LIANAS IN LOGGED AND FRAGMENTED FOREST

The effects of logging and forest fragmentation on liana carbon stock, abundance and species richness

Bachelor thesis
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Preface

Through extensive expansion of palm oil plantations on Sabah, Malaysia, more awareness goes to developing sustainable palm oil production. There is a need for scientific research to support sustainable management of remaining forests located within palm oil plantations. As my bachelor thesis is part of the Socially and Environmentally Sustainable Oil Palm Research (SEnSOR) programme, this research aims to fill in knowledge gaps on carbon stock of forest in fragmentation areas. In this research, the effects of forest fragmentation and logging on carbon stock in lianas will be investigated. Examining how much carbon actually is stocked in lianas and if forest size or logging influence these carbon stocks. When more is known about the effects of logging and forest fragmentation on carbon stock in lianas management can be modified and improved to determining optimal fragment size for future sustainable palm oil production and landscape-level conservation management.

While this projected lasted only two months, I am very grateful for having the opportunity to join the SEnSOR programme with their research on carbon stock in lowland Dipterocarp forests on Sabah, Malaysia. In the two months I spent in Malaysia, I gained various new experiences, from creating my own liana herbarium to meeting the kindest and generous people in Malaysia. Spending time in the beautiful nature reserve Danum Valley as well as the completely different palm oil plantations.

Since I could not have done this project on my own, I would first like to thank my supervisor Peter van der Meer for the invitation and all his help with the planning and assistance during this project. Appreciations as well to my local supervisors Dr. Datuk Yeong Kok Loong (Benny) and Suzan Bennedick for supporting and guiding me through the project.

Many thanks to SEnSOR for supporting the entire project and WILMAR who gave us the privilege to do research on their plantations providing us with accommodation and food as well. Furthermore, thanks to the DVMC and Forestry Department for their help, accommodation and approval to conduct research in their forest area.

At last special thanks for Tamby, our research assistant, Nils Beaujon and Sake Alkema for their outstanding assistance during the field work. Without them, I would never have finished collecting my data on time.

A. de Winter
August 2016

Abstract

There is a need for scientific research to support sustainable management of remaining forests located within palm oil plantations. As lianas have a significant impact on species diversity, structure and dynamics, they are an important element in tropical forests. This study examined liana carbon stock, abundance and species richness in 46 plots, covering a total of 3,46 hectare. The plots were located in High Conservation Value areas (HCV), Virgin Jungle Reserves (VJR) and Continuous Forest (CF) on Sabah, Malaysia. In total 1.919 lianas with a diameter at breast height (DBH) $\geq$ 1.0 centimetre were measured. 915 lianas were identified, comprising 85 species. DBH measurements were used in an allometric equation to estimate liana biomass. After which, the biomass was multiplied with a carbon content of 47,35% to determine liana carbon stock. Statistical analysis was completed using IBM SPSS Statistics 23, Excel t-Tests and Excel ANNOVA tests.

Calculated carbon stock show a range from 1.656,5 kilogramme carbon per hectare (Kg/C/ha) found in Meranti to 5.711,4 Kg/C/ha in Jatu. While the average carbon stock showed that continuous forest contained the lowest amount of carbon (2.971,2 Kg/C/ha), almost no difference was discovered between the HCV areas (3.535,6 Kg/C/ha) and the VJR (3.589,2 Kg/C/ha). Liana species richness varies from an average of 15 species in the HCV areas to 30 species in the continuous forest. The lowest amount of liana species encountered was in Sabasar (6 species), while the Malua B site was most rich in liana species (34 species). Liana abundance was lowest in Meranti with an average of 300 lianas per hectare. The highest abundance of 1.015 lianas per hectare was in Rekasar. The average liana abundance was 629 in HCV areas, 565 in VJR and 533 in CF.

Additional research is necessary because statistical analysis using SPSS linear regression test, Excel t-test and ANOVA test showed no relation between fragmentation size, logging and liana carbon stock, abundance or species richness. Separate analyses were done for fragmentation size, logging history (logged or unlogged), and forest type (HCV, VJR or CF). All tests showed that no significant relation was present in the collected data. Although some trends were detectable, additional sampling is recommended to ensure that further analysis can support trends found in this study.

