The Influence of Tropical Peat-Swamp Forest Edge Effects on Fruit Feeding Butterflies in the Sabangau Forest, Kalimantan.

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The content of this dissertation is entirely the work of the author.

Signed:
Abstract

It is widely understood that the link between an organism and the complex transition between habitat boundaries is an idea that is relatively poorly understood due to the multiple biotic and abiotic influences that can affect said organism. To study this phenomenon in this particular investigation, frugivorous butterflies were used as an indicator to examine the possible edge effects found at a tropical peat swamp forest margin in the Sabangau Forest, Kalimantan. In collaboration with OuTrop (The Orangutan Tropical Peatland Project), Nymphalidae butterfly species were systematically surveyed at varying intervals from the forest periphery to observe whether species abundance, diversity and behaviour was influenced by the proximity to the edge, and whether there was a specific interval or ‘edge effect line’ where these impacts discontinued. By observing the findings it became clear that the overall abundance and distribution of some individual species do appear to be reduced closer to the boundary of the ecosystem, while unexpected aspects such as bait removal and predation are also evident within the study area. Despite the fact that some variables (such as species diversity) did not appear to be heavily influenced by the margin, in general this study suggests that edge effects are evident in this region of the ecosystem when frugivorous butterflies are concerned. Two possible intervals where a theoretical edge effect line could be found are also suggested here, however due to the impact of seasonality and catchment of investigation, further research over a greater distance and time period is needed in this region to fully comprehend how these invertebrates react to the influence of the forest edge.
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Chapter 1: Introduction

It is widely understood that the surrounding edges of an ecosystem can often have an impact on the flora and fauna species that live within said landscape (Murcia 1995; Ries and Sisk 2004). This phenomenon of a habitat’s environs influencing the organisms that live within it is called an ‘edge effect’ and it can be found in patches and landscapes across the globe. However it is equally as understood that different ecosystem edges can affect the environment that they encompass in various ways, generally presumed to have detrimental consequences for the organisms that live with it (Murcia 1995; Fahrig 2003) although some can in fact increase aspects like biodiversity due to the heterogeneity of the habitat conditions (Magura 2002; Hawes et al 2009). The reason why certain areas are affected by this more than others is not comprehensively known as many complex biological, ecological and environmental factors and mechanisms are interconnected together where landscape boundaries meet, making a general algorithm or formula for the impact of edge effects worldwide near impossible (Laurance and Yensen 1991; Camargo and Kapos 1995; Murcia 1995; Fletcher 2005; Harrison et al 2012a). It is for this reason that studying the relationship between a particular bionetwork and the environment that surrounds it must be site-specific or at least habitat-specific as there are multiple factors that vary from ecosystem to ecosystem (Saunders et al 1991).

In this study the habitat that will be studied for the impact of edge effects is tropical peat-swamp rainforest, with the specific patch focussed upon being the Sabangau rainforest in Indonesian Borneo (also known as Kalimantan). Rainforests and the organisms that live amongst them are on the whole studied relatively often when it comes to monitoring the impact of edge effects, especially when considering fragmented areas as these are a common occurrence when human activity interferes with a forest’s natural equilibrium (Fahrig 2003). Though in comparison, less is known on the effect that boundaries have on the fauna that live in peat-swamp rainforest, despite the fact that these ecosystems are crucial habitats for a large biodiversity of life which are often unique or endemic to the environment (Ng et al 1994; Morrogh-Bernard et al 2003), not to mention the fact that these forests are vital for both carbon storage (Sorensen 1993; Jauhiainen et al 2005; Hooijer et al 2006; Harrison and Paoli 2012) and hydrological cycles (Page et al 1999; Moore et al 2013). It appears that any further understanding of how edge effects have an impact on flora and fauna in this type of forest may therefore prove useful for future conservation and management actions as recognizing changes to species biodiversity, abundance and behaviour are essential to ensuring the health and sustainability of the entire ecosystem (Murcia 1995).
A method of obtaining this crucial information in rainforest and other landscape types is to observe the behaviour and relationship that a particular indicator species or group of organisms have with their territory boundaries. This is known as observing an indicator species and of course some life forms react to edge effects differently to others (Ries and Sisk 2004). In this investigation’s case Nymphalidae frugivorous butterfly species known locally as ‘kupu kupu’ will be studied and examined as their short generation periods and sensitive relationship with their environment can be a good indicator of forest changes (Lucas 2005; Houlihan et al 2012b). With these invertebrates in mind, two main objectives will be investigated here; primarily to distinguish whether this patch of rainforest follows a trend that many do in having edge effects which penetrate internally; and secondly to try and locate a theoretical line where this phenomenon ceases to exist. Understanding these factors in detail may not only provide further knowledge on the butterfly species themselves, but in turn may benefit future research or conservation strategies to protect the insects and their natural habitat.

Past Literature

This method of observing the characteristics of a specific fauna type in relation to the edge effects of that particular landscape is not uncommon in the literature and can be used as a useful tool in furthering the understanding in species-habitat relationships (Landres 1988; Magura 2002; Than 2012). It’s fair to say that generally in past research the influence of an ecosystem’s periphery is found to have negative impacts on the flora and fauna species that live amongst them (Murcia 1995; Fahrig 2003; Fletcher 2005). Much like the results found in Paton’s study of nesting birds (1994) or Mills’ study of red-backed voles (1995) which suggest that for these organisms as least, the impacts of habitat boundaries are detrimental.

Due to the multiple necessities of different wildlife species and the various types of edges that exist between landscapes, there are of course exceptions to this general rule with some edge-dependant or generalist species also thriving on the conditions found closer to the habitat boundary. Investigations by Magura (2002) and Hawes et al (2009) imply that despite the biotic and abiotic changes found in periphery environments, wildlife (carabid and moth species respectively) can still have equal if not greater diversity and abundance rates to areas found further into the habitat interior.

Overall by understanding whichever way an organism reacts to the impact of edge effects can help to influence how that particular ecosystem is conserved or managed (Yahner 1988). Which in essence, is the overriding factor why this study is being undertaken in the first place as
comprehending the behaviour and distribution of fruit-feeding butterflies towards the forest edge in
the Sabangau, may have implications for the manner in which the land is managed or preserved.

This particular patch of peat-swamp forest is not only home to frugivorous butterflies, but also
to the base camp of the conservation organisation OuTrop (The Orangutan Tropical Peatland
Project), and it is this research group who have studied wildlife and the vegetation within this region
in the most detail and therefore is arguably the best place to look when trying to understand the
butterflies of this region. A OuTrop survey by Houlihan et al (2012a) for example has identified and
listed some behaviour notes on the 48 known butterfly species found within the Sabangau forest,
including the 27 species that appear to be fruit feeding. There are also previous surveys conducted in
this area by Brady in 2004 and 2006, and Houlihan in 2009 (Houlihan et al 2012a) although few
follow the footsteps of this study in focussing specifically on using butterflies as indicator species for
observing forest edges, despite the fact that these invertebrates can be accurate measurements of
habitat sustainability (Basset et al 1998, Houlihan 2012b).

Some previous literature does exist however which concentrates on viewing these Lepidoptera
species in relation to the forest gaps and disturbed sites of the Sabangau. Brady’s survey (2004) for
example focussed primarily on the impact of forest clearings and canopy gaps on frugivorous
butterflies in the same peat-swamp forest region, whilst a more recent investigation by Houlihan
(2012b) followed a similar thread. Despite some promising results in these projects concerning the
morphology and behaviour of particular species, both studies agreed in the fact that more research
must be conducted to understand the seasonality in these insects which may be a factor behind why
there is currently an unpublished 12 month butterfly survey being documented in the forest, to
understand the annual variations and breeding cycles of fruit-feeding butterflies more clearly
(OuTrop 2012a/b). Again, each of these assessments does not specifically clarify the influence that
dge effects have on these animals; which is perhaps the main driving factor for this particular study
as it is in a field which currently is somewhat poorly understood (Koh 2007).

Project Aims

The overall aim of this assignment is to firstly attempt to determine whether or not there are
any forms of edge effects influencing the butterflies that live within this patch of the Sabangau
rainforest. In order to fulfil this endeavour there are three main ecological factors than will be
addressed and revised:

1) *Species abundance*. The relationship between the overall population of butterflies
and the forest edge will be studied in order to witness whether or not there are any differences
between the two and ultimately, show whether the habitat at the forest boundary is affected by its surroundings and therefore more or less preferable to the butterfly species here.

2) Species diversity. Similarly to the total abundance of butterflies, the number of individual species will also be monitored along the transition from forest periphery to forest centre to try and determine whether or not any impact from being closer to the ecosystem edge effects biodiversity here.

3) Species behaviour. The characteristics of individual species will be looked at to try and understand more about which species prefer particular peat-swamp rainforest areas. For example comparing past work completed by research groups or organisations, with the distribution of species in this investigation, could illustrate which species are edge or interior specific.

