UNIVERSITY OF OXFORD

FHS IN BIOLOGICAL SCIENCES
UNDERGRADUATE PROJECT REPORT
COVER SHEET

PROJECT DISSERTATION SUBMITTED AS PART OF THE FINALS EXAMINATION IN THE HONOURS SCHOOL IN BIOLOGICAL SCIENCES

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COVER SHEET PAGE 1
TITLE:

Establishing the impact of forest disturbance on non-tree flora in Bornean peat swamps.
ABSTRACT

Ecological monitoring is crucial for the successful conservation of the endangered tropical peat-swamp forest ecosystem. Non-tree flora is an important indicator of both the health of a forest and its fauna. It could therefore be used to monitor the ecological condition of peat swamp forests and allow appropriate strategies to be developed to conserve each forest in question should a significant disturbance occur. The effect of disturbance on the non-tree forest flora in a Bornean peat-swamp forest was investigated by comparing the floral composition between plots that had been previously subjected to varying levels of environmental damage. This damage was due to logging operations, draining, burning or a combination of these factors. Analysis found a significant increase in number of early successional plants, including lianas and pitcher plants, with increased disturbance. However no significant difference in the abundance of ground plants and Pandan (sedge) was found with varying disturbance in the forest plots. Burnt plots had lower seedling and sapling density to those that had not been burnt. The more recently burned plot contained higher ground plant abundance compared to one that burned less recently. The study found that differences in soil nutrient availability and peat depth, which varied with disturbance level between the plots, were the main reason for the difference in floral composition between plots.
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COMMON ABBREVIATIONS USED IN TEXT

PSF – Peat-Swamp Forest

IUCN - International Union for Conservation of Nature and Natural Resources

MRP – Mega Rice Project

NTF – Non-tree flora

NLPSF – Natural Laboratory of Peat Swamp Forest

DBH – Diameter at Breast Height

IR – Inter-rail Plot

MR – Mega Rice plot at Kalampangan

MRB – Mega Rice Burnt area plot

PCA – Principal Component Analysis

DFA – Discriminant Function Analysis
INTRODUCTION

The peat-swamp forest (PSF) is classed as one of the most endangered and least well-known ecosystems on the planet (Boehm & Siegert 2001). This is despite fossil records showing the existence of angiosperm dominated PSF in Southeast Asia since the Early Miocene period (Posa et al 2011).

More research in recent years has uncovered the importance of PSF’s in the global carbon cycle (Page et al 2002, 2006; Aldhous 2004). Their role as a major carbon store means that they have the potential to release large amounts of carbon into the atmosphere if disturbed. It is estimated that Indonesian PSF’s alone hold 55 gigatons of carbon (Page et al 2004, Jaenicke et al 2008). Research into PSF’s has also revealed their high diversity of specialised flora and fauna (Page et al 1997, Yule 2008). In comparison to other peatlands, for example, tropical PSF’s have been found to contain the highest diversity of flora (Posa et al 2011) and are inhabited by many endangered and endemic species (Yule 2008). Furthermore, tropical forests hold over half of the world’s terrestrial species alone (Myers et al 2000; Danielsen et al 2008).

However PSF’s also contain many commercially valuable trees such as Ramin (Gonystylus bancanus), which is now red-listed (threatened) under the International Union for Conservation of Nature and Natural Resources (IUCN) (Posa et al 2011) and Jelutong (Dyera costulata); the sap of which is used in latex production (Lucas 2005). This has meant that PSF’s have been subjected to logging for their precious resources. Furthermore, until only recently the inaccessibility of PSF’s harboured the belief that they contained low species diversity (Prentice & Parish 1990, Yule 2008) and therefore the land was earmarked for
agricultural conversion, especially to oil palm, rice and rubber (Yule 2008). Data from 2006 showed that 85% of global palm oil crop (Figure 1) was grown in Indonesia (Danielsen et al 2008). This agricultural expansion proves the principal reason for biodiversity loss and habitat alterations in PSF’s today (Geist & Lambin 2002).

![Figure 1: Typical oil palm plantation on deforested land in Sabah, Borneo. (WWF 2007)](image)

PSF’s exist as a fragile balance between the vegetation, peat and hydrology of a region and are very susceptible to disturbance (Page & Rieley 1998 cited in Boehm & Siegert 2001; Lucas 2005). If this balance is disturbed then positive feedback loops between fire, deforestation and drainage cause the PSF to oxidise and degrade (Posa et al 2011).

It is estimated that only 36% of historical PSF remains worldwide (Posa et al 2011). In Southeast Asia especially, of the original 27 million hectares of PSF, 12 million hectares (45%) had been logged and a similar amount drained by 2006 (Hooijer et al 2006; Yule 2008). The occurrence of such rapid deforestation and consequent habitat fragmentation is predicted to have a significant ecological impact on the PSF ecosystem, for example through altering key nutrient and pollination cycles (Didham et al 1996). Increased disturbance has
also been correlated with a decrease in resistance to invasion of an area by introduced weed species (Asyraf & Mansor 2002). Draining, which commonly occurs as a result of canals being cut to float out valuable timber logs, causes particular damage as it raises the likelihood of forest fire due to alteration of the hydrological conditions (Posa et al 2011). Increases in PSF fires may considerably effect global carbon emissions unless preventative measures are taken (Page 2002). An example of this would be the 1997 PSF fires in Indonesia which caused the release of up to 40% as much CO$_2$ as the average annual global emissions from the burning of fossil fuels (Aldhous 2004). These fires, originally started for land clearance, were augmented by the increased artificial drainage of the soil and the El Nino Southern Oscillation that year (Boehm paper). This resulted in record-breaking fires within areas of Indonesia that are usually regarded as too humid to burn (Cleary & Priadjati 2005).

