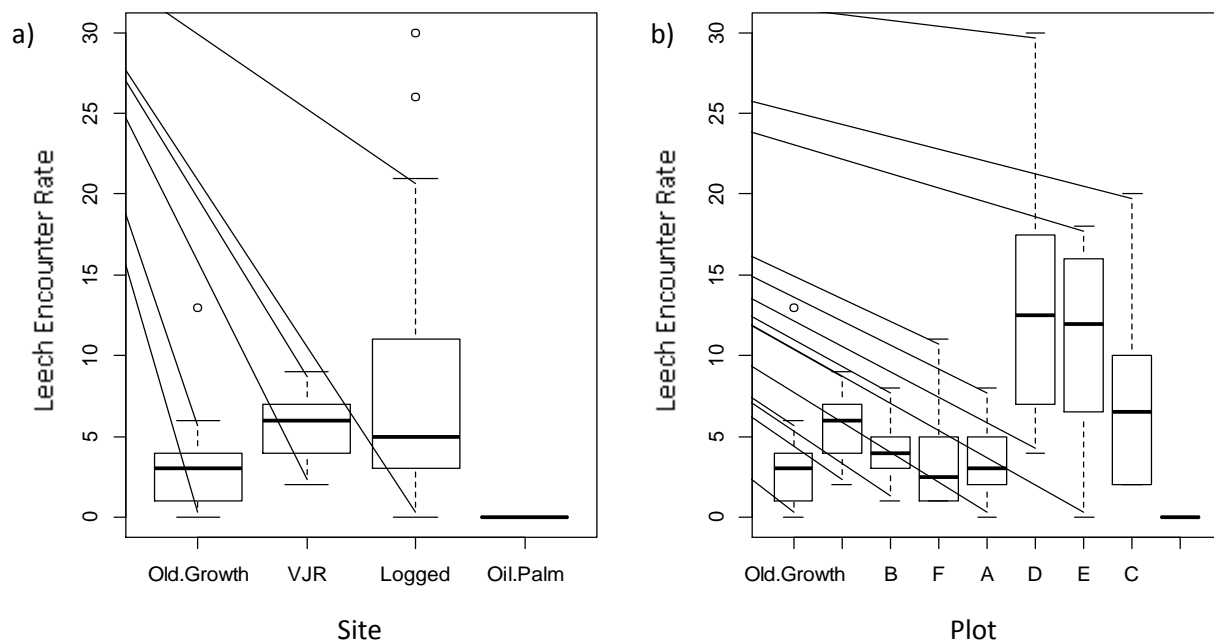
Figure 2. Leech encounter rate (Leeches) increases as Old Growth forest is logged (VJR is 61% remaining forest cover) but then falls to zero in Oil Palm plantations. When this analysis is broken down into plots, ordered by average forest quality score for the plot (Old Growth; VJR = 3.375; B = 2.688; F = 2.625; A = 2.375; D = 2.188; E = 2.125; C = 2.072) the correlation is less clear and analysis of the discrete changes in environmental variables at each sampling point within each plot is required.

	Canopy Openness	Forest Quality	Temperature	Humidity	Soil Moisture
Canopy Openness	X	0.3672	0.2202	0.3747	0.1043
Forest Quality	0.3672	X	0.1856	0.2959	0.0493
Temperature	0.2202	0.1856	X	0.5407	0.2073
Humidity	0.3747	0.2959	0.5407	X	0.2352
Soil Moisture	0.1043	0.0493	0.2073	0.2352	X