Monitoring and understanding these three aspects in this patch of the Sabangau may paint a picture of how the impact of being close to the edge can affect the population and distribution of frugivorous butterflies. Not only that, but observing and analysing this information will help to identify whether these effects are experienced in a gradual transition from the habitat boundary towards the centre, or whether there is a clear point where butterfly distribution and therefore forest conditions change. The idea of there being a specific ‘edge effect line’ that influences butterfly species parallel to the forest border will be explored in this investigation by studying the three previous ecological factors as well as any other biotic or abiotic aspects which may arise during data collection.

It is worth noting that although there are already studies of the butterfly species in this region of the Sabangau that have been conducted in the past and in fact some that are still continuing, the idea of observing the distribution of these frugivorous with relation to this particular forest edge is information that is new to science. Some of this past literature and research will of course be used to a great extent when observing and analysing the results of this investigation, however only when necessary to try and achieve the aims and objectives of this scientific project.

The final goal of this research investigation is for the findings that are recorded in this patch of the Sabangau to ultimately be used in the management and protection of the butterfly species that live here. As previously mentioned in the literature, it is essential to fully comprehend the ecological dynamics of a habitat type when it meets another in order to maintain a healthy and sustainable ecosystem (Bierregaard et al 1992), which is why understanding how far edge effects penetrate into this forest could prove beneficial for the survival of butterfly species as well as other flora and fauna here with the correct integrated management methods (Saunders et al 1991).
Chapter 2: Study area

The island of Borneo is not only the third largest in the world, but occupies some of the oldest natural rainforest still existing today. It’s for this reason that the island is home to thousands of unique, endemic and yet vulnerable wildlife species which in turn makes Borneo one of the most biologically important regions on earth (Myers et al 2000). Despite this fact however, an explosion in the human population as well as the increased global demand for timber and other natural resources has meant that this island is now also one of the places in the world in most need of environmental conservation (Koh 2007). In fact it’s estimated that between 1985 and 2001, over 56% of Indonesian Borneo’s protected lowland rainforest (>29,000km²) has been lost as a result of logging and other human disturbance factors (Curran et al 2004).

Borneo is located in south-east Asia and is separated into three individual nations; Brunei, Malaysia and Indonesia. The Indonesian region is known as Kalimantan and is by far the largest of the three, it consists of four individual provinces, one of which is called Central Kalimantan and it is in this region where this investigation was undertaken (see Map 1). This research more precisely was completed within the Sabangau Forest and closer still within the Natural Laboratory of Peat Swamp Forest or NLPSF (also known as the Laboratoreum Alam Hutan Gambut or LAHG) located just south of the province capital Palangkaraya (see Map 2).

Map 1. (Taken from Google Earth)
This map shows geographically in relation to the island of Borneo where this particular survey was conducted and therefore where the Sabangau rainforest itself is located, and by observing this map closely it becomes clear how large this peat-swamp habitat is (which is positioned just south of the icon named ‘Study Area’).
The Sabangau forest itself is rare in that it is said to be the largest non-fragmented region of lowland forest still remaining in Kalimantan. The hydrology and soil structure of this peat-swamp rainforest is a factor that also makes this 6,000km² region unique and therefore creates an environment that is both valuable to local people for natural resources, and globally important as it creates high biodiversity rates and a vast carbon store (Moore et al 2013). In fact this habitat is estimated to support 12.5% of the world’s remaining Bornean Orangutans (*Pongo pygmaeus*, approx 6,900 individuals) which is the largest known global population (Morrogh-Bernard et al 2003), as well as the highest number of southern Bornean Gibbons (*Hylobates albibarbis*) (Cheyne et al 2008). Of course these primates are not the only vulnerable or threatened species found in this region as there are many other smaller organisms which, much like fruit-feeding butterflies, rely on habitats like this exclusively to survive, and therefore make this particular environment significant and valuable to a wider extent (Harrison et al 2012b). In actual fact, the overall number of invertebrates within a landscape such as this can be far more than scientific research suggests (Ellwood and Foster 2004) and even represent up to 94% of wildlife biomass (Fittkau and Klinge 1973).

Nonetheless in spite of this biodiversity, the rainforest was subject to large logging concessions before 1997 as well as illegal timber extraction after this date which lead to pristine primary peat-swamp forest being transformed to drained, channelled and deforested patches of exposed peat (Husson et al 2002). This drier environment in turn led to further heartache for the ecosystem and its inhabitants as the bare peat lead to a boost in the number of forest fires and is predicted to be accountable for around a 15% decrease in the overall area between 1997 and 2009 (Harrison et al 2009). This uncovered peat is exposed to sunlight in the dry season and submerged by water in the wet season which makes it harder for vegetation to regenerate and it is this sedge-dominated environment that lies at the edge of the forest studied in this investigation.
It’s for this reason that the NLPSF was first established in 1994 by CIMTROP (the Centre for the International Cooperation in Sustainable Management of Tropical Peatlands) and then policed by a local Community Patrol Team from 2002 to prevent this terrain and its contained ecology from being transformed into disturbed land much like the nearby Mega Rice Project (Harrison et al 2009) and other surrounding areas. This 50,000ha expanse is now focussed on primarily for the purposes of research and conservation with the help of OuTrop (The Orangutan Tropical Peatland Project) and parts are also bordered by the Sabangau National Park (established in 2004). It is alongside this organisation that the investigation was conducted as not only have they created a hub for scientific exploration within the NLPSF (the Setia Alam Research Station), but they also possess background knowledge and literature on the frugivorous butterflies in this forest (albeit with little on the influence of edge effects). As a result, this investigation may therefore be used as a tool to help further the understanding of the distribution and behaviour of these butterflies.

Map 2. (Taken from Google Earth) This satellite image is a closer look at the study area shown in Map 1; it shows where in relation to the forest edge much of OuTrop’s work is carried out. Although the organisation does work in other areas as well, much of their research is centred around the Setia Alam base camp within the yellow network of transects in this map. The sedge-dominated land and Sabangau River can be seen immediately above this patch of forest and further north at the very top of this image is the province capital of Palangkaraya.
Methodology

In order to successfully survey the fruit feeding butterflies of this forest the strategy that has been used is one that is tried and tested here by OuTrop as they are the primary organisation that study wildlife in this part of the Sabangau and have been doing so since 1999. Not only will systematically assessing frugivorous butterfly species in this way create results which are likely to be more accurate and in turn less bias, but they will also be able to correspond to past and future work completed by OuTrop and as a result, possibly help to support any conservation management issues that may face this stretch of forest.

In order to actually gather the vital information needed for this investigation, a total of 20 Blendon© butterfly traps (Image 1) were used with the intention of attracting and containing specimens until they could be checked, documented and then released back into the wild. To draw butterflies to these traps, bait was mixed every day before heading out into the field and added to the trays after they had been surveyed. The bait consisted of approximately 40-60 ripe or rotting bananas, roughly 10 tablespoons of sugar and a generous helping of ‘Malaga’ (mild local liquor). This recipe is one that has been proven the most successful for OuTrop when collecting butterfly species as the sweetness of the bananas and sugar are combined with the fermenting properties of the ‘Malaga’, which is why it has also been adopted for this research project.

OuTrop do possess their own transect system for navigating and surveying wildlife in this part of the Sabangau, however these are arguably too sparsely distributed to show where edge effects are occurring as well as where they may come to an end, therefore for the purposes of this investigation new pathways and transects had to be developed in order to collect data at specific intervals away from the forest’s edge. Altogether five transects were monitored in this study, each of them lying 300 metres across and arranged as parallel to the forest boundary as possible. These transects are also positioned with varying spacing between them; positioned at 50, 100, 200, 400 and 650 metres away from the habitat periphery (Map 3). This arrangement will not only mean that a larger area of forest is covered, but simultaneously will collect sufficient species data towards the forest edge were the distance between them is only 50 metres as opposed to 250 metres towards the forest interior.
Figure 1
A brief representation depicting how high each set of traps are hung in this investigation.
In this studied area of the Sabangau there is a relatively large diversity of tree species with some of the canopy and sub-canopy being found between 7 and 10 metres of the ground which is where some species of butterfly are likely to congregate in search for food. Other species are also likely to be found assembling around the forest floor looking for fallen fruit which is why positioning traps in these locations should collect a larger range of species information.

Along each of these plots, four individual traps were divided into two groups of two and in order to collect as many butterfly species as possible at each of the pairings, one trap would be suspended between 7-10metres and one between 1 and 2metres from the forest floor (Figure 1). The idea here is to attract species that feed at both ground and canopy level, and therefore get a more general view of the characteristics and distribution of butterfly species in this patch of forest. Emergent trees at the top of the canopy in the Sabangau can reach as high as 35 metres, however there are other layers of tree heights between 15-25 and 7-12 metres in this part of the forest’s peat dome (Page et al 1999; Shepherd et al 1997) and it’s this second layer that will studied alongside ground cover as it is both more abundant and easier to hang traps from.