The impact of deforestation, draining and other such disturbances on the flora and fauna of tropical forests is still poorly researched although the consequences are likely to be severe (Smith et al 1993 cited in Carlson and Hartman 2001). Information about the effects of logging on the biodiversity of PSF’s in particular is sparse due to the deficiency of primary data about their flora and fauna (Posa et al 2011). Although Anderson (1963) pioneered the study of PSF flora back in the 20$^{th}$ century (Posa et al 2011); Danielsen, writing his paper in 2009, was still expressing difficulties in assessing damage to PSF’s as ‘no published data on flora were available’ (Pg384, Conservation Biology). The aim of this project is thus an attempt to fill this gap of knowledge through looking at the effects of disturbance on non-tree forest flora in a typical PSF.

Flora will be assessed in an area of PSF in the Sabangau catchment area of Borneo, Indonesia. As flora is an important indicator of forest health and has a strong influence on
fauna, it means that comparing floral presence in plots of varying degrees of disturbance (logged, drained and burnt) can give a better idea of the effects of each of these disturbances on overall PSF health.

The Sabangau PSF (Figure 2) certainly exemplifies the notion of PSF’s being high in biodiversity and many species found in this forest are red-listed under IUCN guidelines (Lucas 2005). Eight primate species inhabit the forest, including the world’s biggest orang-utan (*Pongo pygmaeus*) population of 6,900 individuals (Aldhous 2004; Wich *et al* 2008) and also the predicted world’s largest Bornean agile gibbon population (*Hylobates albibarbis*) (Cheyne *et al* 2008). There are in excess of 200 bird species, a diverse plant life and many timber trees of commercial value as well as a flourishing invertebrate community (Lucas 2005). However in just 15 years (1990-2005) this forested area of Kalimantan (and Sumatra) combined have been subject to a 41% loss in total area due to deforestation and accounted for 70% of all forest clearing in Indonesia in that time (Hansen *et al* 2009; Posa *et al* 2011). The

*Figure 2: The Sabangau PSF (left) contains many endangered animal and plant species including the largest population of orang-utans (*Pongo pygmaeus*) (right). Orang-utan image courtesy of Barrow 2012.*
area was logged under concession until 1997 however after that time illegal logging and canal construction were still prevalent and chain saws were heard daily even in 2003 (Husson and Morrogh-Bernard 2002). In the 1997-98 Indonesian fires, 10-15% of the forest was also burnt (Lucas 2005). The effect of this upon the ecosystem and carbon sequestration has sparked much recent research (Boehm et al 2001).

Given the threats currently posed to this area of PSF and those it has already faced, it is important to implement correct conservation strategies in an attempt to prevent further damage to this ecosystem and its significant biodiversity. To do this requires monitoring of the area to gain an understanding of this biodiversity and therefore tailor conservation activities as needed (Marchant 2012). There is still a high demand for biofuels and this pressurises governments for agricultural expansion into native habitat regardless of costs to biodiversity (Danielsen 2008). In Borneo especially, the legacy of the failed 1996 Mega Rice Project (MRP) initiative has not stemmed PSF land clearance for agriculture. The MRP (Figure 3), under the control of former dictator Suharto, involved clearance of 1 million hectares of unspoilt PSF in Central Kalimantan for rice production to make Borneo the ‘rice bowl’ of Indonesia (Aldhous 2004). The operation was deemed a complete failure (Aldhous 2004) as the peat soil was too acidic to support rice growth. Block C land from the MRP will also be studied in this project.
In order to prevent such ecological disasters from occurring in the future, clear guidelines should be set out for conservation of PSF’s. It is estimated, however, that only 9% of PSF’s in Southeast Asia are located in designated protected areas (Posa et al. 2011) and the figure is as low as 3% in Indonesia (Yule 2008). Even then many protected areas are still subject to illegal logging and their long term conservation status is not guaranteed (Corlett 2009, Gaveau et al. 2009). Hence continual ecological monitoring is crucial in maintaining the successful conservation management of PSF’s for the foreseeable future.

**Figure 3:** The failed 1996 MRP initiative cleared 1 million hectares of PSF in Borneo and left large canals criss-crossing the landscape. (Jess S. 2011)
METHODS AND MATERIALS

Study site

The research took place between 14th July to 13th August 2012 in Sabangau Forest, Central Kalimantan, Indonesia (21° 31’ S and 113° 90’ E) (Figure 4) as part of the OuTrop multi-disciplinary research project in collaboration with CIMTROP. During this time the average daily temperature was 27.0 °C and the average daily rainfall was 4.0 mm (Wunderground 2012).

![Figure 4: Location of field research station in Central Kalimantan, South Borneo, Indonesia (OuTrop website). Green © shows location of Block C MRP (Kalampangan research station)](image)

The majority of data collection was carried out at the Setia Alam Field Station in the Natural Laboratory of Peat-Swamp Forest (NLPSF) where a 2 x 2 km² grid system had been set up for primate research (Figure 5). This area of Mixed Swamp Forest (MSF) was selectively logged under concession until 1997 and then illegally until 2003 (Manduell et al 2011) as well as being affected by some major forest fires, most recently in 2006-2007 and 2009 (Cheyne 2008;
Harrison et al 2007; Harrison et al 2009). A number of phenology plots were established in the area by previous studies (Morrogh-Bernard 2009) that were the basis of the non-tree flora (NTF) plots used in my research. These covered a range of forest types (Table 1); the forest edge (Transect PH), relatively undisturbed forest (T0.4, T1C and TU1.6), burnt forest (Burnt area), sedge swamp just outside forest (KH1) and forest that was regenerating from the logging operations in the area (Inter-rail, Rail and T16).