Table 2. The correlation coefficients between the explanatory variables. They are all significant with each other.
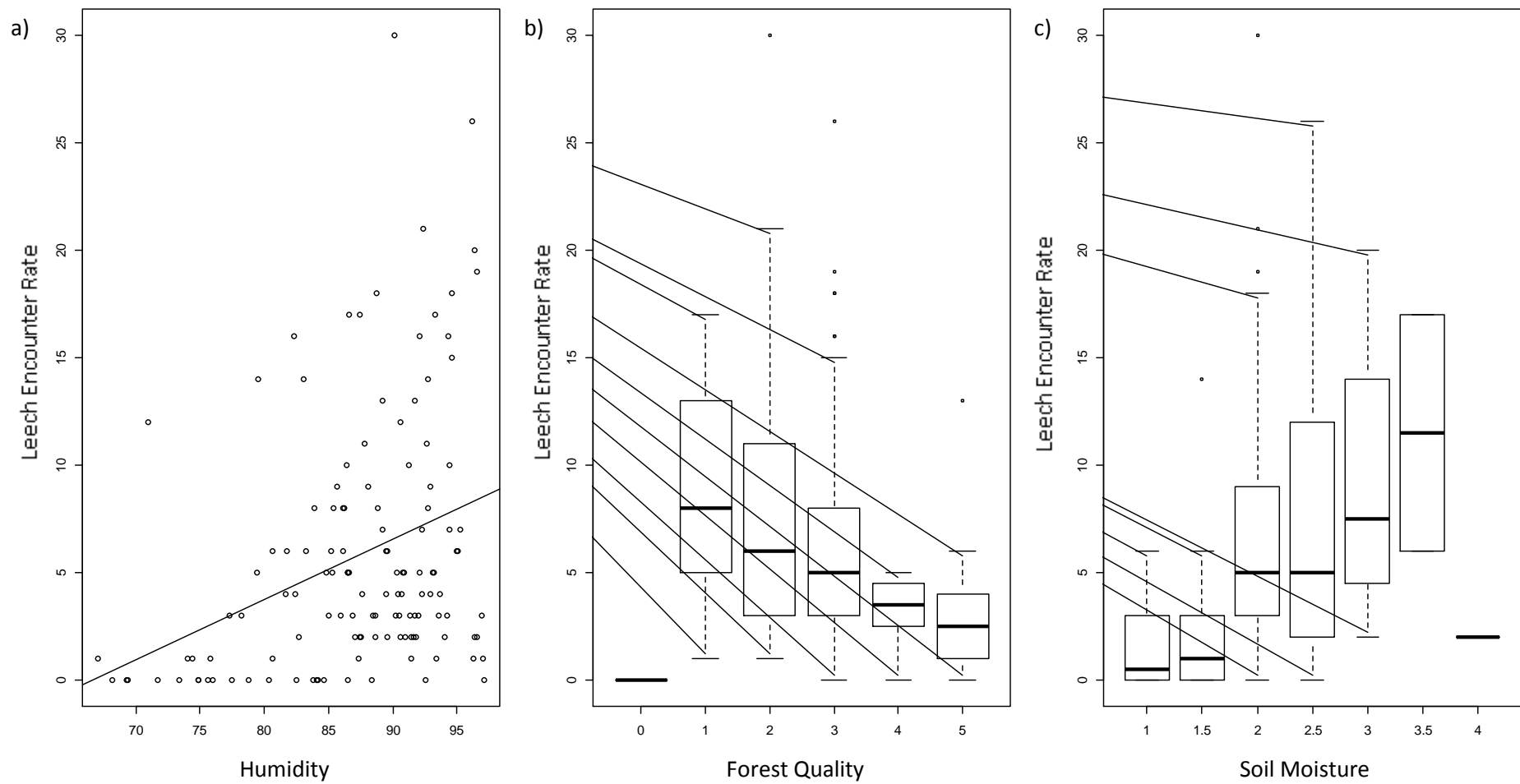
Figure 3. Leech encounter rate compared to significant environmental explanatory variables; a) humidity; b) forest quality; c) soil moisture.
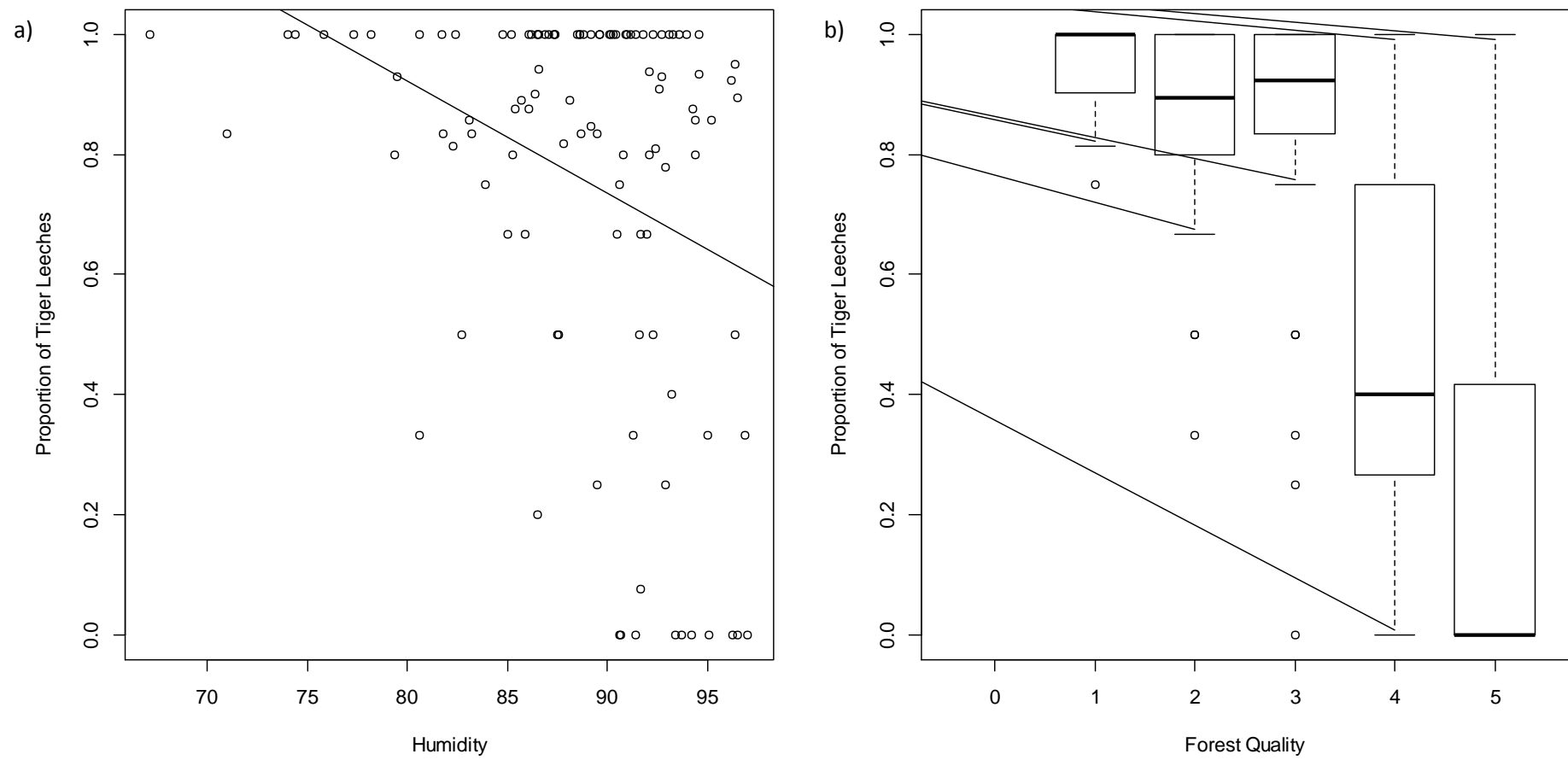
Figure 4. The proportions of the two species *H.zeylanica* and *H.picta* compared to the significant environmental factors; a) Humidity; b) Forest Quality.