Table of Contents

1. Introduction

1.1 Background

Malaysia is one of the foremost countries facing the consequences of the increasing demand for palm oil products. The last few decades the palm oil plantations have been rapidly expanding (Wetlands International, 2013). As a result, Sabah, the second largest state of Malaysia, already lost almost half of its intact forest between 1990 and 2008 (Osman, Phua, Ling, & Kamlun, 2012). The replacement of forest by agricultural fields has resulted in a transformation in the landscape (Seng, 2015). From former continuous forest, only forest patches remain due to the process of fragmentation. Deforestation and large-scale transformation of tropical forest to oil palm plantations are a threat to biodiversity and other ecosystem services (Lucey et al., 2014; Millennium Ecosystem Assessment, 2005). Besides these environmental impacts, the palm oil industry has a significant contribution to economic development and rural livelihood improvements (Ferdous Alam, Er, & Begum, 2015; Seng, 2015).

Responding to the loss of primary forest in Malaysia and the expanding palm oil industry South East Asian Rainforest Restoration Project (SEARRP) established the Socially and Environmentally Sustainable Oil Palm Research (SEnSOR) programme. The SEnSOR programme is an integrated multi-disciplinary research programme designed to fill key knowledge gaps in testing and developing the Roundtable on Sustainable Palm Oil (RSPO) principles and criteria for sustainability in oil palm agriculture (SEnSOR, 2015). As part of this programme, this research was conducted to investigate the effects of fragmentation size and logging on the carbon stock in lianas.

Fragmentation is the process of dividing large tracts of contiguous forest into smaller isolated tracts surrounded by human-modified environments (CLEAR, 2009). Fragmentation is considered as a dominant driver of biodiversity loss (Gonzalez, Mouquet, & Loreau, 2009; Laurance et al., 2007). Due to isolation and edge effects on forest fragments, transformation in species composition occurs, especially in smaller fragments (Hill & Curran, 2003). These processes can lead to further decline in species diversity, changes in abundance, and other aspects of biodiversity in forest patches (Andrén, 1994; Fahrig, 2003; Ewers & Didham, 2006). Despite several legislation efforts, the relatively small protected forest patches are not sufficient to prevent biodiversity losses (Franklin & Lindenmayer, 2009; Lucey et al., 2014; Perfecto & Vandermeer, 2002).

Referring to the global concern of carbon emissions and environmental changes, the importance of understanding how much carbon is stocked in the forests has been increasing. The standing carbon stock of an oil palm estate is variously reported at 50 to 100 T ha^{-1} (Morel et al., 2011; MPOC, 2007). This is significantly lower than the carbon stocks of logged natural forests where carbon stocks range from 90 to 180 T ha^{-1} subject to logging intensity and recovery time, or unlogged rainforest where values range from 175 to 215 t ha^{-1} (Morel et al., 2011; Sayer, Ghazoul, Nelson, & Klintuni Boedhihartono, 2012).

Lianas are climbing plants that produce true wood (i.e., xylem tissues derived from a vascular cambium) and germinate on the ground (Jeffrey J. Gerwing et al., 2006). They lose their ability to support themselves as they grow, so they have to rely on external physical support to ascend to the canopy. Lianas can reduce tree- growth, regeneration, and fecundity, as well as alter forest regeneration and successional trajectories(S. A. Schnitzer, Rutishauser, & Aguilar, 2008). Lianas, in addition, contribute to forest ecosystems as a valuable food source for animals by physically linking trees together, thereby providing canopy-to-canopy access for arboreal animals (S. A. Schnitzer & Bongers, 2002). Lianas play a major role in species composition as they can contribute up to 45% of the woody stems (DeWalt & Chave, 2004) and 35% of the woody plant species (Van Der Heijden et al., 2013). Therefore, any alteration to lianas has consequences for species diversity, productivity and carbon storage (S. A. Schnitzer & Bongers, 2011).

Previous studies have shown that liana abundance increases in more disturbed areas (Putz, 1984; Schnitzer, Parren, & Bongers, 2004; Schnitzer et al., 2004; Schnitzer & Carson, 2010). However, liana abundance and diversity can be quite variable among individual sites (Appanah, Gentry, & Lafrankie, 1993; Gianoli, 2015; Perez-Salicrup, Sork, & Putz, 1998). In liana poor forest such as in Semengoh, Sarawak, lianas can encompass less than 10% of the overall woody species (Appanah, Gentry, & Lafrankie, 1993). Whereas, in forests on the border of the Amazon basin liana diversity can be as high as 44% of the woody species (Perez-Salicrup et al., 1998; Schnitzer & Bongers, 2002). As differences in lianas numbers might alter tree abundance or reduced tree growth, lianas may have a larger influence on biomass, and consequently, carbon stock in the tropical forest than we thought.