![Figure 5: Phenology plots and transect system used for primate and biodiversity research at Setia Alam Field Station (Milner 2009).](image)

The phenology plots were each 5m x 300m in area except for the burnt area where there were 3 plots of 5m x 100m (giving an equivalent total area). Research work was also undertaken on the northern side of the Sabangau River at the Kalampangan Research Station. A network of deep canals for peat drainage was constructed in this area to be used for the 1990’s Mega-Rice Project Government Initiative. When this failed, the peat was left dried and vulnerable to fire which has meant that the area has been burnt annually since 1997 (Aldhous 2004). Thus this constitutes a highly disturbed area of the Sabangau catchment. Here the tree plots covered heavily degraded forest and burnt, degraded forest. There were 6 plots of 5m x 100m and the burnt area plot was 5m x 300m.
<table>
<thead>
<tr>
<th>Plot Name</th>
<th>Site</th>
<th>Location</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>KH1</td>
<td>NLPSF</td>
<td>-50m (outside forest edge)</td>
<td>Sedge swamp. Used to be a riverine forest before it was burnt and deforested in 1950’s. Thin peat layer and sandy surface.</td>
</tr>
<tr>
<td>PH</td>
<td>NLPSF</td>
<td>0m – Following forest edge</td>
<td>Regenerating riverine forest. Last deforested in 1950’s. Thin peat layer. May be affected by edge effects as at edge of forest.</td>
</tr>
<tr>
<td>1C</td>
<td>NLPSF</td>
<td>180m</td>
<td>Regenerating forest at least 500m from logging railways. Peat layer approx. 1m.</td>
</tr>
<tr>
<td>IR (Inter-Rail)</td>
<td>NLPSF</td>
<td>470m - Between 2 old logging railways</td>
<td>Regenerating, heavily disturbed forest. Last logged 15 years ago.</td>
</tr>
<tr>
<td>0.4</td>
<td>NLPSF</td>
<td>850m</td>
<td>Undisturbed. Little logging activities (at least 500m from logging railways). Thick peat</td>
</tr>
<tr>
<td>Rail</td>
<td>NLPSF</td>
<td>1100m - Strip plot approx. 1km along railway</td>
<td>Regenerating, heavily disturbed forest. Completely cleared as recently as 15 years ago for logging railway access. May be affected by edge effects as at edge of forest.</td>
</tr>
<tr>
<td>1.6</td>
<td>NLPSF</td>
<td>1800m</td>
<td>Generally undisturbed but adjacent to railway so more affected by logging than U1.6.</td>
</tr>
<tr>
<td>U1.6</td>
<td>NLPSF</td>
<td>1900m</td>
<td>Undisturbed. Little logging activities (at least 500m from logging railways). Thick peat</td>
</tr>
<tr>
<td>Burnt</td>
<td>NLPSF</td>
<td>-50m (outside forest edge)</td>
<td>Burnt in 2006. Thin peat layer and sandy surface. Fed by rainwater and flood water from river.</td>
</tr>
<tr>
<td>MR (Mega-rice)</td>
<td>Kalampangan</td>
<td>2000m from forest edge/river flood plain</td>
<td>Canals drained surface soil decreasing strength of peat. Led to increased tree fall and gaps in upper canopy. Thick peat.</td>
</tr>
<tr>
<td>MRB (Mega-rice burnt)</td>
<td>Kalampangan</td>
<td>3000m</td>
<td>Burnt. Thick but damaged peat layer. Fed only by rainwater.</td>
</tr>
</tbody>
</table>

*Table 1*: The forest types studied. N.B. Distance from forest edge measured (to nearest 10m) in due North direction from site to ensure homogeneity of measurement among sites. Average distance value taken for MR from 6 plot measurements. Site descriptions from Marchant 2012; Page et al 1999.
General Procedure

Each 5m x 300m phenology plot was then subdivided into 6 sub-plots of 50m x 5m (Figure 6). These were divided further into ten 5m x 5m quadrats; giving a total of 60 quadrats in each plot (the smaller burnt area plots were merged). At Kalampangan, the 6 forest plots were united and treated as 1 large plot as individual plot differences could not be accounted for. The non-tree flora would be surveyed in 15 randomly selected quadrats within each plot regardless of the conditions e.g. tree fall, affecting the quadrat. This sample size was selected as it would allow for sufficiently accurate statistical analysis of the data. Within each plot there would always be 2 quadrats in each subplot 1-6 (giving 12 quadrats in total) to ensure that the quadrats gave a true representation of the conditions in the plot. The final 3 subplots to be used (each with one quadrat bringing the total quadrats up to 15) would be chosen by picking 3 cards at random, without replacement, from a set of 6 cards (ace to 6). To select the quadrats used within each subplot cards were randomly selected, with replacement, from a set of 10 cards (ace to 10) as there are 10 potential quadrats in each subplot. If a quadrat was selected that would be directly adjacent to another quadrat already chosen in the plot then the next suitable alternative quadrat should be used, once again by selecting cards, without replacement, from the set of 1-10.

Figure 6: Experimental technique. Division of 300m plot at each forest site. Each sub-plot was further divided into 10 quadrats (60 quadrats per plot). Of these 60 quadrats 15 were selected at random per plot to be studied.
The quadrats would be placed adjacent to the transect (in order to minimise the disturbance effect from the transect) and on the left hand side unless the tree plots were located only on the right hand side (such as at Kalampangan). Boundaries of the quadrat were marked with string. To collect the data, a team of 4 surveyors were required consisting of an Indonesian botanist to identify the NTF, a searcher to assist the botanist as well as 2 data recorders. Within each plot, all NTF were recorded (Latin names reference Gibson 2005; Husson et al 2011). This included the abundance of Lianas, Vines, Ficus, Nepenthes, Pandanaceae species (Pandanaceae Pandanus sp.1 L, Pandanaceae L ‘Gerising’, Pandanaceae Pandanus sp.2 L and Pandanaceae Freycinetia sp. L), Arecaceae (Palmae) Calamus L, Ferns and Zingiberaceae L (local name ‘Suli’) species as well as any other flowering plant. NTF were classed as present in the plot if the roots lay within the boundaries of the plot. Liana (woody stems) and vine (non-woody stems) abundance was counted together for ease of classification. Each liana counted was identified by local name unless it was unknown by the botanist in which case it would be labeled as ‘unknown’. Vine species were not differentiated. For Lianas /Vines and Ficus, the abundance was divided into 4 size classes of <0.5cm, 0.5-1cm, 1-3cm and >3cm diameter at breast height (DBH) in order to give an accurate representation of the maturity of the plants. The DBH was calculated using calipers and measured at 130cm from the base of the plant (Schnitzer et al 2006). For the largest Pandanaceae Pandanus sp.1 plant in the quadrat, the length and width of the longest leaf were also measured. The number of fallen trees and stumps in the plot were recorded and these were classified by size of the diameter of the trunk at the widest part (<6cm, 6-20cm, >20cm). All Nepenthes plants were identified and if unknown were classified as ‘unknown’. Any ground flora was also named and if it was a previously unstudied and therefore unclassified species then an appropriate name would be selected.
Within the centre of the quadrat, a smaller 1m x 1m quadrat would be marked out, using string. Within this smaller quadrat all fungi would be recorded and allocated to one of 3 categories; present on dead wood, live wood, or leaf litter (free living) species. The number of different morphospecies and the abundance of fungal bodies would be counted for each group. All species of seedlings and saplings present in the 1m x 1m quadrat would be identified and recorded. A seedling was classified as a young plant <1m in length and a sapling >1m in length (Cassie Freund, personal communication, July 2012) in all cases except 7 quadrats at the Inter-Rail plot where due to methodology changes the cut off was 20cm. The percentage ground cover was estimated within the smaller quadrat in the following categories; living material, dead wood, leaf litter/bare ground and water. This was calculated to the nearest 5%.