There are five potential hanging points on each transect with each one having a gap of 50 metres between one another (Map 3). The pairs of high and low lying traps are hung at two of these five intervals, however always making sure that there is always a 100 metre space between each pairing to ensure an even spread of traps along each transect. The traps are then left to collect individual butterflies for five days and are monitored, recorded, cleared of specimens and then re-baited everyday to collect as much data as possible. The traps are aimed to be checked between the times of 11am and 2pm as it is the window of the day that it is assumed to be most active for fruit-
feeding butterfly behaviour and would therefore produce maximal data records. They are checked in the same order starting from near the forests boundary at R50 (the transect 50 metres from the edge) and then moving towards the forests interior to R650 (transect 650 metres inside the habitat), and then checked in the reverse order the next day. This rotation from monitoring traps clockwise and then anticlockwise is repeated daily so that individual traps and transects are not observed at the same time each day and therefore should give a broader range of results.

Following this five day period (or ‘survey block’) that the traps are left out for, they are then removed from the forest completely, given a break for a few days, and then installed at different points on the transects to cover a larger catchment area. In total, four sets of survey blocks were undertaken between the 15th July 2012 and the 15th August 2012, resulting in the possibility of having 20 full trap days of species data per trap and therefore 80 for each transect. This number of records would be considered to be adequate in order to sufficiently get an idea of the species abundance, richness and behaviour at each forest transect; and therefore would be satisfactory in understanding the extent to which edge effects do or do not penetrate this particular forest habitat.

**Hanging traps.**

In order to collect the data required for this investigation, the butterfly traps used must first be hung at specific points along the transects and to accomplish this the following items were used: 20 butterfly traps and their corresponding trays, a large bundle of strong rope, plenty of raffia (local pink string), slingshot, fishing line, fishing weight, measuring tape, transect map, GPS device and bait bucket with pre-mixed bait.

Exactly which point along each transect the traps would be hung at would be determined before entering the field, however on arrival, each hanging site would be marked on the GPS device to ensure it would be found on the data collection days that followed (Map 3). Traps were arrived at and installed roughly between the hours of 11am and 2pm in order to give a window of approximately 24 hours for specimens to be attracted to the bait and held within the traps.

On arrival at the specific plots, the vicinity is studied to firstly ensure there are no noticeably large gaps in the canopy and no other environmental factors that may affect butterflies in gathering to the traps. Equally, the nearby forest floor is inspected so that fractions of various ground covers such as living material, dead wood, leaf litter, bare ground and standing water are all roughly similar at each plot within an approximate five metre radius of the GPS signal. When an adequate location is found, ropes are then fired over particularly high branches (for the canopy traps) using the slingshot, fishing line and weight in order to catch on the correct tree limb, before the traps are baited and hoisted up into position using the ropes and measuring tape.
These photographs show examples of some of the possible edge effects that these butterflies may face. Image 2 represents an example of a Zeuxidia aurelius that has been damaged, most likely from some form of predation. While Image 3 shows a Rhino beetle inside a bait tray that has been subject to bait removal. (Photographs by Robert Durgut)

Although for the majority of the time wind speeds are relatively low within the canopy and near the forest floor, the rope and raffia are always tied tightly to resist any wind from loosening the trap from its position or spilling any bait onto the ground. It’s also worth noting that wherever possible, traps were hung at least a metre or two from any nearby tree or foliage to resist temptation from any wildlife species (such as orangutans, squirrels or mantids) that may wish to prey on either the bait or butterflies within the traps.

Data collection

In order to collect the data required, each day two volunteers accompanied by a OuTrop member of staff would travel to every one of the 20 traps distributed along the chosen transects with the following kit: map, GPS device, hand net, binoculars, callipers, permanent markers, pencils, butterfly identification cards (Houlihan et al 2012a), data collection sheets, butterfly code sheet, first aid kit and of course sufficient food, water and clothing for a day of walking in this challenging terrain.

Using a map and perhaps GPS device, the transects are navigated and on approach to the pair of high and low traps, binoculars are often used from a distance to get an idea of what species there may be inside without disturbing them, before the trap with the highest probability of data is approached first and covered as soon as possible with a hand net to stop any Lepidoptera from escaping. If when completing this process specimens do fly away, the number, species and possible sex is side noted in order to receive as much species data as possible and therefore get an enhanced idea of their behaviour.
Only when the trap in question is successfully lowered and covered can the actual species data collection start. The exact transect, trap, and time of recording is noted down before any butterfly information can commence, and it begins by cautiously removing an individual from the trap and manoeuvring it in such a way that the thumb and finger are pressed firmly yet carefully onto the point where the butterflies thorax and wing shoulder meet (Image 3 and 4). This has proved to be the best method of handling this delicate creature safely by OuTrop workers however can prove somewhat challenging when there are several butterflies, moths and predatory insects flying around within the cylinder.

Once a specific butterfly is collected and held safely the first trait to be recorded is the type of species and this can be confirmed using the butterfly identification cards brought into the field. Many of the species found here do look similar in appearance or change their appearance depending on seasonality (like *Melanitis leda*), fortunately though as the Sabangau is a peat-swamp rainforest that has a history of being studied for butterflies, a classification and characteristics sheet is also available to ensure the correct species is identified every time (Houlihan 2012a).

The second variable collected is the gender of the butterfly in question to help get more of an understanding of their seasonality. Similarly this can prove somewhat challenging as some sexually monomorphic species such as *Melanitis leda* can appear to be difficult to differentiate, although inspecting the characteristics of the abdomen often confirms whether the specimen is male or female. Sexually dimorphic species such as *Zeuxidia aurelius* are in general easier to differentiate, however if a particular species or genders cannot be definitively identified, photographs of both the upper and lower wing are to be taken and studied in detail at a later date for confirmation.

Forewing and body length are the next traits to be recorded and are completed using vernier callipers to measure in millimetres firstly from the wing shoulder to tip (forewing length), and then from the top of the head to end of the abdomen (body length). Using this data may also aid in establishing an individual specimen to a particular species at a later date if this has not already been predetermined. Plus, this information may be beneficial in understanding the characteristics of specific species either in this investigation or indeed in ones to follow.
These photographs illustrate how the butterflies in this study were handled during the survey. Image 3 shows a *Melanitis leda* which has just been recorded and coded before being released. An *Agatasa calydona* can be observed in Image 4 being handled after being removed from a trap. Visible on the underside of this particular specimen’s forewing is the code 412. This appears to be an individual already caught and recorded in a previous study (OuTrop 2012a/b) and may help show the life span and territory range of the species. (Photographs by Robert Durgut)

Finally before the individual butterfly is released back into its natural habitat it has to be coded using a permanent marker on its wing so that if found in future sampling, it can be indentified and recorded as a recurring specimen. This process is potentially the most dangerous to the butterfly as the scales on its wings are extremely delicate which is why it is placed on a laminated surface and gently dabbed with the pen whilst attempting to cause as little damage to the wings as possible. The codes of butterflies already caught are noted down before being released whether they are from this study or another (OuTrop 2012a/b), and the fact they currently do not appear to be ‘trap happy’ (Houlihan *et al* 2012b) in this forest means that this knowledge may prove to be useful in future investigations when understanding the behaviour of this wildlife as their ranges and life expectancies can be observed.

The codes of butterflies already caught are noted down before being released whether they are from this study or another (OuTrop 2012a/b), and the fact they currently do not appear to be ‘trap happy’ (Houlihan *et al* 2012b) in this forest means that this knowledge may prove to be useful in future investigations when understanding the behaviour of this wildlife as their ranges and life expectancies can be observed.

The number of large moths and small moths (roughly >2cm and <2cm respectively) were also noted down as these can also be found in traps and may have some significance to future studies surrounding the forest and possibly the edge effects that may or may not be evident here.

The final pieces of information recorded at each trap were whether any other forms of wildlife had interfered or tampered with the traps. This would be understood by observing whether there are any signs of bait missing or predation, and it could be evident by finding anything from the lack of bait left in the tray, predators in the trap or Lepidoptera parts littered on the tray or ground. In addition to this, any environmental changes such as intense wind or rainfall since the last monitoring period would also be recorded to help understand why species abundance or diversity behave in the manner that they do.
Chapter 3: Results

Each survey block in this study consisted of five days worth of data collection during the summer of 2012 and were carried out between the following dates; Survey Block 1: 15th-20th July, Survey Block 2: 23rd-27th July, Survey Block 3: 5th-9th August, Survey Block 4: 11th-15th August.