Another major aspect influencing liana abundance is logging. Logging can affect forests carbon stock in several ways. Logging, applied through selective- or clear-cut logging, is the most direct form of altering forest structures. Although clear-cut practices are mostly applied when agricultural field replaces forested areas, in the case of Malaysia most likely palm oil plantations, selective logging is still applied on a large scale as a contribution to the state's economy (Sayer et al., 2012; Yeong, Reynolds, & Hill, 2016). In addition, management practises of predestined logging forest ensuring a constant and improved tree growth can cause severe decreases in liana abundance. A well-known example of this methods is climber cutting, in which climbers will be cut down or removed from trees to reduce competition and improve growth (S. A. Schnitzer et al., 2004).

Hence, we need to understand the trait biology of climbing plants which majorly contribute to forest ecosystem functions. As human disturbance continues to increase in tropical forests, lianas would continue to grow in abundance, which could ultimately lead to an increase of biomass they store (Patrick Addo-Fordjour & Rahmad, 2013). Furthermore, with the expansion of palm oil plantations the awareness for developing sustainable palm oil products rises. However, lots of scientific research needs to be done to underline the need for sustainable management of remaining forests located within palm oil plantations. For that reason, the effects of forest fragmentation and logging on carbon stock in lianas will be investigated in this research. Examining how much carbon is stocked in lianas and if forest size or logging influence these carbon stocks.

1.2 Research objective

The purpose of this research is to assess the effects of fragmentation and logging on the carbon stock in lianas. Additionally, the research will contribute to the request of SEnSOR to investigate how much carbon is stocked in fragmentation areas and if there is a difference between fragment sizes and logged versus unlogged areas. When more is known about the effects of logging and forest fragmentation on carbon stock in lianas, management can be adapted to determining optimal fragment size for future sustainable plantation and landscape-level conservation management. This research will contribute to add knowledge about the impacts of forest fragmentation and logging on liana carbon stock, abundance and species richness.

1.3 Research question & hypothesis

For the research the following research questions were setup

Main research question:

What are the impacts of logging and forest fragmentation on the carbon stock, composition and abundance of lianas?

The main research question is divided into the following sub-questions:

1. *Is there a difference in carbon stock stored in lianas of small fragments compared with larger fragments (or continuous forest)?*
2. *Is there a difference in liana carbon stock of logged fragments compared with unlogged fragments?*
3. *Does fragmentation size or logging influence species composition?*
4. Does logging influence species composition?

Based on the research objective and the sub-questions the following assumptions of expected results are:

- *Areas with a higher disturbance caused by logging and/-or forest fragmentation have a higher abundance of lianas and therefore a higher carbon stock.*
- *When fragmentation size increases the number of lianas decreases, in other words, when you have a small fragmentation patch you find a higher abundance of lianas, with a large fragmentation patch there will be a lower amount of lianas.*
- *In previously logged forest the amount of lianas is higher than in unlogged forest.*
- Species composition is higher in unlogged primary forest and will decrease when area size decreases or disturbance increases.

2. Methodology

2.1 Study area

The study area concerns 14 sites in lowland dipterocarp forest on Sabah, Malaysia. These sites were selected for the reason that previous research was conducted within the SEnSOR programme on the same locations. Therefore, previously collected data can be used in this research and data gathered in this study can contribute to subsequent studies.

2.1.1 General information:

The 14 sites are situated in three different forest types: Continuous Forest (CF), Virgin Jungle Reserves (VJR) and High Conservation Value (HCV) areas on palm oil plantations of Wilmar International Limited, see figure 1 for an overview. The two sites in the continuous forest are situated in Malua Forest Reserve (Malua A – Near SBE and Malua B - Gate) whereas the other 12 sites are located in forest fragments (High Conservation Value and Virgin Jungle Reserve), see Table 1.