In order to assess the environmental conditions within the plot, the canopy height was estimated. This was the highest point within the plot in which tree branches or foliage covered part of the plot (regardless of whether the tree roots were outside the plot) and was estimated in categories to the nearest 5m. The average canopy cover for the plot was recorded by standing in the middle of the 1m x 1m quadrat and using a densitometer to calculate the percentage of the view obscured by the canopy (to the nearest 5%). A photograph of the canopy was also taken from the centre of the quadrat at breast height. This image would later be processed to binary using ImageJ software to give another value for the assessment of canopy cover (Figure 7) (Campillo et al 2008; The Ecological Forester 2011).
Canopy stratification was measured by estimating the percentage of canopy cover (to the nearest 5%) in the quadrat at height intervals of 5m. Due to the overlapping canopy layers, it meant that the sum of the readings from the different height classes could exceed the overall densitometer reading. In order to eliminate individual bias the percentage cover in the 1m x 1m quadrat, canopy cover, height, stratification and the canopy photo were all carried out by the same individual throughout the data collection although their estimation was cross checked by other member of the research group. A basic text description of the habitat was made noting the habitat type and level of disturbance as well as any unusual characteristics e.g. flooding. All these measurements would give a portrayal of the light conditions available to the NTF within the quadrat. The numbers of all the tagged trees (Morrogh-Bernard 2009) within the plot were also recorded. In all tree plots, the tagged trees were those greater than 6cm DBH and tagged lianas >3cm DBH and all had been previously identified and measured.

Figure 7: Canopy cover photograph processed to binary with ImageJ software to create a more accurate total canopy cover value.
**Statistical Analysis**

**Tests**

Microsoft Office Excel 2010 and JMP-8 software were used to input the data and produce graphs. JMP-8 was also used for statistical analysis. Simpson’s Index of Diversity (Figure 8) was used to calculate species diversity of lianas and pitcher plants. This index measures both species richness and species evenness. It gives more weight to the more abundant species and less weight to the rare species in a sample.

\[
D = \frac{\sum n(n - 1)}{N(N - 1)}
\]

*Figure 8: Formula used to calculate Simpson’s Index of Diversity. Where n=total number of organisms of a particular species; and N= total number of organisms of all species.*

Principle component analysis (PCA) was carried out on the environmental variables (transformed to reach suitable normality) of all Sabangau plots (excluding the burnt areas as they were under different disturbance influences) in order to create a single factor axis of disturbance through a data reduction method. This axis would then be used in further analysis. After primary PCA was carried out, KH1 (sedge swamp and therefore no trees) was excluded from the data as the PCA eigenvectors were skewed towards canopy data differences when compared to forest plots. PCA without KH1, however, showed that the first (best) principle component (PC1) explained only 18.4% of the variation in the data. This was too low for suitable analysis of disturbance to be carried out using the PC1 axis alone. Discriminant Function Analysis (GFA) was then carried out using PC1 and PC2 from the PCA (excluding KH1) in order to attempt to categorise the forest plots by disturbance level to be used for subsequent floral data comparison.
As well as this, in depth comparisons between certain plots were carried out. The means of the two burnt areas were compared using a two sample t test to ascertain whether they were significantly different when the data were normally distributed and had equal variances. When the data did not have equal variance Welch’s approximate t test was used. The Mann-Whitney U test (Wilcoxon test) was the nonparametric test used as an alternative to the two sample t test when the data were not normally distributed and could not be suitably transformed. Normality was assessed using a goodness-of-fit test. A post hoc Tukey-Kramer HSD test was used when more than 2 plots were compared such as 0.4, IR, U1.6 and MR. The nonparametric alternative, the Kruskall Wallis test, was used if the data were not normally distributed and an appropriate transformation could not be found. The X² contingency test was carried out to determine the association between liana DBH and disturbance.