As the encounter rate for leeches was found to increase as forest quality decreases, and also as the proportion of tiger leeches increases over that of brown leeches, it is important to determine how much each species contributes to the overall increase in leech numbers with declining forest quality. This is shown in figure 5.
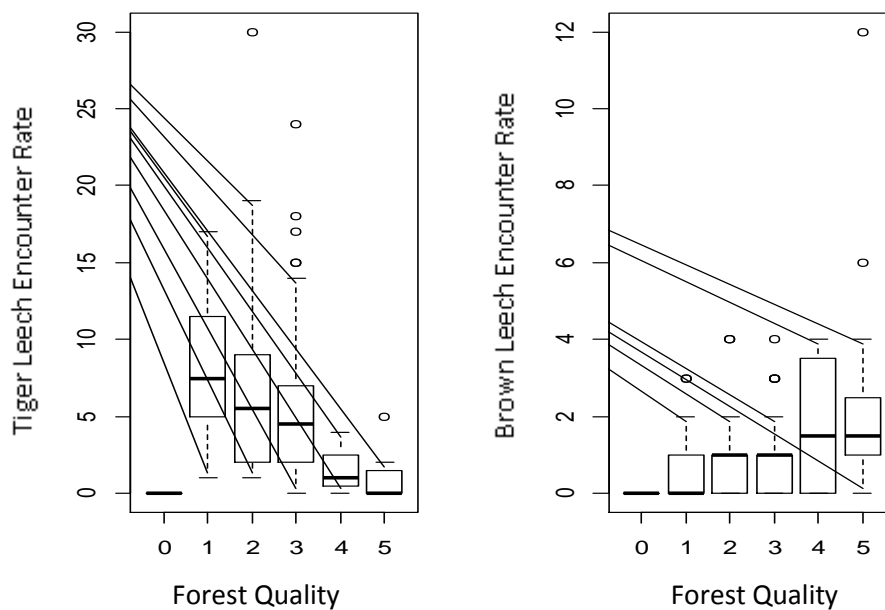

Figure 5. The encounter rate for leeches is separated into the different species to determine which species is responsible for the increase in encounter rate as forest quality declines; a) tiger leech; b) brown leech.