Once each of the four monitoring survey blocks had been completed, the results were then inputted into a spreadsheet format (see appendices) before being displayed into the following tables and figures:

Following the first survey block of data collection however, it appeared that the number of individual traps that had been affected by either predation or bait removal was unusually high. This phenomenon was unexpected as in a previous butterfly survey completed by OuTrop (2012a/b) in other parts of the Sabangau, the levels of predation and bait loss in traps appeared to be very low. If this occurrence was to continue for the duration of this experiment, the final results are likely to be severely affected and not representative of the true distribution of species. It is for this reason that predator deterrents had to be created, and the first one was introduced before the beginning of the second survey block. It consisted of a washing-up bowl being mounted on the rope a metre above the trap so any predators climbing down would not be able to get around the obstacle. These were added to all traps found on transects R50, R100 and the canopy traps of R200 as these were observed to be the most affected by disturbance and interference.

In practice however this device did not appear to work as intended because squirrels and other possible predators were still seen near traps and occasionally even inside them, therefore a second solution had to be created and implemented. This time aluminium sheets were cut and folded into large cones before being secured with wire at the same point on the rope where the bowls had been fastened. In this instance the cones were attached before the third survey block on every trap on transects R50, R100 and R200 so that predators would find the downward facing metallic surface too slippery and precarious to navigate. In addition to this, on the second day of the third survey block a wire mesh was also created and installed over the top of the bait trays to every single trap on every transect. The purpose of this being to prevent larger wildlife such as squirrels or birds from removing the bait, whilst simultaneously having gaps large enough so that butterflies were still able to access the bait and therefore get a more accurate picture of their population and distribution.

<table>
<thead>
<tr>
<th>Survey Block</th>
<th>No. of Butterflies</th>
<th>Total</th>
<th>Overall average</th>
</tr>
</thead>
<tbody>
<tr>
<td>R50</td>
<td>2 3 0 0 4</td>
<td>9</td>
<td>35 8.75</td>
</tr>
<tr>
<td>R100</td>
<td>4 2 0 0 0*</td>
<td>8</td>
<td>57 14.25</td>
</tr>
<tr>
<td>R200</td>
<td>3 5 8 5 7</td>
<td>28</td>
<td>72 18</td>
</tr>
<tr>
<td>R400</td>
<td>8 4 6 6 11</td>
<td>35</td>
<td>95 23.75</td>
</tr>
<tr>
<td>R650</td>
<td>9 8 15 7 14*</td>
<td>53</td>
<td>92 23</td>
</tr>
<tr>
<td>Total</td>
<td>26 22 31 18 36</td>
<td>133</td>
<td>351 17.55</td>
</tr>
</tbody>
</table>

Table 1.1. This table shows the overall number of individual butterflies caught in traps on transects R50 to R650 on each of the days within each survey block. (*Unfortunately during the final day of testing in survey block 1, the team involved could not locate transect R100 or R650. Therefore these transects had to be monitored the following day, meaning that these traps were left in the field for approximately 48 hours as opposed to the 24 hours for each of the others. This may have implications on the data as butterflies will have a longer period of time to gather inside the traps, as well as allow a longer period of time for predators to prey on the specimens or remove the bait)
Table 1.2.
This table represents the total number of butterflies collected in this study that were not affected by either predation or bait loss and therefore shows the ‘true’ data set of disturbed findings that will be used to analyse the abundance, diversity and behaviour of all species data.

<table>
<thead>
<tr>
<th>No. of Butterflies</th>
<th>Survey Block 1</th>
<th>Total</th>
<th>Survey Block 2</th>
<th>Total</th>
<th>Survey Block 3</th>
<th>Total</th>
<th>Survey Block 4</th>
<th>Total</th>
<th>Overall total</th>
<th>Overall average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1  2  3  4  5</td>
<td></td>
<td>1  2  3  4  5</td>
<td></td>
<td>1  2  3  4  5</td>
<td></td>
<td>1  2  3  4  5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R50</td>
<td>1  0  0  0  0</td>
<td>1</td>
<td>4  0  0  1  0</td>
<td>5</td>
<td>3  4  1  2  0</td>
<td>10</td>
<td>0  2  1  1  0</td>
<td>4</td>
<td>20</td>
<td>5</td>
</tr>
<tr>
<td>R100</td>
<td>0  0  0  0  0*</td>
<td>0</td>
<td>1  1  2  0  0</td>
<td>4</td>
<td>1  3  3  1  3</td>
<td>11</td>
<td>2  0  0  0  1</td>
<td>3</td>
<td>18</td>
<td>4.5</td>
</tr>
<tr>
<td>R200</td>
<td>4  4  7  0  2</td>
<td>17</td>
<td>0  0  0  0  0</td>
<td>0</td>
<td>1  4  2  4  2</td>
<td>13</td>
<td>1  3  0  2  4</td>
<td>10</td>
<td>40</td>
<td>10</td>
</tr>
<tr>
<td>R400</td>
<td>8  3  0  5  1</td>
<td>17</td>
<td>3  2  0  0  2</td>
<td>7</td>
<td>6  0  0  2  3</td>
<td>11</td>
<td>0  5  5  2  1</td>
<td>13</td>
<td>48</td>
<td>12</td>
</tr>
<tr>
<td>R650</td>
<td>8  8  7  11*</td>
<td>42</td>
<td>0  3  4  6  0</td>
<td>13</td>
<td>3  2  0  1  3</td>
<td>9</td>
<td>1  2  3  1  0</td>
<td>7</td>
<td>71</td>
<td>17.75</td>
</tr>
<tr>
<td>Total:</td>
<td>21  15  15  12 14</td>
<td>77</td>
<td>8  6  6  7  2</td>
<td>29</td>
<td>14  13  6  10 11</td>
<td>54</td>
<td>4  12 9  6  6</td>
<td>37</td>
<td>197</td>
<td>9.85</td>
</tr>
</tbody>
</table>

Figure 2.2
This graph shows the total number of specimens collected and monitored from each transect over the four survey block periods. It is much like that found in Figure 2.1 however this time only includes individuals that have not been affected by either predation or bait loss, also known as the true data set. This data can also be found in Table 1.2.

Figure 2.3
This chart depicts the overall total number of butterflies examined in both original and true data sets throughout each survey block. The blue vertical lines between data sets therefore reflect the amount of predation and bait loss that has occurred at each survey block.
Figure 2.4
Data taken directly from the true data set in Table 1.2 was used to construct this line chart and it represents the overall number of butterflies surveyed at each transect. The transects are ordered from R50-R650 and therefore show numbers of specimens caught as if travelled towards the forest interior from the edge. With a positive correlation of 0.9136, this graph shows that there is a significant rise in butterfly population towards the heart of the forest.

**Table 2.1** Displayed in this table is the overall amount of predation that took place in the original data set. The numbers correspond to the number of traps that had some evidence of predation (e.g. wings found in the bait tray) on each day for every transect. As there are four traps located at each of the five transects, a predation percentage can be calculated for each day, survey block or transect.

<table>
<thead>
<tr>
<th>Predation</th>
<th>Survey Block 1</th>
<th>Survey Block 2</th>
<th>Survey Block 3</th>
<th>Survey Block 4</th>
<th>Overall total</th>
<th>Predation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R50</td>
<td>1 1 3 3 3</td>
<td>11</td>
<td>11</td>
<td>11</td>
<td>11</td>
<td>29</td>
</tr>
<tr>
<td>R100</td>
<td>2 3 1 3 4*</td>
<td>13</td>
<td>14</td>
<td>0</td>
<td>2</td>
<td>35</td>
</tr>
<tr>
<td>R200</td>
<td>1 1 0 2 2</td>
<td>6</td>
<td>14</td>
<td>0</td>
<td>2</td>
<td>22</td>
</tr>
<tr>
<td>R400</td>
<td>0 0 3 2 3</td>
<td>8</td>
<td>13</td>
<td>0</td>
<td>1</td>
<td>32</td>
</tr>
<tr>
<td>R650</td>
<td>1 0 1 1 1*</td>
<td>4</td>
<td>7</td>
<td>0</td>
<td>1</td>
<td>15</td>
</tr>
<tr>
<td>Total</td>
<td>5 5 8 11 13</td>
<td>42</td>
<td>59</td>
<td>12</td>
<td>20</td>
<td>133</td>
</tr>
</tbody>
</table>

The coloured vertical lines indicate the points at which predator deterrents were first implemented on some of the butterfly traps. Blue shows when the washing-up bowls were installed on the rope above some of the traps, Red represents when this was then taken over by the aluminium cones, and Orange shows when the mesh guards were placed over the bait traps.

**Figure 3.1**
These four pie charts depict a visual representation of the results found in Table 2.1. They show the percentage of data obtained in this study for each survey block that was affected in some way by predation. Also visible here is the extent to which each individual transect was subject to occurrences of predation.