Missing and altered data

The change in methods for the seedling/sapling cut off identification meant that 7 values in IR were measured incorrectly. Furthermore in IR 2 values for total Pandan (*Pandanaceae Pandanus sp.1* L) number and 7 values each for species richness of seedlings and saplings (14 in total) were missing due to methodology change. All these data were still used in the analysis although the changes in sample size were taken into consideration. Two values of total number of lianas in the <0.5cm DBH category in the IR data were also missing. These values were estimating by calculating the proportions of the values in the other IR quadrats and using these to predict the 2 missing values. The percentage cover within the 1mx1m quadrat in 2 quadrats in IR was transformed from a categorical to a numerical variable by taking the median of the category. The MR data, which consisted of 30 quadrats in total, was not split up for data analysis but instead treated as one large plot. This was because the
correct way of splitting the data into two plots was not known. The MR plot landscape is poorly studied and may have meant that confounding variables would have affected the analysis of the results if the plot was split. The doubling in quadrat number was taken into account when carrying out statistical analyses.
RESULTS

DFA analysis

The DFA analysis of PC1 and PC2 from the PCA which excluded the KH1 plot produced a canonical graph for the remaining plots (Figure 9). The Canonical 1 axis produced 3 marked groups; Rail and PH, IR and IC, and 0.4, 1.6 and U1.6. These appear to be roughly divided by distance from edge of forest with PH and Rail, for example being located right on the forest edge and making up one group. IR and IC make up a distinct second group and both of these are located at similar distances from the edge of the forest. They are, however, not of the same disturbance level which is contradictory to the other findings. 1.6 and U1.6 form the third distinct group and these are the interior forest plots (relatively undisturbed) although 1.6 is also close to the former logging railway. 0.4 (undisturbed) overlaps the second and third groups however it is more significantly prevalent in the third group. Thus it suggests that edge effects may be indicators of disturbance although this correlation is weak as discriminant scores show that 62.5% of the data points are misclassified. This means that 62.5% of the data is predicted, based on all data, to be in a different plot than to the one it truly belongs to.
Nevertheless following the theory that plots can be grouped by distance from forest edge as a measure of disturbance level, a bar graph was produced to compare plot (ordered by distance from forest edge in the DFA groups) against mean liana number (Figure 10). Total mean liana number generally decreased as DFA group increased. The highest total mean liana number was in PH and the lowest was in IR. This trend was similar in the <0.5cm liana DBH category suggesting that the total mean liana number was heavily influenced by the <0.5cm DBH liana category compared to the other categories. The other DBH categories did not show any significant correlations with plot location. The Simpson’s Index of Diversity values for total lianas were also compared to plot and distance from forest edge by DFA grouping (Figure 11). Simpson’s values, on average, were higher in forest interior plots. There was no significant difference in species diversity at the highly disturbed IR plot which followed the
same pattern of increase of species diversity with distance from forest edge as the rest of the plots.

Figure 10: Mean liana number at each DBH for each plot. Plots are arranged by distance from forest edge and in the 3 groups marked by the DFA. ANOVA test proves that at least one of means in each DBH category is significantly different between plots (Prob. >F is <0.05). Error bars for standard error are given for each mean.

Figure 11: Simpsons Index of Diversity value for each plot. Plots are arranged by distance from forest edge and in the 3 groups marked by the DFA. Error bars cannot be given due to nature of calculation.
Comparison of burnt plots

The burnt areas in Kalampangan and Sabangau were analysed separately as they represented a different form of disturbance and thus a direct comparison of flora to the rest of the plots would be inappropriate. Results (Table 2, Appendix 3 in more detail) were analysed using the Mann-Whitney U test comparing the significance of medians between the two groups. Data were presented using the chi-square approximation values in the Mann-Whitney U test output. This nonparametric alternative to the 2 sample student’s t-test had to be used as none of the data could be suitably transformed to reach the normality required as part of the tests assumptions. Results showed that liana abundance was considerably larger, $X^2 (1, N=15) = 11.18$, $p=0.0008$, in the Burnt area than the MRB where median liana abundance was null. Median Nepenthes (pitchers) and fungi abundance was zero for both plots. Ferns, on the other hand were present in both plots with a significantly larger proportion of ferns in the MRB plot compared to the Burnt plot, $X^2 (1, N=15) = 17.42$, $p=0.0001$. Median sapling abundance was zero for both plots and there was no significant difference between the burnt areas in terms of seedling abundance, $X^2 (1, N=15) = 1.0$, $p=0.4268$, although there were slightly more seedlings in the Burnt plot. The seedling and sapling species richness was of the same pattern as their abundance. Similarly there was greater overall plant abundance in the Burnt area than MRB with the median difference being significant, $X^2 (1, N=15) = 23.08$, $p<0.0001$. Interestingly, the KHI plot, which when first burned (in the 1950’s) had a similar habitat to the Burnt plot, now contained a much higher proportion of both saplings, $t(14)=8.77$, $p<0.0001$ and pitchers, $t(28)=23.16$, $p<0.0001$, than the Burnt plot. (Figures 12 & 13 respectively).
**Table 2:** Comparison of main floral features between the two burnt plots – Burnt and MRB.

<table>
<thead>
<tr>
<th>Plot</th>
<th>Lianas</th>
<th>Pitchers</th>
<th>Fungi</th>
<th>Ferns</th>
<th>Plants</th>
<th>Seedlings</th>
<th>Saplings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burnt</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>60</td>
<td>90</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>MRB</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>250</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

P value  
- 0.0008*  
- 0.1503  
- 0.3173  
- <0.0001*  
- <0.0001*  
- 0.4992  
- 0.3173

DF  
- 1  
- 1  
- 1  
- 1  
- 1  
- 1  
- 1

*Significant difference

Data were transformed if not normally distributed ($p = 0.05$). A 2 sample t-test was carried out comparing the means of the 2 groups. If data could not be suitably transformed to normality then the nonparametric Mann-Whitney U test was carried out comparing the medians of the 2 groups. The Chi-square approximation values were used to present the output of the Mann-Whitney U test. $P<0.05$ implies a significant difference between the means/median values of the 2 plots.

**Figure 12:** Comparison of mean number of saplings between KH1 and the Burnt area, $t(14)=8.77$, $p<0.0001$. Error bars for standard error are given for each mean.