Leech length and average length

Total length of leeches was measured as a proxy for biomass. Temperature had a significant negative effect on tiger leech total length ($p < 0.05$) (Figure 6) as did the three way effect of canopy openness, forest quality and soil moisture ($p < 0.001$). None of the measured variables had a significant effect on tiger leech average length, brown leech average length or brown leech total length.
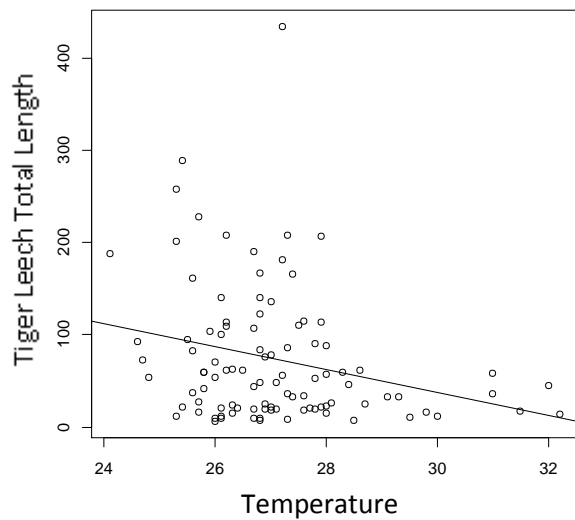
Figure 6. Temperature has a significant negative effect on tiger leech total length.

As there were no other factors significantly affecting leech length for either species, this can be seen as a result in itself. Forest quality, for example, has been shown to determine leech encounter rate. If it has no effect on leech length, this could indicate compensatory growth (Figure 7 and 8).
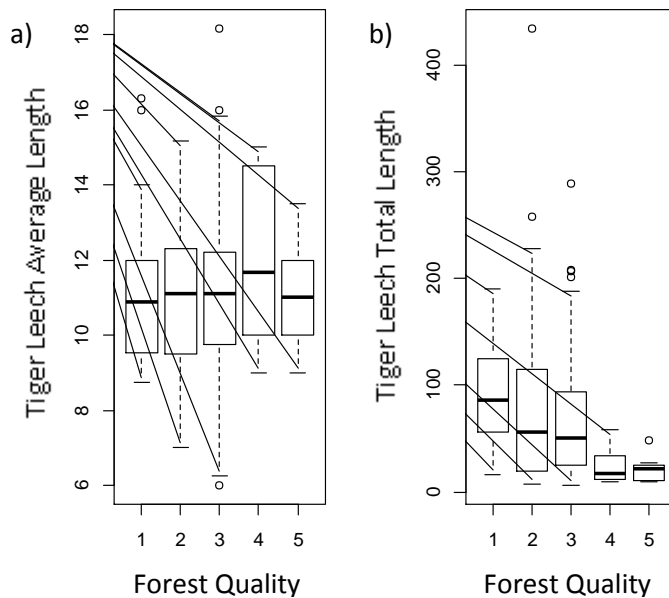

Figure 7. The total and average lengths of tiger leeches found during surveys as a function of the forest quality. Neither is a significant effect.
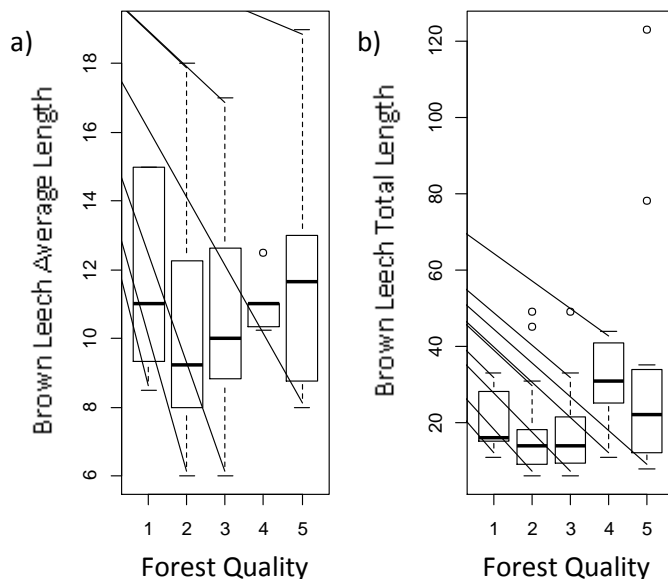
Figure 8. The total and average lengths of brown leeches found during surveys as a function of the forest quality. Neither is a significant effect.