**Predation percentages:**
- 42% No predation
- 59% R50
- 12% R100
- 20% R200
- 12% R400
- 5% R650
This line graph illustrates the information previously shown in Table 2.1. In particular however, comparing the average percentage of predation at butterfly traps for each transect. With a negative $R^2$ figure of 0.3679, it does not appear that there is a particularly strong relationship between the levels of butterfly predation and distance from the forest edge.

**Table 2.2.** In this table is represented the total number of times that bait loss was recorded from the original data set for each of the four survey blocks. Similarly to the previous table representing the overall levels of predation (Table 2.1), an average percentage can be calculated as there are four possible opportunities for the bait to be removed from traps on each transect every day.

**Figure 3.3.** The ratio of overall bait loss, as well as the number of times bait removal was found in transects is displayed in these four pie charts. It mirrors the bait loss results found in Table 2.2 over the duration of the four survey blocks.
Figure 3.4  
This line graph was created using the overall bait loss information found in Table 2.2. It represents the average percentage that bait removal was witnessed as the transects travel towards the forest interior from transect R50 to R650. Much like the overall predation percentage it does decrease further into the forest, however in this case with a considerably stronger \( R^2 \) number of 0.7792. Although this figure is not completely conclusive evidence, it does show that there is at least some relationship between the levels of bait loss and the distance from the forest edge here.

Figure 4.1  
Over the duration of the four survey blocks in this study, a total of ten different frugivorous butterfly species were monitored. The number of individual species that were found at each transect over this period of time is represented in this bar chart and it shows that overall the highest rate of species richness can be found towards the forest interior as opposed to nearer the forest edge.

### Table 3

<table>
<thead>
<tr>
<th>Species</th>
<th>R50</th>
<th>R100</th>
<th>R200</th>
<th>R400</th>
<th>R650</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agatasa calydonia</td>
<td>6</td>
<td>6</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>25</td>
</tr>
<tr>
<td>Charaxes bernardus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9</td>
</tr>
<tr>
<td>Charaxes borneensis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Dophla evelina</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>10</td>
<td>29</td>
</tr>
<tr>
<td>Lexias cyanipardus</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>8</td>
<td>18</td>
</tr>
<tr>
<td>Lexias pardalis</td>
<td>4</td>
<td>2</td>
<td>8</td>
<td>6</td>
<td>15</td>
<td>35</td>
</tr>
<tr>
<td>Melanitis leda</td>
<td>3</td>
<td>1</td>
<td>10</td>
<td>11</td>
<td>16</td>
<td>41</td>
</tr>
<tr>
<td>Prothoe franck</td>
<td></td>
<td>3</td>
<td>4</td>
<td>1</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Tanaecia munda</td>
<td></td>
<td></td>
<td>1</td>
<td>1</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Zeuxidia aurelius</td>
<td>1</td>
<td>1</td>
<td>6</td>
<td>9</td>
<td>10</td>
<td>27</td>
</tr>
</tbody>
</table>

**Total**  
20 18 40 48 71 197

The total number of butterflies of each species that were collected and studied throughout this investigation is shown in this table. Represented exactly is the number of times that each species was found at each of the five transects within the true data set over the four survey blocks. This information can be used to try and understand where in this stretch of forest particular species tend to prefer and live amongst. In turn, this may also shed some light on how far into the peat-swamp rainforest effects from the edge penetrate, and ideally show a possible line where these factors discontinue.
**Figure 4.2.** The number of butterflies found at each transect in this study that were of the *Melanitis leda* species are represented in this line graph. Despite a fall in the number of this species found at 100m from the forest edge, there does appear to be a positive relationship between this species and travelling towards the centre of the Sabangau ($R^2 = 0.8594$).

**Figure 4.3.** The number of butterflies found at each transect in this study that were of the *Lexias pardalis* species are represented in this line graph. Although the overall population of this species does appear to increase towards the forest interior, it does also drop at 100m and 400m from the edge as it rises ($R^2 = 0.676$).

**Figure 4.4.** The number of butterflies found at each transect in this study that were of the *Dophla evelina* species are represented in this line graph. This species appears to have some relationship with the distance from the forest edge as there are more than double the amount found at 650m than at 50m from the habitat boundary ($R^2 = 0.7903$).

**Figure 4.5.** The number of butterflies found at each transect in this study that were of the *Zeuxidia aurelius* species are represented in this line graph. This species appears to have the strongest positive correlation towards the forest interior with by far the majority of sightings being at 200m, 400m and 650m from the habitat boundary ($R^2 = 0.9235$).
Figure 4.6. The number of butterflies found at each transect in this study that were of the Agatasa calydonia species are represented in this line graph. It is visible that this particular species was found several times at every transect and has no real correlation to the distance from the forest edge ($R^2 = 0.4$).

Figure 4.7. The number of butterflies found at each transect in this study that were of the Lexias cyanipardus species are represented in this line graph. Here there is a large influx in this species between 400m and 650m from the forest edge, giving the overall projection a positive correlation towards the forest centre, albeit not a conclusively strong one ($R^2 = 0.3676$).

Figure 4.8. The number of butterflies found at each transect in this study that were either of the Charaxes bernardus, Charaxes borneensis, Prothoe franck or Tanaecia munda species are represented in this line graph. Each of these particular species were found less than ten times each in this study period and therefore are likely to shed little light on the possible edge effects than influence this forest patch. Having said that, it does appear that Charaxes bernardus and Prothoe franck increase towards 400m from the forest edge before dropping slightly at 650m. Whilst Charaxes borneensis and Tanaecia munda on the other hand only begin to be found towards the core of the ecosystem around 400m and 650m from the edge.
Analysis and Discussion

As a result of the data displayed in the previous tables and figures, some conclusions can be drawn about how edge effects may be influencing the population and distribution of butterflies in this area of peat-swamp forest. By looking at Table 1.1 and Figure 2.1 for example, a few conclusions can be made about the overall number of specimens collected and recorded in this study.

Perhaps the most striking aspect to be taken from these representations is the difference in the total number of butterflies found from survey block one to survey block four as the overall population of individual's decreases consistently from 133 found in the first period to only 44 found in the final block (an approximate overall decline of two thirds). Figure 2.1 equally follows this pattern and shows how each transect's total population decreases in some way towards the final survey block.

One possible reason for this noticeable fall in numbers may be a result of the testing strategy itself. As previously mentioned, in order to obtain a truer reflection of the population and distribution of these butterflies, anti-predation methods were implemented with the first technique (washing-up bowls) being installed prior to the second survey block. Perhaps as a result of this, an overall drop of 18.8% (133 to 108) arose in that period and may have unintentionally discouraged butterflies from entering traps as some light above the top of the cylinder could have been impaired and therefore give the impression of being less appealing to wildlife. However this is highly unlikely as the bowls were mounted approximately a metre above each trap, allowing more than enough light into it.

Equally, some would argue that the second predator deterrent (the aluminium cones) could follow suit, although these too were mounted for the third survey block roughly a metre above traps and would similarly allow sufficient light into the cylinders. The third method used on the other hand (mesh tray guards) installed on the first day of the third period may have had some influence in deterring butterflies from the traps, because although every effort was made to push guards down and allow the butterflies' proboscis to reach the bait, some may have been harder to reach than others and therefore deter some individuals. There is a noticeable drop in the total population caught between survey block one to two of 37% and a combination of these two methods may have been one of the deciding factors in reducing the amount of specimens.

However as interesting or intriguing as this data may appear to be at face value, it does not fully represent the population or distribution of the butterflies in this forest as much of the data has been interfered with by either predation or bait loss. In fact around 56.1% of the original data set was found to have been a victim of wildlife disturbance in some way, and it's for this reason that this
information cannot be used to successfully represent the species abundance, diversity and behaviour in the forest. Consequently the more accurate findings that were not disturbed during surveying or the ‘true’ data set displayed in Table 1.2.

Similarly to the original data set, the true data represented in Figure 2.2 does in general decrease, in this instance however by over half; from 77 specimens in survey block one to 37 specimens by the end of the study. Again this may be a result of the predator deterrents that were installed during the surveying period, but another major aspect which perhaps would affect the number of butterflies even more so is the seasonality of the fruiting vegetation, the local climate and the breeding cycles of butterfly species (Blundell 1999; Basset et al 1998). *Lexias pardalis* amongst other species for example are known to alter their behaviour when foraging in different seasons and habitat types (Houlihan et al 2012b). Plus, a relatively long larval and pupal stage followed by a comparatively short adult life for many butterflies means that seasonal fluctuations of breeding species will occur in abundance and at various times of the year in this forest, this too may influence the results found in this study as dryer season specialists make way for wetter season specialists for example (OuTrop 2012b).