**Figure 13:** Comparison of mean number of pitcher plants between KH1 and the Burnt area, $t(28)=23.16$, $p<0.0001$. Error bars for standard error are given for each mean.
0.4, U1.6, IR and MR comparison

These 4 plots were compared to allow an ordinal distinction to be made between plots that were disturbed vs. undisturbed (IR and MR vs. 0.4 and U1.6) and those that were closer to the edge of the forest vs. those in the interior (0.4 and IR vs. MR and U1.6). These categories would allow the detection of any patterns within the flora to be compared directly with the variables within that plot. All datasets were able to be transformed to reach suitable normality for the post hoc Tukey-Kramer HSD test to be carried out to compare the results between plots (Table 3a). The Tukey-Kramer test could not be carried out for Simpson’s index of diversity values (Table 3b) as these were calculated separately to the main dataset. Mean liana abundance was similar across all plots with the exception of MR where it was significantly higher. In contrast, liana species diversity was lowest in MR with a difference of 0.59 to the next value (IR). The plot was dominated by Liana Kuning (Menispermaceae Fibraurea or Fragraea L.)
### Tables 3a and 3b: Comparison of main floral features between 0.4, U1.6, IR and MR.

#### 3a

<table>
<thead>
<tr>
<th>Plot</th>
<th>PERCENTAGE</th>
<th>SIMPSONS INDEX OF DIVERSITY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% canopy cover (ImageJ)</td>
<td>Liana species diversity</td>
</tr>
<tr>
<td>0.4</td>
<td>79.67&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.73</td>
</tr>
<tr>
<td>U1.6</td>
<td>81.01&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.76</td>
</tr>
<tr>
<td>IR</td>
<td>79.33&lt;sup&gt;a&lt;/sup&gt;</td>
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<tr>
<td>MR</td>
<td>78.83&lt;sup&gt;a&lt;/sup&gt;</td>
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</table>

#### 3b

<table>
<thead>
<tr>
<th>Plot</th>
<th>Lianas</th>
<th>Pitchers</th>
<th>Fungi</th>
<th>Pandan</th>
<th>Ferns</th>
<th>Plants</th>
<th>Seedlings</th>
<th>Seedling species richness</th>
<th>Saplings</th>
<th>Sapling species richness</th>
<th>Stumps</th>
<th>Fallen trees</th>
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<tr>
<td>0.4</td>
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<td>0.18&lt;sup&gt;b&lt;/sup&gt;</td>
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<td>1.08&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.37&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.06&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.50&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.16&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>1.57&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.49&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.61&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.98&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
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<td>0.77&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>1.38&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.44&lt;sup&gt;a&lt;/sup&gt;</td>
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<td>1.37&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.87&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.80&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>0.68&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.86&lt;sup&gt;b&lt;/sup&gt;</td>
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<td>0.30&lt;sup&gt;b&lt;/sup&gt;</td>
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<td>0.97&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>0.83&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.35&lt;sup&gt;c&lt;/sup&gt;</td>
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<tr>
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<td>0.91&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.90&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.47&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>abc</sup> Levels not connected by the same letter are significantly different.

All data were able to be suitably transformed to reach normality and allow the post hoc Tukey-Kramer HSD test to be carried out. Values show means for each plot to 2dp. For liana and pitcher species diversity, the Simpson’s Index of Diversity value is shown for each plot. These values could not be statistically compared to determine whether differences observed were significant due to the method of calculation.
A Chi-squared contingency analysis showed that liana DBH and plot disturbance/distance level are not independent (Figure 14). There was a larger proportion of younger lianas (DBH<1cm) in the disturbed plots vs. the undisturbed plots. Lianas of DBH <0.5cm constituted 96.4% of the total liana abundance in MR.

Figure 14: Comparison of liana proportions (with standard error bars) classified by DBH within four different plots of varying disturbance and distance from forest edge. 0.4 and IR are located closer to the forest edge whereas U1.6 and MR are located further into the forest interior. $X^2$ contingency test carried out concluded that liana DBH and disturbance level are not independent ($X^2 = 316.12$, df = 9, $\alpha = 0.05$)

Abundance of pitchers was also significantly higher in MR. Mean number of fungi was lower in the interior forest plots with MR containing the lowest total colony number. On the other hand there were more ferns, on average, in the interior forest plots as oppose to the exterior forest plots. There was no significant difference between seedling, overall plant number and Pandan (a sedge plant) between plots. However, the seedling species diversity was higher in undisturbed forest plots than in disturbed plots although there was some overlap between IR
and 0.4. Saplings were highest in 0.4 in terms of both abundance and species diversity although undisturbed U1.6 did not show the same trend.
DISCUSSION

Forest ground plants, seedling and sapling development

Monitoring the biodiversity of ground flora, including seedling and sapling development, is important in determining the health of a forest, especially one that is regenerating after a disturbance event. Studies have estimated that it takes 35-70 years for a timber forest to fully regenerate (Johns & Johns 1995). As both the Sabangau burnt area and the MRB plot burnt recently, there is unlikely to have been much time for growth of plants, especially saplings. This is reflected in the data as both burnt areas lacked sapling growth. The KH1 sedge swamp at Sabangau, burnt in the 1950s, contains more saplings than the Burnt area, which was burnt in 2006. This suggests that time is a key factor in abundance of sapling growth in a disturbed forest and in time the abundance of saplings in the Burnt area may increase to that of KH1.

The Burnt area contained significantly more ground plants than MRB. Soil nutrients are vital for successful plant growth (López-Bucio et al 2003) and burning is usually considered to increase soil nutrient availability (NSW webpage). The ash that is produced from peat burning, however, is low in nutrients (Yule 2008). Therefore as the burnt area burnt more recently, we would expect less nutrients there than MRB. This would imply that there would be lesser plant growth there, which contradicts results. However, MRB has a thicker peat depth due to its position in the interior of the forest (before logging) (Page et al 1999) and peat soil has low nutrient availability (Whitten et al 1987). Furthermore, the peat dome on which the MR plots including MRB are positioned is fed only by rainwater, which is low in nutrients. The burnt area, on the other hand, is also partially flooded by the Sabangau River, which contains a high nutrient load. Thus, the Burnt plot seems to have higher nutrient availability than MRB, which could be the reason for higher plant growth.
Interestingly, there was no significant difference in seedling growth between the 2 plots, both of which were very low. This could be due to the inability of seedlings to reach the area, for example due to a lack of animal vectors to transport seedlings there for germination. Alternatively, it may be that the seedlings that have been transported to the area successfully are not native species and therefore cannot grow there. The lack of seedlings in MR could also be due to the frequent burning episodes to which the plot is exposed leading to destruction of the seedlings.