The frequency of leech lengths was also compared between logged forest and old growth forest (Figure 9). Oil Palm was left out as there were no leeches found and so no distribution of lengths.
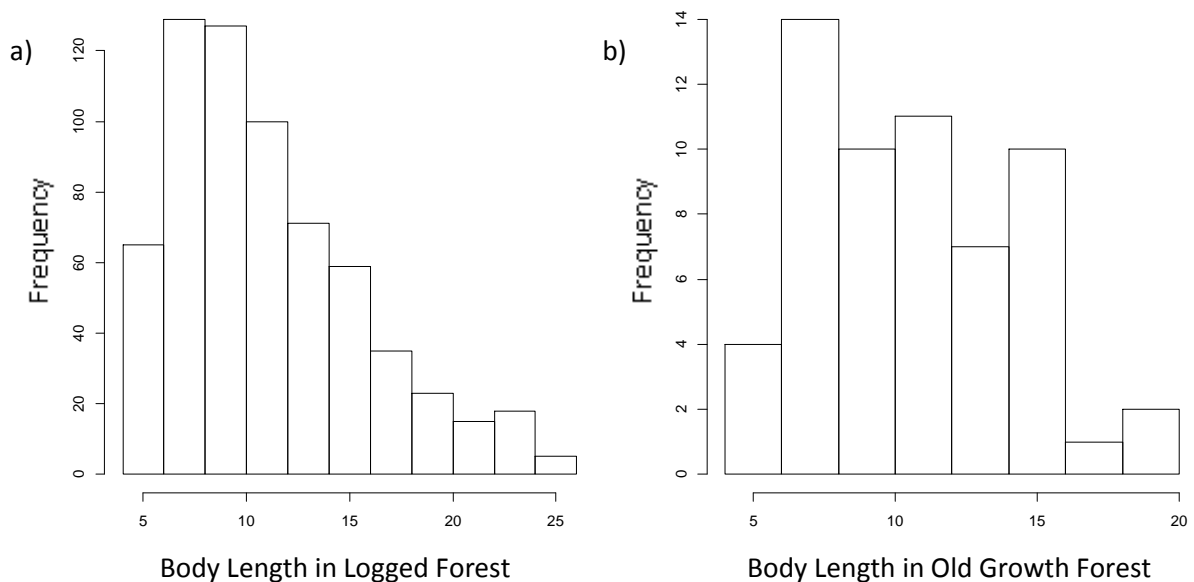

Figure 9. Histograms comparing the distribution of the lengths of leeches found in Logged and Old Growth Forest. In both cases the distribution appears skewed to the left as there are a higher frequency of shorter leeches (approximately 7mm) than longer leeches. The greater number of leeches found overall in the logged forest leads to a smoother and more obvious distribution.

Leech abundance along river banks

The encounter rate of leeches, the proportion of *H.zeylanica* to *H.picta*, and the total and average lengths for leeches found at each survey were compared with the environmental variables. The environmental variables measured for the rivers were river type (forest, riparian reserve and oil palm), temperature, humidity, soil surface moisture and riparian reserve width. Riparian reserves are strips of forest alongside rivers, surrounded by oil palm plantation. There was a significant difference in the number of leeches found at each river type ($p<0.001$) and leech number differed with humidity ($p<0.001$) (Figure 10). For the ratio of the two species, there was no significance found with any of the environmental variables, though this is probably due to the small sample size. Type of river had a significant effect on both leech total length ($p<0.05$) and average length ($p<0.001$) (Figure 10). None of the other environmental variables significantly affected leech total or average length.
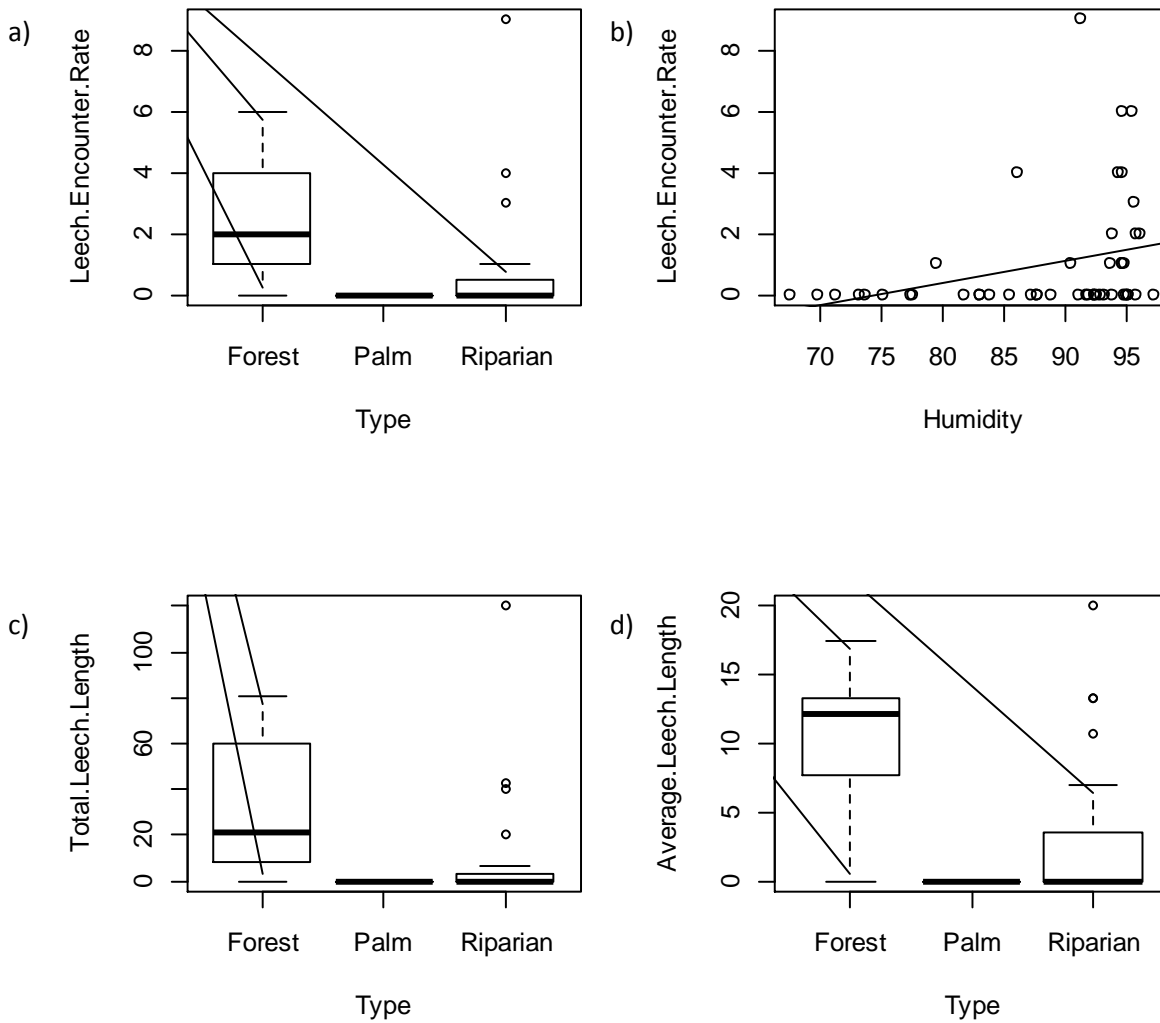
Figure 10. The nature of the environment surrounding the waterway significantly affects a) leech encounter rate; c) leech total length and d) leech average length. Forest waterways are surrounded by large areas of logged forest within the SAFE study area. Riparian reserves are rivers surrounded by Oil Palm plantation but with strips of forest alongside the river. 'Palm' are rivers running through Oil Palm plantation with no remaining forest. Humidity (b) also has a significant effect on the leech encounter rate.