The influence of annual climate cycles is likely to have had an impact on species population and distribution found in this forest at this time of year, and may in turn result in the number of generalist or specialist species found being different to other seasons (Basset et al 1998; Novotny and Basset 1998). Until the results of the current 12 month survey within the NLPSF are analysed in more detail and published however (OuTrop 2012a/b), it is unclear to what extent seasonality has a bearing on the frugivorous butterflies found here. The investigation by OuTrop has collected data in a disturbed patch of forest between two former railways, 900m and 1900m from the very same periphery studied in this survey as well as at the edge itself, therefore acquiring this knowledge may also prove useful in attempting to observe the impact of edge effects.

By observing the data set comparison in Figure 2.3 it is clear that whatever the reason was for the overall fall in butterfly population over the study period, the predation deterrents did appear to drastically reduce the amount of specimens that were affected by disturbance and therefore are vital for the successful analysis of this study and could possibly be used in similar investigations by OuTrop or other conservation organisations.

Looking at species abundance with regards to the distance from the edge however shows a very different side to the true data set. Figure 2.4 for example clearly represents the full extent to which butterflies were found at each interval within this patch of the Sabangau. It’s evident from this graph that there is a clear relationship between the butterflies that inhabit this forest and the distance from the habitat boundary. Furthermore, a positive coefficient of over 0.9 suggests that not only is
there an affiliation with these two factors, but there is a significant one, meaning that biotic and abiotic conditions towards the forest edge must be less favourable to the majority of butterfly species here. Proof then that there does appear to be edge effects influencing frugivorous butterflies in some manner in this region of the Sabangau.

One aspect that may contribute to the edge effects that manipulate the butterflies here is the levels of predation, and this is represented in Table 2.1. Much like the results found in Table 1.1, this chart shows how the first predation method had no real effect on reducing the levels of predation (in fact overall it actually increased by over 40%), but the combination of aluminium cone and mesh guard at the start of the third survey block drastically reduced the number of predators removing specimens or potential specimens from the raps. Rates plummeted from nearly a 60% predation rate, to just 12% in one survey block period and remained relatively low for the remainder of the study. Again it is possible that external environmental factors such a change in weather patterns may play a role in this fall in predation; although it does seem unlikely that any other influence could refine the findings in such a way. The pie charts in Figure 3.1 also give a clear visual representation of this dramatic change and in general may be a sign of how well the final anti-predator mechanisms worked although external factors also cannot be ignored (Burkey 1993).

These diagrams along with the results shown in Figure 3.2, represent how the volume of predation was shared at each of the five transects in this study. They show that there is no definitive trend in the amount of predation that occurs away from the forest edge as the levels continue to rise and fall from R50 to R650. Although it is worth noting that there is a sudden drop in predation from 40% at R400 to 18.75% at R650; this may not only highlight the fact that edge effects (such as the number of butterfly predators) are in fact found in this forest, but may even show where a possible edge effect line is found.

This slight tendency towards the edge for predation levels is also mirrored in some of the initial findings by OuTrop with three and a half times more predation being found at the forest margin than any other of the surveyed sites (Table 4, OuTrop 2012a). Although again, the role of seasonality may have some role to play in the number of predators found preying on butterflies nearer the habitat boundary (Cresswell 1998).

As well as the number of predators, another possible edge effect that may manage where butterflies are found in this forest is the amount of other animals that complete with them for food. The amount of bait lost from each trap should give a fair indication of this, however as the bait used in this study (which is largely comprised of ripe or rotten bananas) is not found naturally in this forest, species of other animal that are opportunists or generalists are also likely to be attracted to this lure. The results of this can be found in Table 2.2 and Figure 3.3 and immediately the similarity
between this factor and predation begin to emerge as both respond similarly to the predator deterrents over the course of the study and drop significantly after the second and third methods. Of course the mesh guard over the bait tray in particular is likely to have had the largest success in preventing this loss, and indeed this appeared to be the case with a 57% bait removal level in survey block two being reduced to a mere 8% by the next period on all transects. This sudden change indicates how potentially successful in reducing the amount of predation and bait loss this technique is, and as a result makes the survey more representative of the true butterfly population and distribution in the forest. This knowledge, if nothing else, makes this particular study significant as the methods used here can be replicated and used in future studies by organisations such as OuTrop who continue to work in this peat-swamp rainforest, or even for research in other ecosystems where butterfly behaviours are not fully understood (Houlihan et al 2012b).

Recognizing the impact that edge effects have on the butterflies in this patch of rainforest would also prove this study to be noteworthy and a step closer to understanding this can be seen in the bait removal data represented in Figure 3.4. Observing this line graph reveals how clearly this phenomenon is distributed closer towards the habitat boundary than the interior as the majority of bait removal was found at R100 and R50. A negative coefficient of around 0.78 shows that unlike the rates of predation, there is a relatively strong connection between the volume of bait loss and the distance from the rainforest edge. Although not definitively conclusive evidence that other fruit feeders are equally affected by the impact of the edge, it does strongly suggest that the availability of food may be one of the decisive factors influencing the distribution of butterfly species here. Plus with such a dramatic drop in bait removal from 56.25% at R100 down to just 2.5% at R650, this too may be a region where a possible edge effect line could be found. This is unlike the preliminary results of OuTrop’s 12 month study however which shows very little bait removal from traps whatsoever (OuTrop 2012a). An unusual occurrence due to the relative proximity of where the two investigations have taken place, and therefore this may reflect the small-scale territories where fruit feeders are found although more analysis on this subject is essential to understand this further.

As well as species abundance and the impacts that other factors have on these butterflies, species diversity is another major aspect of this environment that this investigation aimed to observe and this is displayed in Figure 4.1 where a clear overall increase in the number of species rose from six different types nearest to the edge, to ten at the innermost of these transects. The findings are promising in one way because to actually find 10 of the 27 known Sabangau frugivorous butterflies (in five different subfamily groups: Charaxinae, Limenitidinae, Morphinae, Nymphalinae and Satyrinae) within the 600x300m patch over a month period implies that it is in a relatively healthy environment for this fauna, albeit located in close proximity to the periphery. In another way
however these findings reveal little to suggest that edge effects influence species diversity as, despite a gradual increase from 6 to 10 species, there is very little change in the number of individual species throughout the transects.

Having said that, there were fewer species found closer to the forest boundary which is what to be expected to a degree as previously disturbed and regenerated forest can possess more complex microhabitats and can lower nymphalid biodiversity (Houlihan et al 2012b). However this does not reflect the findings of many studies in this field which suggest that in this type of periphery or more disturbed habitat, Lepidoptera diversity can remain high or even higher than interior sites (Willott et al 2000; Hawes et al 2009). Even in the preliminary results of OuTrop’s 12 month survey, the diversity of specimens found was highest at the very margin of the forest (Table 11, 2012a) furthering the need for a higher level of understanding about Nymphalidae species both at the edge and when seasonality is concerned.

Species behaviour is the final ecological aspect that this study went out to observe in order to understand whether or not edge effects are noticeably influencing butterflies in this area of the Sabangau. Table 3 represents the distribution of each individual butterfly species that was found within the true data set at each of the five transects and is an excellent tool to help understand this process as it shows where each species is likely to prefer within this patch of rainforest. The first aspect that is noticeable in this data however is the increased total abundance of individuals that are found nearer to the forest interior that the exterior. Again this issue may be distributed in such a way due to the edge effects imposed on these species and reflects the results previously found in Table 1.2.

The most frequently caught species during this survey was Melanitis leda occupying 20.8% of the total species record. Houlihan, Marchant and Harrison’s general guide to butterflies in the Sabangau (2012a) states that this species is common throughout all rainforest types, including disturbed habitats and edges. This information mirrors the findings in Table 3 and Figure 4.2; however with a positive coefficient of 0.8594, there does appear to be a strong (although not certain) preference of these butterflies towards the rainforest interior as well. Reasoning for this may be due to food availability, mating opportunities, number of predators or external environmental factors, but all of these can be influenced by a habitat boundary and the edge effects that naturally occur alongside them. Unusually however another study by members of the OuTrop team (2012a) indicates how butterflies of this species were indeed found to be located in many habitat sub-types (edge, disturbed, un-disturbed, etc), but were also found to be more abundant at the forest edge than anywhere else in the forest. In fact within the four different sites they monitored, almost 40% of the Melanitis leda population was discovered to exist at the rainforest
periphery. This reiterates how important seasonality has a bearing on the behaviour and distribution of butterflies in this peat-swamp forest because there is clearly a change in this species activity between January-May (when the survey was taking place) when _Melanitis leda_ appear to prefer the edge, and the summer period (July-August) when they favour interior forests. Explanation for this phenomenon is unclear but one reason could be a result of the dry season itself as the forest periphery is likely to have a lower amount of canopy cover due to the younger trees that exist there, and this increase in sunlight and/or heat may create an microclimate less favourable to this species (Young and Mitchell 1994; Willott _et al_ 2000; Houlihan _et al_ 2012b). Of course this is only assumption but a realistic possibility for this act of behaviour and another feasible explanation is the distribution of fruit found in this forest as this can often impact the movement of a certain species (Blundell 1999), yet further research into the fruiting phenology at this edge is needed throughout the year to accurately address this issue though.