Cleary & Priadjati (2005) found that sapling and seedling density was higher in unburnt forest than burnt forest. This was also seen in the Sabangau results as seedling and sapling abundance was higher in the forest plots compared to the burnt plots. There was, however, no significant difference between mean plant and seedling abundance in the 4 plot comparison. The same lack of variation between plots was also seen in Pandan abundance. As all of these flora are ground dwelling, it suggests that light availability on the forest floor may be an important factor in their distribution and growth (Fankhauser & Chory 1997). Percentage canopy cover (ImageJ reading), which was used as an environmental indicator of the light reaching the floor of the plot, was not significantly different between the plots, suggesting that light availability influenced ground plant growth in the 4 plots. However, the light reading was taken from the centre of each plot, so may not therefore give an accurate representation of the light conditions in other areas of the plot where the ground plants may have been observed.

Sapling abundance, on the other hand, was significantly higher in 0.4 compared to the other plots. This could be due to the fact that 0.4 incorporates relatively undisturbed forest which
means that seedlings are able to successfully develop into saplings without suffering from any of the effects that disturbance would bring to the forest ecosystem. It would be expected, then, that U1.6 would also display the same pattern, as it is an undisturbed plot; however sapling abundance was not significantly higher in U1.6. Possible explanations for this could be the change in peat depth between 0.4 and U1.6 resulting in changes in nutrient level. Peat soil is low in nutrients and as saplings require nutrients for successful development, it would mean that fewer seedlings would be able to reach maturity in deeper peat soil. Sapling species richness was also highest in 0.4. This could be due to a direct correlation with the increased sapling abundance in the plot.

The species richness of seedlings was generally higher in undisturbed plots and there was a significant difference in species richness between the interior forest plots (U1.6 and MR). Seedling species richness may be lower in disturbed plots as only certain tree species are able to grow successfully in the post-logging, damaged environment. Furthermore, disturbed areas are usually characterised by large treefalls, which lead to low soil nutrients and decreased water availability as the tree roots, which usually help to prevent soil degradation, are absent. This means that many floral species, especially those that proliferate in early succession environments, may infiltrate the area and outcompete native seedlings. The native seedlings able to compete with the colonisers will be few and therefore the species richness of seedlings would decrease in disturbed areas. The actual reason for decreased seedling richness in disturbed areas, however, would require further investigation such as through thorough comparison of seedling composition between disturbed areas over a course of many years.
Pitcher plants

Pitcher plants (*Nepenthes spp. L.*) are known for their characteristic carnivorous habit of nutrient uptake which allows them to survive in areas where other plants cannot, mainly in exposed habitats with nutrient poor soils (Adam *et al* 1992). This could explain the significant increase in pitchers in the MR plot compare to the plots in Sabangau. The canals that were cut into the MR area drained the water and nutrients contained within the peat leaving it uninhabitable for many plants (Aldhous 2004). These arid conditions are shown by the near absence of fungi in the MR plot as fungi are known to grow wherever moisture is present (Prescott *et al* 1996). Pitchers, on the other hand, would have been able to thrive in this environment using carnivory as a feeding strategy to obtain nutrients and water (*Nepenthes* webpage). Interestingly, pitchers were not significantly present in either of the burnt areas, even though they would contain low soil nutrients due to the burning, removing many plant competitors. A possible explanation for this could be that the burnt areas were too exposed to allow even pitchers, which are better adapted than many plants to exposed conditions, to proliferate.

Pitcher plant abundance was highest in KH1 compared to all other plots. A possible reason for this was the impoverished, sandy soil within the sedge swamp, due to previous disturbance events, that meant that there was low nutrient availability creating a favourable habitat for pitcher proliferation. The plot was dominated by the *Nepenthes rafflesiana* L. species known for inhabiting degraded, swampy areas (Phillipps & Lamb 1988).
Lianas

Lianas play an incredibly important role in maintaining the biodiversity of forest ecosystems (Pe’rez-Salicrup 2001; Schnitzer & Bongers 2002) and yet there are very few forests across the world where liana ecology has been studied in detail (Addo-Fordjour et al 2012), usually due to difficulty in their identification by researchers on site (Schnitzer & Bongers 2002). The analysis in Sabangau encountered similar problems; all unknown lianas were classed into one category meaning that species diversity was under-represented in the Simpson’s index of diversity.

The analysis of the burnt areas at Sabangau and MR found that there were more lianas present in the Burnt area than in the MRB area. One explanation for this is the number of ferns, which was greater in MRB than in Burnt. Ferns are pioneer species and inhibit the growth of other species by shading out seedlings underneath them and increasing moisture levels (Walker 1994). As lianas thrive in the high light and low water environments of early successional habitats (Schnitzer et al 2001), they are outcompeted by the ferns in MRB. The results from the Burnt plots, however, may not be reliable indicators of liana growth in the areas. The Mann-Whiney U test that had to be used for much of the data comparison, due to the non-normality of the datasets, compared medians as opposed to means. Median values are more affected by outliers and skew which may have affected the results.

For the 0.4, IR, MR and U1.6 comparisons, the Tukey-Kramer test showed that liana abundance was highest in MR, but species diversity of lianas was lowest there. The other 3 plots showed no significant differences between each other. Abundance may be higher in MR due to the highly disturbed nature of the plot. It is commonly cited in literature that lianas proliferate and are more diverse in disturbed areas (Schnitzer & Carson 2010; Schnitzer et al
2004) where there is low soil nutrients and decreased water availability. This is due to their efficient root system which means that they are able to withstand water stressed environments (Schnitzer 2005). Thus more lianas would be able to grow in the MR plot. Liana Kuning dominated the MR plot and was the reason for the low species diversity value for the plot. Its dominance may be due to this species of liana being better suited to the disturbed environment than other liana species. Thus it would have that Liana Kuning would have been able to outcompete other liana species for resources in the MR plot.