Table 1: overview of the 14 sites

Site	Area (ha)	Location
High Conservation Value areas		
1. Jatu	12	Rekahalus plantation
2. Meranti	30	Rekahalus plantation
3. Yong Peng	57	Sabahmas plantation
4. Rekasar	85	Rekahalus plantation
5. Sabasar	88	Sabahmas plantation
6. Water Catchment	120	Rekahalus plantation
Virgin Jungle Reserves		
7. Sapi A	45	Sapi Plantation
8. Keruak	220	Sukau
9. Materis	250	Kota Kinabatangan
10. Sapi C	500	Sapi Plantation
11. Ulu Sapa Payau	720	Telupid
12. Lungmanis	3.529	Beluran
Continuous forest		
13. Malua A	∞	Malua Forest Reserve
14. Malua B	∞	Malua Forest Reserve

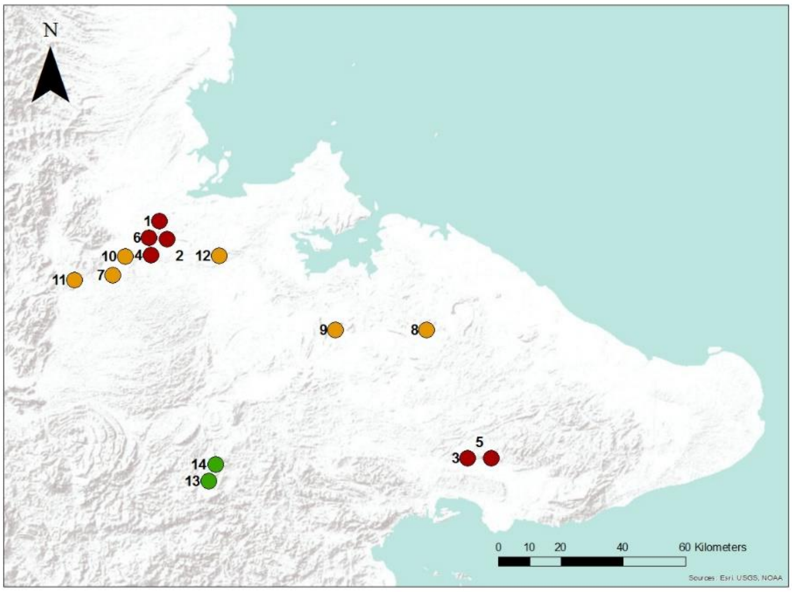

Figure 1: Map including the 14 study sites

The first division concerning the sites is the area size. The smallest forest fragments (12 – 120 hectare) are located on the palm oil plantations except for Sapi A Virgin Jungle Reserve with an acreage of 45 hectares. The remaining virgin jungle reserves have an acreage of 220 to 3.529 hectare of which Lungmanis Virgin Jungle Reserve is much larger than the other virgin jungle reserves. The Malua Forest Reserve covers an area of 33.969 hectares but with its surrounding forest it is perceived as continuous forest.

The second variance is that the Malua Forest Reserve and the high conservation areas were previously logged while the other six virgin jungle reserves are classified as unlogged forest. Additionally, there were two other unlogged sites planned in Danum Valley Conservation Area in order to be able to parallel the unlogged sites with the logged sites. Unfortunately, due to lack of authorization, it was not possible to measure the Danum Valley Conservation sites.

In the 14 sites, a total of 46 plots were measured. In the smallest forest fragments a minimum of two plots was measured (Jatu and Meranti) and up to five plots for the larger forest fragments or continuous forest (Lungmanis Virgin Jungle Reserve, Malua- A and B). Further plot details including ID-plot, site, location, area size, and GPS points are presented in Appendix 1.

2.1.2 Geographical information

Sabah is the second largest state in Malaysia after Sarawak, with which Sabah shares its borders on the south-west region. Sabah is located in the northern part of the Borneo Island between the latitudes of 4º to 7º north of the equator and longitudes of 115º to 120º east (Goh & Lee, 2010). Sabah covers a land area of approximately 73.600 km² which is about 10% of Borneo (amazingsabahborneotravel, n.d.; Marsh & Greer, 1992)). The western part of Sabah is mountainous, containing the three highest mountains in Malaysia. The most prominent range is the Crocker Range which houses several mountains of varying height from about 1.000 meters to 4.000 meters (GosuBlogger, 2008). With 4.095 metres, Mount Kinabalu is the highest mountain in Malaysia (WN Network, 2016). The lower ranges of hills extending towards the western coasts, southern plains, and the interior or central part of Sabah. These mountains and hills are traversed by an extensive network of river valleys and are in most cases covered with dense rainforest (Sabah State Government, 2016; GosuBlogger, 2008). The central and eastern portion of Sabah are lower mountain ranges and plains with occasional hills. Kinabatangan River begins from the western ranges and snakes its way through the central region towards the east coast out into the Sulu Sea (GosuBlogger, 2008).