To analyse the differences in the body length distribution between the forest waterways and the riparian reserves, two histograms were made, which are displayed in figure 11.
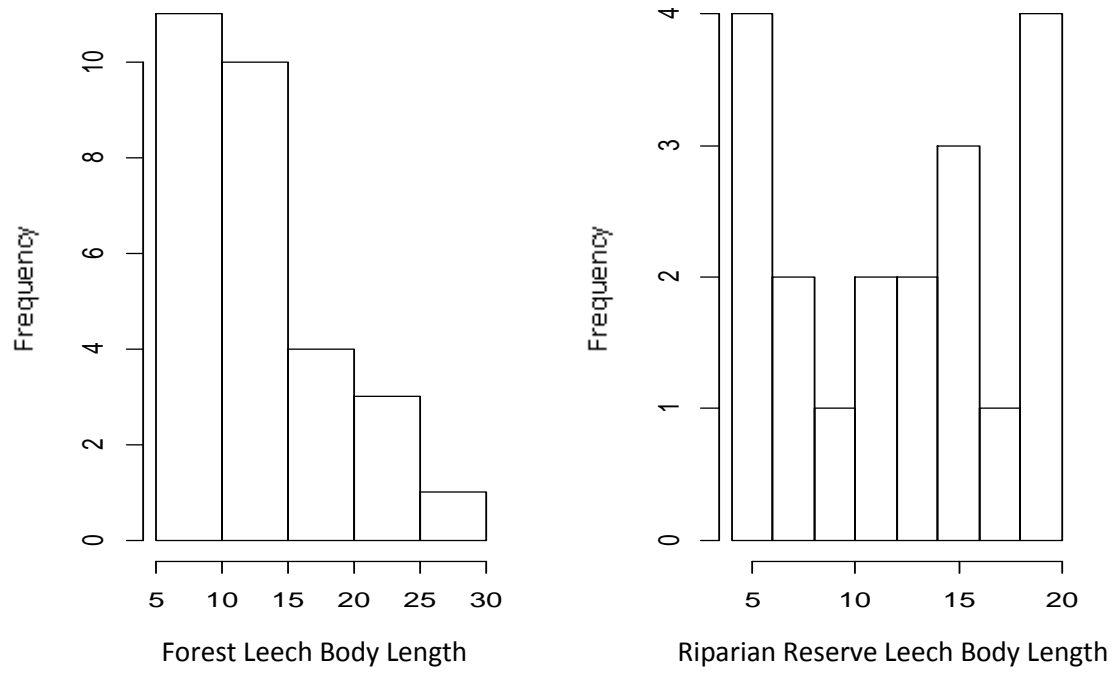
Figure 11. The frequency of the different leech body lengths found beside forest waterways and in riparian reserves.