Total liana abundance decreased with increased difference from forest edge. A similar pattern was also described by Schnitzer & Bongers (2002), working in central Amazon, who found that liana abundance was significantly higher within 100m of forest edges compared to forest interiors. Abundance of very young lianas of <0.5cm DBH also decreased with increased distance from forest edge suggesting that this was the principle reason for the total liana abundance figures. Liana basal area decreases with increased disturbance (van der Heijden & Philips 2009). This could be because at forest edges, disturbance is higher, with more canopy gaps and therefore light to encourage liana proliferation. In the forest interior, on the other hand, only lianas which are well adapted to the environment, such as those that have reached sunlight through growing up tree trunks, are able to survive.

**Conclusion**

Overall, the results collected in this investigation have demonstrated that disturbance has a significant effect on floral composition in the Sabangau PSF. There was a significant increase in the number of early successional plants, including lianas and pitcher plants, with increased disturbance. However interestingly, there was no significant difference in the abundance of ground plants and Pandan between the forest plots. The burnt plots had lower seedling and
sapling density compared to the interior forest plots. MRB also contained lower ground plant abundance than the Burnt area. The main reasons for this change in flora with disturbance level was concluded to be linked to soil nutrient and water availability and peat depth, both of which varied throughout the plots. Furthermore, lack of regeneration of certain plots following disturbance, such as the burnt area, may have been due to an inability of seedlings to reach the damaged areas to repopulate them, for example if they were transported through animal vectors. Floral species found in forest edge plots were also found in disturbed plots suggesting that edge effects correlated with disturbance.

The Sabangau data, however, may not give an accurate representation of the relationship between flora and disturbance in other PSFs across the world due to the complex nature of PSF habitats. This ecosystem is still very poorly studied and thus any significant correlations found should be treated with caution when making predictions for other forests or even other areas of the Sabangau PSF. Furthermore, all the data collected could not be analysed in a single study and therefore there is scope for further analysis of this information, as well as the addition of more data from other PSFs, in future work. Accurate and continuing ecological monitoring of PSFs must continue to be carried out if there is any hope of conserving this endangered ecosystem from the constant threats it faces from industry and agricultural expansion. If politicians and local populations are made more aware of the effects disturbance will bring to the biodiversity of this unique habitat then the numerous populations of both flora and fauna inhabiting PSFs across the world will be able to persist for longer into the future.
ACKNOWLEDGEMENTS

First and foremost, I would like to thank my supervisor Dr Susan Cheyne for supporting me throughout this project.

Also big thanks to Nick Marchant, Dr Mark Harrison, Cassie Freund and Sara Thornton for their guidance and advice out on location and after.

Many thanks to Chris Cooney and Calvin Fereday for advising me on statistical methods to use for the analysis of my results.

Thank you to all the staff and volunteers at Outrop and CIMTROP for making my stay so enjoyable and supporting me with fieldwork.

Thanks also to Udin, Cis-Coes and Santi for their incredible expertise and accompanying me daily in the field.

Finally many thanks to the Christian Deelman Travel Fund, Olga Chetina and Dmitry Yufit for their donations and making this trip possible.
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Appendix 1: JMP output of PCA analysis with KH1.

Maximum percentage reached with Principle Component 1 (PC1) is 40.2%. This is mostly due to KH1 being a sedge plot and therefore creating a large gradient between tree canopy environmental data leading to a strong PC1 percentage. This PCA result was therefore not used for data analysis.
**Appendix 2**: JMP output of PCA analysis without KHI.

**Eigenvectors**

<table>
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<tr>
<th></th>
<th>PC1</th>
<th>PC2</th>
<th>PC3</th>
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<tbody>
<tr>
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<td>Log(fallen trees+1)</td>
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Maximum percentage reached with PC1 is 18.4%. The next most suitable principle component is PC2 at 14.3%. None of these are very significant showing that the PCA does not explain very much of the variation found in the data.
**Appendix 3**: Comparison of main floral features between the two burnt plots – Burnt and MRB.

<table>
<thead>
<tr>
<th>Plot</th>
<th>Lianas</th>
<th>Pitchers</th>
<th>Fungi</th>
<th>Ferns</th>
<th>Plants</th>
<th>Seedlings species richness</th>
<th>Saplings species richness</th>
<th>Stumps</th>
<th>Fallen trees</th>
<th>% canopy cover (ImageJ)</th>
<th>% canopy cover at 0-5m</th>
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<td>1</td>
<td>0</td>
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Roman titles - 2 sample students t-test carried out (means)
Italic titles - Mann-Whitney U test carried out (medians)
* Significant difference

Data were transformed if not normally distributed (p = 0.05). A 2 sample t-test was carried out comparing the means of the 2 groups. If data could not be suitably transformed to normality then the nonparametric Mann-Whitney U test was carried out comparing the means/median values of the 2 plots. P<0.05 implies a significant difference between the means/median values of the 2 plots.
MANAGEMENT REPORT

Figure 15 shows the Gantt chart created near the beginning of my project in order to establish a time framework for the completion of the work. It shows the expected time taken to complete each section versus the actual timescale it took to complete. Fieldwork had to take place between the 8th July – 24th August due to the nature of the study.

Before the fieldwork the actual timescale matched the predicted one. The timing of the literature review altered slightly as time became available during the fieldwork in August that meant that some of the reading was completed then as oppose to later on in the year. This change had no overall impact on the timing of the project itself. After the fieldwork there were however delays in the completion of certain sections. The main one of these was data analysis which took until December to complete. This was partly due to difficulties in the practicalities of international communication with the supervisor and other key individuals that meant that resolution of problems was slightly slower than expected. Also the large volume of data collected meant that the analysis process itself took longer than expected as multiple variables needed to be compared. Because of this it meant that other sections that followed this one, such as the results and discussion sections were subsequently delayed.
<table>
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*Figure 45: Gantt chart for the project showing predicted schedule (checked) and actual schedule (grey).*