Climate:

The climate on Sabah is considered as equatorial, which means that temperature is never extremely hot, neither does it gets extremely cold. Sabah has two seasons: the wetter season running from October to February and the drier season from February to August (Sabah State Government, 2016). The distinction between seasons is not very obvious because the weather patterns and rainfall levels are unpredictable (Selective Asia Ltd, 2010). Rainfall in southern Sabah is lower than in the north, and falls quite evenly throughout the year, with a decrease in millimetres between February and April. Sabah receives about 2.500 to 3.500 mm of rainfall annually. However, some localities obtained much lower or above this range due to influenced of coastal and in shadowed to large land-mass or mountain ranges (CAIMS, 2005g). The estimated temperature on Sabah is 32°C for lowland areas and an average of 21°C for Highlands area (Sabah State Government, 2016).

Soils:

The soils of Sabah are for 90 % covered with four different soil groups (CAIMS, 2005c; Fox, 1972):

- Lithosols, red/yellow latosols and podsolics: 41 %.
- Red/yellow latosols and podsolics: 36 %
- Active riverain alluvial and organic soils: 9 %.
- Lithosols and red/brown ferralsols: 4 %

The first group includes soils derived from sedimentary sandstones and shales (much of the Crocker Range under shifting cultivation and other steepland areas) and also soils on steeplands derived from volcanic ash and conglomerate (large areas north of Tawau and east of Lahad Datu) (CAIMS, 2005c; Fox, 1972).

The second group includes much of northeastern Sabah, including land between the Kinabatangan and Segama Rivers. Dipterocarp forests in the Kinabatangan/Segama area are found on ferric and orthic Acrisols and Luvisols. They developed on low mudstone and sandstone hills in undulating areas; on gleyic Acrisols and luvisols on mudstone or alluvium in low-lying areas; and on orthic acrisols, dystic cambisols tending to lithosols on sandstone hills (Fox, 1972). Because ferric and orthic Acrisols and Luvisols are mainly equivalent to red/yellow podsolic soils, they are put in the same group.
Lithosols are skeletal soils developed on harsh terrain covering the range of parent materials, with high stone profiles and poor zonation. Red/brown ferrasols are deep soils of stable structure on the olivine basalts and ultrabasic rocks.

As active riverain alluvial and organic coils only distinguish four zones: meander belt, flood plain, backswamps and peat swamps, which are not, or in very small amounts present in our plots, they are left out of the further detailed description.

2.1.3 Forest types

The forests of Sabah can be categorised in seven different forest classifications, see Table 2. As already mentioned before the sites used in this study are located in three different forest types: High Conservation Value Areas (HCV), Virgin Jungle Reserves (VJR, class VI) and the continuous forest in Malua Forest Reserve (CF, class II). In this study lowland and hill dipterocarp forests, the most extensive vegetation type in Sabah (Fox, 1972; Newbery, Campbell, Proctor, & Still, 1996), were examined. The High Conservation Value areas, Virgin Jungle Reserves and Continuous Forests are elaborated below.

Table 2: Classification of forest reserves in Sabah

Class	Forest Reserve	Area (ha)	Function
Class I	Protection	773.706	Environmental protection and biodiversity conservation
Class II	Commercial	2.241.501	Extraction of timber and non-timber products (e.g. rattan, damar, etc.) contributing to state's economy
Class III	Domestic	6.919	Small-scale harvesting of timber and non-timber products for the consumption of local communities
Class IV	Amenity	15.725	Provision of amenity and recreational uses for local communities
Class V	Mangrove	331.620	Environmental protection and biodiversity conservation
Class VI	Virgin Jungle	102.043	Research, education and training purposes
Class VII	Wildlife	137.735	Protection and conservation of wildlife
Total		3.609.249	

High Conservation Value Area:

The 6 HCV areas were located in previously logged forest fragments on the Rekahalus and Sabahmas plantations which are under the supervision of PPB Oil Palms Berhad, a subsidiary of Wilmar International Limited (Yeong et al., 2016). The forest fragments from both Rekahalus and Sabahmas were previously state-owned logging concessions in the past. Rekahalus contains 4 forest fragments (numbers 1,2,4 and 6 in Table 1) of which the last logging activities took place in 1985 (Awang Ali et al., 2011; Yeong et al., 2016). On Sabahmas there are two HCV areas present (number 3 and 5 in Table 1), these were last logged in 1991 (Awang Ali et al., 2011; Yeong et al., 2016). After the logging activities, most of the areas were transformed to plantations.