Another likely factor which may influence this behaviour is the increased number of butterfly-feeding predators or other fruit-feeding animals that are present along the habitat boundary in the dry season. In this study and OuTrop’s earlier survey (2012b) there is clear evidence of predation and bait loss on butterflies surrounding the rainforest border in the dry season, in fact the month of July appears to have been the most heavily effected in both categories (Table 5 and 6, OuTrop 2012b) which (despite a peak in predation levels in April) suggests that this is a highly likely possibility in this _Melanitis leda_ behaviour and distribution.

The second most abundant species found in this investigation was _Lexias pardalis_ taking up 17.8% of the overall species captured. Its distribution in relation to the distance from the forest edge can be observed in Figure 4.3 and like _Melanitis leda_, it too was found at every location and does to some extent appear to favour the forest further into the interior as opposed to nearer the fringe (albeit not as strong a relationship with an R² value of 0.676). By observing this study and previous data collected by OuTrop it appears that this species behaves much like _Melanitis leda_ in the sense that it is likely to be more of a generalist and opportunist when it comes to finding somewhere to feed, and despite having a slight preference towards the forest interior (Figure 4.3 and Table 11, OuTrop 2012a) is not exclusive to a particular region or sub-habitat of this forest and therefore reveals little about the edge effects found here.

Another species found in this survey was _Dophla evelina_, and by studying the results found in Table 3 and Figure 4.4 it appears that it too shares the same kind of behaviour and distribution patterns as the previous two species. With a steady incline in the population towards the centre of the forest (and a positive coefficient of 0.7903), it would be understandable to state that these butterflies are too affected by edge effects, however the relationship is not completely in sync and
again cannot realistically be relied upon to determine the potency of these impacts. A previous survey this year (OuTrop 2012a) found *Dophla evelina* in high numbers at various sites in the Sabangau with most situated at the same forest boundary as the one studied in this investigation. This suggests that much like *Melanitis ledo*, seasonality has a control on aspects that occur at the edge for this species (whether they be feeding, mating, climate related, etc) and in turn impact on how this species is distributed near the periphery. Observing the special behaviour of this species as well as many others in this survey annually or perhaps even longer would help paint a clearer picture of why frugivorous butterflies here react to the influences of the edges in the manner that they do.

*Zeuxidia aurelius* was one of, if not the species which appears to favour the forest interior over the edge the most, and this is mirrored in the results found in Figure 4.5 as it has the strongest relationship of all of the species in this study between the species abundance and the distance from the habitat rim (with an $R^2$ value of 0.9235) implying that edge effects do have a bearing on where these butterflies are found. This is somewhat reflected in the results of OuTrop’s previous survey last year (Table 11, 2012a) which shows how the lowest population was found feeding at the edge whilst higher volumes were discovered further into the middle of the forest. In fact the highest abundance of *Zeuxidia aurelius* was found in more disturbed forest unlike the majority of species in this particular study, which may provide further clues to their behaviour, but again only further research in this field will provide a comprehensive understanding of why specific species are located in the areas that they are found.

A species that was found earlier in 2012 to be by far the most abundant in this region of the Sabangau was *Agatasa calydonia* because between the months of January and May it took up over 40% of the overall species found (OuTrop 2012a). In this research endeavour however, the species accounted for only 12.7% of the total butterflies caught, despite being found at every transect that was observed. This highlights how once again the power of seasonality can influence the overall species population as it appears to decline in drier periods. In this instance though there seems to be no real correlation between *Agatasa calydonia* and the distance from the habitat boundary, so seasonality plays no evident part in their edge distribution at least. Figure 4.6 reiterates this theory as despite a very minimal rise in population towards the forest edge, with an $R^2$ value of 0.4 it’s a far cry from calling this an edge-specific animal, but rather a more generalist one that is at home in various sub-habitats in this forest (Houlihan et al 2012a).

A species that was not really expected to be found in the numbers that were in fact recorded is *Lexias cyanipardus* which in last year’s earlier survey (OuTrop 2012a) wasn’t found in traps once between January and March, and even after this period until the drier season were only sporadically caught. Table 3 and Figure 4.7 show how even though this species occupied less than 10% of the
In this survey, the overall number of butterflies was found in every site more than once, which is more than what can be said for earlier in the year. In fact, Figure 4.6 illustrates how despite a positive coefficient of just 0.3676, the number of *Lexias cyanipardus* found at R650 is noticeably higher than any other transect which are all closer to the ecosystem periphery. Unfortunately, due to the lack of data from previous studies in this forest about this particular species, it’s difficult to predict what its behaviour may be like as it’s the only butterfly of the species previously mentioned in Houlihan, Marchant and Harrison’s guide to the butterflies of the Sabangau (2012a) to be noted as being ‘uncommon’. All that can be gathered from this study is that although found at the edge, it does appear to be much like the majority of previous species in that it can be found in higher numbers further from the habitat boundary were the influences of edge effects are less likely to alter their behaviour, although again these findings are not strong enough to verify whether edge effects are definitely impacting this species.

The four other species to be found in this survey were *Charaxes bernardus*, *Charaxes borneensis*, *Prothoe franck* and *Tanaecia munda*. A combination of these specimens covered just over 10% of the total butterflies recorded at these sites which is why a great deal cannot be drawn from the information gathered on where they can be found. What little is visible however is represented in Figure 4.8 and shows that on average these species much like the ones exhibited beforehand, do too appear to favour habitat further towards the interior, or at least are more likely to feed more opportunistically on the bait provided as distance from the periphery increases. Of course due to the little information on these species, this evidence is by no means conclusive, but for species such as *Charaxes borneensis* and *Prothoe franck* it does at least match some of the results found in previous surveys (OuTrop 2012a). Perhaps if surveys such as this were expanded over a greater area for a longer period of time, the relationship between these species and the edge effects that appear to exist here could be far better understood. This idea continues to all of the species in this survey as despite the fact that this research can convey a great deal about distribution of butterflies towards the edge (Houlihan et al 2012b), it still only represents a 600x300m patch of the 6,000km² Sabangau over a relatively short period of time, and cannot fully represent the impact of edge effects throughout this ecosystem. If further research incorporated these aspects, perhaps also alongside sexes, recapture rates and moth behaviour, more could be understood about the edge effects of this forest boundary.

Overall by observing the relationship between species abundance, diversity and behaviour and the distance from the habitat boundary, it is clear that there is some form of pressure imposing on some of the frugivorous butterflies that live in this forest closest towards the forest edge. However, what isn’t so evident is firstly the notion that there is indeed an ‘edge effect line’ where
this phenomenon ceases to exist (or at the very least dramatically reduces), and secondly, whether or not this theoretical line can be found within the 650m distance from the forest edge that was studied in this instance.

The total number of specimens found at each transect in this survey is displayed in Table 1.2 and Figure 2.4 and not only represents at increasing number of butterflies further away from the edge of the ecosystem, but also shows dramatic changes in population where an edge effect line could be distinguished. A large increase in the total abundance can be found between the transects situated 100m and 200m from the forest edge (from 18 to 40 specimens) which suggests that there may be some change in the living conditions for frugivorous butterflies between these sites. Having said that the number of individuals still appears to increase past this transect towards the forest interior, and in fact rises steeply again between 400m and 650m from the periphery (from 48 to 71 specimens). Although this second region may too seem to be a possibly when it comes to finding a destination for an edge effect line, it is impossible to tell without studying past transect R650 whether or not this trend continues into the vegetation or changes in some other way.

A combination of the percentages of predation and bait loss in this study equally mirrors this theory as there appears to be steep reductions in trap interference at both of the previously mentioned regions (see Figures 3.2 and 3.4). Bait removal in particular shows a great deal of alteration amid transects furthest from the habitat edge with the largest percentage loss being 23.75% between R100 and R200 (56.25% down to 32.5%) and another striking reduction down to just 2.5% at R650 (from 17.5% at R400).

It has begun to emerge that the biggest alterations in fruit-feeding butterflies’ distribution, as well as some of the impacts that influence this, can be found between the sites of R100-R200 and R400-R650, implying that these regions are worthy of being the location for a possible edge effect line. However one aspect in this investigation that has no real bearing on this theoretical line is the diversity of butterfly species found at each of the different transects (see Figure 4.1). The reason for this is despite an increase of two species from R100 to R200, there is an overall gradual increase in diversity towards the interior with no vast increase in the number of species found and therefore has little to offer when observing where this theoretical line could be found.