Discussion

Previous work on the terrestrial leeches of Borneo by Fogden and Proctor (1985) predicted that as leeches were sensitive to changes in humidity, they would be absent from logged forest. This study has shown that a far more complicated pattern emerges and that, far from declining from logged forest, overall abundance, measured by encounter rate increases. Along a gradient from primary forest down through logged forest of reducing quality, leech encounter rate increases. Leeches are however completely absent from Oil Palm plantations. There therefore must be environmental factors that change as forest is logged, increasing the suitability of the habitat for leeches. These factors though are clearly dependent on certain factors that are present even in a highly logged forest but which are absent from the industrial agricultural environment of an Oil Palm plantation. This study further aimed to look further at what these factors could be and to analyse the different responses of the two different terrestrial leech species *Haemadipsa zeylanica* (the brown leech) and *Haemadipsa picta* (the tiger leech).

Environmental Variables

It can be seen clearly that many of the environmental variables measured in the study are correlated with each other. The most acute is between temperature and humidity, as humidity declines when temperature rises. But it is also true of other factors such as canopy openness and forest quality. Teasing apart the individual effect each factor has is impossible in the field without a controlled experiment. An experiment to determine the response of leeches to moist or dry surfaces was attempted as part of this study but as it had to be undertaken at the research site it was impossible to nullify other factors such as the leeches' attraction to research staff nearby, so the test was abandoned. It is an assumption of this study that the explanatory variables are all in some way correlated with each other but that significance tests show which are the most important at determining the patterns shown.

Leech Encounter Rate

Leech encounter rate drops with decreasing humidity and increasing temperature and also, at a shallow rate, with increasing canopy openness, which probably causes the changes in temperature and humidity. However, although canopy openness and forest quality are

negatively correlated, leech encounter rate increases with declining forest quality, though it drops to zero at the 0 quality score which indicates Oil Palm plantation. Clearly there is something happening to the forest structure as measured in the forest quality score other than the openness of the canopy.

The increase in overall leech abundance as forest quality declines will no doubt have some affect on their mammal hosts. The effect of the increased parasite load on mammals with the corresponding blood loss is a subject for further study. The data for mammal abundance was not available for the plots surveyed; while some studies have seen abundance decline in logged forest (Berry et al. 2010; Turner et al. 2011) others have seen some mammal species' abundances increase (Slade et al. 2011). At present, the changing mammal abundance between primary forest, logged forest and Oil Palm plantations cannot be directly compared with leech abundance.

Leech encounter rate also increases significantly with increasing soil moisture, though they are absent from the wettest sites, where the water is visible on the soil surface. Since soil moisture is related to the presence of an understory and the ability to hold water in the soil by plants, and leeches suffer from the danger of desiccation, it is clear that a moist environment is preferable. An environment that is too wet however may prevent efficient movement of leeches across the ground to prey, and may also be indicative of a high water table and the lack of an understory to take up the water.

It is difficult to determine exactly why there are no leeches at all in the Oil Palm plantation. There is frequently an understory of planted cover crop which keeps the soil moist in many places. Temperature and humidity may be crucial, as the temperature is higher and the humidity lower than in primary or logged forest. There may also be fewer host mammals, as shown for Oil Palm in general by Turner et al. 2011. Another issue may be the intense use of fertiliser used by the Oil Palm industry (Turner et al. 2011), and other forms of disturbance. Or the effect may be historical; when the forest was cleared leeches may have died out locally and may not have time to re-colonise a more favourable habitat.

Comparing the proportions of each leech species

There is not much information on the differences between the two species of leech and how they vary ecologically. The only piece of information comes from Fogden and Proctor (1985) and clearly visible by anyone in the forest; that the brown leech prefers to inhabit the forest flood whereas the tiger leech is found in the understory up to 2 metres above the ground. Looking at how the proportion between the species found in a 5 minute survey changes depending on the conditions was therefore also vital in determining how the species react differently to forest modification.

The proportion between the two species does change as forest quality is reduced. The brown leech becomes less abundant and the tiger leech becomes more abundant. In primary forest it is the brown leech that is the most abundant species; as the forest quality declines, tiger leeches increase in abundance and brown leeches decrease in abundance to such an extent that below a forest quality level of 4, tiger leeches become the dominant species. The increase in total leech encounter rate observed with declining forest quality is found to be entirely due to the increase in tiger leeches, masking a decrease in the encounter rate of brown leeches. The decrease in humidity also significantly affects the change in proportions; as humidity declines, the tiger leech increases in proportion to the brown leech. It is possible that changes in humidity affect the leech species in different ways though this would need to be proved by controlled experiment. It seems likely that the effect of humidity is due to the decrease in forest quality.

Temperature and soil moisture do not have significant effects on the changing proportion of the species. Although they do have an effect on the overall leech encounter rate, they are not related to the species shift. Since the tiger leeches inhabit the understory more than the forest floor, soil moisture may have less of an impact on them and so may not be a direct cause in their increase compared to brown leeches.