The HCV areas on Rekahalus cover only 10% of the total 5.352 hectares of this 10 % only 3% remains natural forest fragment while 7% is unplantable (Yeong et al., 2016). One of the four forest fragment is now dedicated as a water catchment. The remaining three sites are located on steep slopes (40-45%). The forest fragments were appointed as HCV areas in 1995.

The Sabahmas plantation covers 10.447 hectares. The original vegetation in the plantation area was a natural forest of which by 1995 already 20% was converted to plantation. Nowadays, the remaining 40% of forest patches within Sabahmas is a natural forest. These 40% includes; unplantable areas (33.5%), the Rainbow Ridge HCV (5%) and natural forest fragments (1.5%). The two sites measured for this study were on the steeper and top riches (unplantable areas).

Virgin Jungle Reserve:

Of all forests on Sabah, 9.5% of the total forested area is Virgin Jungle Reserves, or Protection Forest Reserves, which are conserved for environmental protection and biodiversity conservation and therefore protected by law (CAIMS, 2005a). VJR are preserved for research education and training purposes. Although timber extraction is prohibited, it is still probable that small-scale logging still takes place illegally. In this research 6 Virgin Jungle Reserves were measured.

Two VJRs were located within the former Sungai Sapi Forest Reserve. Sq. Sapi was first gazetted in 1958 but received in 1984 the status of Virgin Jungle Reserve (CAIMS, 2005b). Both fragments Sapi A (45 ha) as Sapi C (500 ha) are located about 30 kilometre northeast of Telupid town and are 4 kilometres separated from each other. The fragments are currently used as a source of dipterocarp seeds and seedlings.

Another two Virgin Jungle Reserves, Keruak and Materis, were located adjacent to the Kinabatangan River. Materis (250 ha) was gazetted as a forest reserve in 1930, yet over time the forest reserve was reclassified multiple times (1935, 1947 and 1956) before gazetted in 1984 as class VI Virgin Jungle Reserve (CAIMS, 2005c). Through all the reclassifications Materis is still recovering from past timber harvesting (CAIMS, 2005c). Keruak (220 ha) was gazetted in 1984 as VJR (CAIMS, 2005d). The Reserve was also reclassified multiple times in the past. The current use of Keruak is providing edible bird's nest (swiftlets) and wood to the local communities. The local communities use this wood to build houses and boats.

The last two larger reserves are the Ulu Sapa Payau VJR (720 ha) and Lungmanis VJR (3529 ha). Ulu Sapa Payau was gazetted as VJR in 1984 (CAIMS, 2005e). Ulu Sapa Payau is used by The Forest Research Centre for a study on silvics of indigenous species such as individuals of Palaquium rostratum (Nyatoh sidan), Cratoxylum formosum (geronggang biabas), and Dyera costulata (jelutong bukit) (CAIMS, 2005e). They are regularly observed for the purpose of seed collecting and planting trails. The largest of all VJRs, Lungmanis, was gazetted 1984 (CAIMS, 2005f). The VJR is made up of five blocks, in this study, only Lungmanis 45A and Lungmanis 33A combined one block, were used for the measurements. The VJR is actively used by mostly the Forest Research Centre as a research facility for tree improvement, growth and yield studies, agroforestry and plantation trials (CAIMS, 2005f).

Continuous Forest:

Two study sites were located in the continuous forests of the Malua Forest Reserves. The Malua Forest Reserve covers 340 km^2, but with the surrounding forest it covers approximately 8000 km^2 and is perceived as continuous forest. Through its size there an influence of edge effects does not occur and is therefore chosen as a baseline data for carbon stock in logged forest.

The Malua Forest Reserve has previously been used as a commercial logging forest. The last two logging operations were in 1980 and 2005-2006. The first operation was a selective logging (DBH ≥60cm) and the second operation was a Reduced Impact Logging (RIL), leaving only small disturbances to forest ecology (Reynolds, Payne, Sinun, Mosigil, & Walsh, 2011). The Reserve received its protection status in 2013.

2.2 Data collection

2.2.1 General

In this study, multiple steps were taken in order to determine the carbon stock of lianas. For two moths a forest inventory was completed in which liana DBH was measured. Besides the DBH also the Point Of Measurement (POM) was noted. Every plot had a new field form on which each DBH measurement and POM was written down. An illustration field form can be found in Appendix 2. This data was later on analysed and used to calculate the present biomass of lianas. Finally, the carbon content is determined by use of conversion factors. A more detailed description of all the steps is followed.