When observing the individual species however there does appear to be a similar trend to the ones previously encountered when studying the other aspects in this investigation. For example examining Table 3 and the following figures gives the impression that again the interval between transects R100 and R200 influences the population and distribution of fruit-feeding butterflies in some way. Not only do *Daphia evelina*, *Charaxes Bernardus* and *Prothoe franck* begin to increase at this period but there is also a dramatic influx in butterflies of *Lexias pardalis*, *Melanitis leda* and
Zeuxidia aurelius. Nevertheless the overall number of specimens in this survey continues to rise past this interval and in fact rises at an even steeper rate between R400 and R650 for Dophila evelina, Lexias cyanipardus, Lexias pardalis, Melanitis leda and even prompts the only occurrence of Charaxes borneensis.

When taking into account each of these variations in species behaviour as well as the overall abundance, predation and bait removal levels, it has become evident that in this survey there is a possible region around 100m-200m from the forest margin where an edge effect line could be found due to the number of sudden changes to this fruit-feeding butterfly population. On the other hand by analysing the information found here in more detail it appears that these edge effects do not actually cease to exist and in fact continue into the habitat’s centre. Equally the region between 400m and 650m from the ecosystem’s edge also looks as if there is a case for this theoretical line as not only is there a dramatic change in the distribution of individual species, but aspects that may influence where these butterflies are found (such as predation and bait removal) similarly experience a noticeable reduction. It has become evident that this particular distance from the habitat periphery may indeed be the location in this environment where an edge effect line could be found (in relation to the frugivorous butterflies of the forest at least), however this theory is impossible to verify without surveying for longer and further into the Sabangau. Between 400m and 650m may well be the area most likely to find a possible edge effect line in this study, although further research is essential here to determine once and for all where the influence of the habitat boundary ceases to influence the distribution and behaviour of fruit-feeding butterfly populations and species.
Chapter 4: Problems Encountered and Future Study

Despite the relative success of this research endeavour in observing the relationship between fruit-feeding butterflies and the boundary of this habitat, if it was to be carried out again would understandably have to make a few adaptations. Chief among which being the time frame for this investigation which was sufficient in obtaining enough information about aspects such as the levels of predation and bait loss towards the edge, however it would ideally be implemented for a longer period to acquire more butterflies for species analysis both in relation to edge effects, and to understand the seasonal variations in this part of the Sabangau.

In this investigation in general there were few obstacles that held back the collection of data in this part of the rainforest, this is perhaps largely due to the fact that the systematic technique used has been implemented previously by OuTrop and is known to obtain quality results when it comes to frugivorous butterflies. However one hurdle that did influence the findings in this study was of course the levels of predation and bait loss that occurred during survey blocks, especially towards the forest periphery. At the start of the investigation these factors disturbed up to around 60% of the original data set (Figure 3.1 and 3.3) and for this phenomenon to occur on such a vast scale was not only unheard of in previous surveys in this region of the forest, but there were no specific means of reducing this level of external interference. If this exploration was indeed to be repeated, it’s imperative that a combination of the aluminium cones and mesh bait tray guards used half way through this study, would have to be used for the duration to more accurately reflect the distribution of fruit-feeding butterflies.

One other aspect that varied throughout this study which, if repeated, would ideally be altered is the number of different people each day completing the experiment over the four survey blocks. Various groups of people (although always with at least one person who had extensive experience in completing butterfly surveys) undertook the collection of data in the field throughout this investigation due to practical reasons. However ideally, the same team of individuals would continuously carry out this work over the entirety of the study to not only maintain the same level of opinion when it comes to identifying species etc, but also at a more basic level, to make sure the traps in question are travelled to and observed in the same systematic manner each and every day. Fulfilling a repeated survey in this fashion would avoid instances similar to one that occurred on the final day of the first survey block where, despite the use of GPS devices, transects R100 and R650 could not be found on that particular outing and therefore were left exposed in the forest for one extra day. Luckily incidences such as this were rarely encountered during this research endeavour,
nonetheless if the study were to be repeated, every possible effort to avoid disrupting the data in this way must be avoided in the future.

Perhaps the largest change that would have to be made to this study in terms of observing the edge effects of butterflies however is the number of transects and the distance of these from the peat-swamp rainforest periphery. As previously mentioned, the overall findings of this investigation found that although there are some areas where an edge effect line could be found, it is likely that the impact of the habitat boundary on frugivorous butterflies is likely to penetrate deeper into the rainforest interior. Therefore if any research is to follow this surveys footsteps in the future, it must take into account the fact that instead of measuring up to 650m from the periphery of the ecosystem, it would be far more effective to examine further into the interior and at more intervals to determine once and for all whether a definitive edge effect line can be found.

**Conclusion**

The overall aim of this scientific investigation was to attempt to determine whether or not edge effects influence the abundance, diversity or behaviour of fruit-feeding butterflies in this region of the Sabangau. By observing the data collected in this survey it has become clear that the diversity of these Lepidoptera species perhaps sheds the least amount of light on this idea. Despite a visible slight increase towards the forest interior (Figure 4.1), it is conceivably too gradual to suggest that there is a lower biodiversity of butterflies nearer the forest margin as a result of edge effects, especially when considering the duration of this study or the amount of results.

Species behaviour is another aspect that is questionable when observing as an indicator of peat-swamp forest edge effects here as there were no species found which appeared to be border specific or reliant, and regardless of many species seeming to have some preference to the conditions further from the edge (Dophla evelina, Lexias cyanipardus, Lexias pardalis, etc), few had noticeably close relationships with this. Zeuxidia aurelius was perhaps the only exception to this idea however (Melanitis leda arguably being another) due its strong correlation with distance from the periphery and therefore does show some evidence of edge effects influencing species behaviour to a negative degree closer to the habitat margin.

The total abundance of butterflies monitored in this inspection on the other hand does show how the edge appears to have an overall impact on these organisms. Unlike the majority of individual species, the total population of butterflies in this survey has a significant trend which suggests that higher abundance is found closer to the forest centre, and that therefore the influence of edge effects is indeed highly likely to exist here.
A possible edge effect that was not only unexpected to shape the findings of this study in such a way, but became almost an overriding authority due to the amount of data that it discounted was natural disturbance. A combination of predation and bait loss resulted in the original findings to be reduced by almost 44%, and may have been even greater were it not for the introduction of anti-predator devices, but these aspects too were able to help paint a picture of the influence the margin has over frugivorous butterflies since despite a not particularly strong correlation (especially for predation), there did appear to be more disturbance found nearer the fringe of the ecosystem. This represents a possible clue to some of the edge effects that have affected species abundance and distribution in this investigation, but further knowledge and research is needed to understand the full extent to which biotic and abiotic dynamics influence Lepidoptera at this complex transition between habitat boundaries (Yahner 1988; Saunders et al 1991).

Another major goal for this study was to attempt to understand if these impacts either gradually filter through the habitat from the outskirts or dramatically change at some stage, and if the latter, to try and identify an edge effect line where these issues cease to exist. By observing all of the data collected here it is difficult to accurately decide on one of these options as a definitive answer. The regions between 100-200m and 400-650m from the forest margin are arguably as stated before the most likely areas where a line could be found due to several changing factors in these periods, although additional enquiries into the edge effects themselves are needed to justify whether it is one or the other or perhaps even further into the forest. Previous studies of various fauna species in different habitats give an assortment of results into the distance of an edge effect line from the margin; it can be as a little as 50m (Paton 1994; Young and Mitchell 1994) or up to 200m (Laurance 1991) depending on the animal and location of research. A 22-year-study in the Amazon rainforest by Laurance et al (2002) for example observed several possible biotic and abiotic edge effects and found that despite the majority changing at around 100m from the habitat boundary, disturbance-adapted butterflies appeared to come to an end at 250m, while some other factors continued up to 400m. This shows just how complex and how much variation there can be between a particular animal, the edge effects that can influence it, and the surroundings in which it lives (Yahner 1988; Laurance et al 2002). Once again the pursue for additional knowledge in this dynamic environment continues and with many studies also saying that edge effects may well spread into any habitat up to a kilometre or more from a margin (Skole and Tucker 1993; Laurance 2000; Cochrane and Laurance 2002), the need for a survey that reaches further than 650m into this patch of the Sabangau over a longer period of time becomes ever more apparent.
The final aim of this investigation was to provide an essential tool for conservation organisations such as OuTrop in understanding the population and distribution of fruit-feeding butterfly species in relation to this peat-swamp rainforest boundary where awareness is relatively poorly understood (Koh 2007; Houlihan et al. 2012b). Observing some of the findings and conclusions touched upon here in relation to edge effects may hopefully not only add to previous knowledge of these insects, but be used in conjunction with previous research to aid the forest’s management and protection in the foreseeable future so that butterflies continue to be found here, and that the habitat’s edge follows Central Kalimantan’s state motto “Isen Mulang”, or “Never Retreat”.

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