It is known that ground vegetation in primary forest is sparse and increases as light is let in from logging (Berry et al. 2010). It has also been observed, in this study and in Fogden and Proctor (1985) that whereas brown leeches inhabit the forest floor, tiger leeches inhabit the ground vegetation up to 2 metres above the ground. The extra ground vegetation caused by the extra light could therefore be acting as habitat for tiger leeches and allowing their

numbers to increase. The data to test this hypothesis are not currently available and should be the subject of further studies. However, if canopy openness is taken as a proxy for undergrowth density, it can be seen that tiger leech proportion increases as canopy openness increases, providing evidence for this hypothesis. If this were true, it would still pose problems for the complete absence of leeches from Oil Palm plantations, as these frequently have extensive ground layers made up of a planted cover crop.

Total lengths and average length of each leech species

Leech length was used as a proxy for biomass. The only variable affecting any length measurement was temperature having a significant effect on tiger leech total length. Although the graph does show a negative correlation, it seems more likely that there is a 28°C threshold above which tiger leech total length reduces dramatically. It is probable that brown leeches have already reduced to such an extent by this point that the stepwise reduction is not significant.

That none of the other environmental factors have any significant effect on the average or total lengths of either species is interesting since they have such an effect on the number of leeches and the proportion between the species. The graphs for forest quality show the lack of length differences over different levels of forest quality. Since leech average or total length doesn't change over different forest quality scores but tiger leech number increases as the forest quality declines, this implies compensatory growth. Therefore, as forest quality decreases and tiger leech number increases, the size of the average tiger leech must decrease. The larger amount of tiger leeches found in areas high in logging and with low forest quality may therefore not necessarily be a function of the increasing ground vegetation; as if these leeches are on average smaller, they may require a smaller habitat per leech. In other words, a small number of large tiger leeches may require the same area of habitat as a large number of small tiger leeches. The histograms in figure 8 do show a shift towards larger leeches in old growth forest. Brown leeches, which decrease in abundance as forest is logged, may show the same effect but in the opposite direction; larger brown leeches may therefore be found in logged forest, but there will be fewer of them.

The effect of different waterways on leeches

In an aim to look at how fragmented forest may affect the distribution of leeches, this study looked at the forest surrounding waterways. Comparing waterways surrounded by logged forest, riparian reserves of forest within Oil Palm plantations, and waterways without any surrounding forest in Oil Palm plantations, the effect of the riparian reserves on leeches could be determined. It was interesting to see that leech numbers within 20 metres of waterways in logged forest were lower than leech numbers found further within the forest. The reason for this should be examined.

Of all the environmental variables, humidity was found to affect leech count near waterways, which increased as humidity increased. This follows the predicted effect of humidity on leeches. The type of waterway, whether forest, riparian reserve or Oil Palm, significantly affected the leech encounter rate, average leech length and total leech length. All these three measurements declined from forest waterways to riparian reserves; Oil Palm waterways had no leeches at any of the study sites. The riparian reserves did maintain communities of leeches, though not as much as the forest rivers. This could be because of the effect of pollution from the Oil Palm plantations or because of a reduction in host mammal abundance. The frequency of the different body lengths for those leeches collected near the forest waterways resembles the logged forest leech size frequency (comparing figures 11 and 9). The frequency of body lengths for the leeches found in the riparian reserves is weighted towards the high and low ends of the distribution. It is hard to tell why this has occurred without more data about the individual riparian reserves, but it may be that smaller and larger leeches occupy different niches within the reserve, perhaps because of a changed mammal population, affected by the forest but also by the surrounding Oil Palm plantation.

The dataset was too small to detect any change in the proportion of leeches; this may be because there was also no opportunity to add primary forest rivers to the analysis, which would probably have had more brown leeches. Furthermore, all the riparian reserves were also logged forest, rather than primary. Further analysis should be also done on the effect of reserve width on leech encounter rate, average and total length. This study did analyse reserve width but the sample size was too small to detect any effect.

Conclusion

In conclusion, this study has revealed that as a primary forest is logged, the leech encounter rate increases. The proportion of the species also shifts, from a situation where brown leeches are more abundant than tiger leeches in primary forest to tiger leeches vastly outnumbering brown leeches in logged forest. The increase in leech encounter rate is entirely down to the increase in tiger leeches rather than brown leeches, and despite a decrease in the encounter rate of brown leeches. Although these changes in encounter rate and proportion occur, there is no resultant change in average leech length or total length of leeches caught in a sample throughout different levels of forest quality. This indicates that although leech number increases as forest is logged, these leeches are on average smaller. Several environmental factors also have effects on leeches, most likely resulting from the change in forest quality. Temperature, humidity, canopy openness and soil moisture also affect the encounter rate whilst canopy openness and humidity also affect the proportions of the species. No leeches are found in Oil Palm plantations.

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