2.2.2 Plot design

All 46 plots were located at least 100 meters from the edge of the forest fragment to prevent the vegetation from being under the influence of any edge effect. The plots were all located on a track of maximum 1 kilometre, where all plots were at least 200 meters separated from each other on this track. Each plot has its own unique ID code, the first part of the code refers to the site, the second part relates to the station on that site. For example, J3 refers to Jatu (J) and the third station (3), MA4 refers to Malua – A and the fourth station.

In general, all liana DBH measurements were done in 20 by 50 meter (0.1 ha) plots. However, due to canopy gaps, dense vegetation and steep slopes, it was not always possible to set up such a large plot. Whenever it was not feasible to set up the 20 by 50-meter plot, a 20 by 20-meter plot was used.
The 20 x 50-meter plots were divided into two subplots, see figure 2.

- In subplot A (30 x 20m) all lianas and climbing palms with a DBH ≥ 1 cm will be measured.
- Subplot B consists of two 10x 20m subplots located on both sides of the plot. In this subplot, all liana and climbing palms with a DBH ≥ 1m will be measured. All lianas will be identified, for climbing palms, this will be done as far as possible.

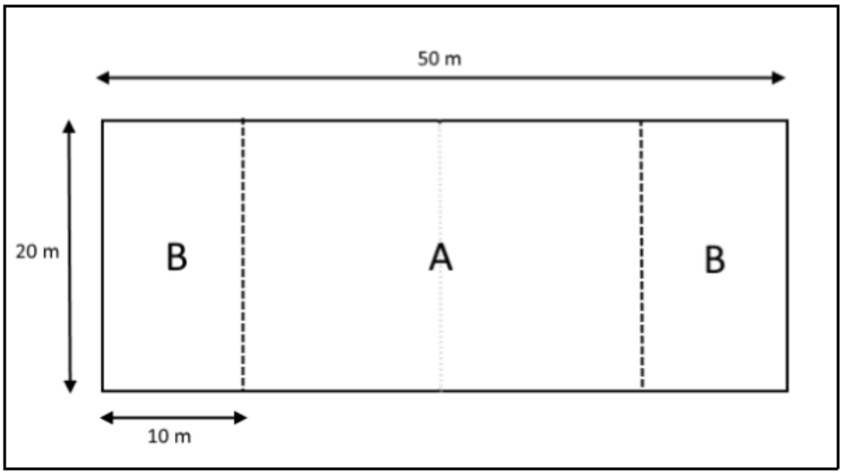

Figure 2: Measurement plot design

In the case of the 20 x 20-meter plot all lianas were measured and identified in the same way as in the B subplots.

2.2.3 DBH measurements

When measuring lianas decreasing the minimum diameter measurements from 2 cm down to 1 cm may result in substantial increases in both liana abundance and diversity (Jeffrey J. Gerwing et al., 2006). For example, in wet and dry evergreen forests in India, measured species richness increased by 12 to 29 percent and stem density increased by 22 to 71 percent when the cut-off was 1 cm instead of 2 cm, (Parthasarathy, Muthuramkumar & Sridhar Reddy, 2004). Similarly, in a forest in Ecuador, measured species richness increased by 22 percent and stem density increased by 31 percent (65–150 stems/ha), when 1–2 cm stems were included (Burnham, 2002). Therefore, in this research, there was chosen to measure all lianas ≥ 1.0 cm in DBH.

As lianas move and curl along the bottom, twine around trees and do not grow straight up as most trees do, a protocol by Gerwing and colleagues, (2006) and Schnitzer and colleagues, (2008) on how to measure the DBH is followed to ensure a consistent way of measuring. A detailed description of this method is presented in Appendix 3.

A couple of considerations in addition to the protocol:
1: Only lianas with their last rooting point inside of the plot is measured.
2: When a portion of the liana is horizontal or the liana roots multiple times, the rooting point is the last substantial rooting point before the stem ascends
3: Anomalies (e.g., bulges, nodes, damage, or stem splitting) are measured 5 cm below stem anomalies.
4: Lianas measured on a slope or uneven terrain, they are measured from the uphill side of the stem.

2.2.4 Species identification

Each liana that was measured in subplot B has been identified. Lianas of which leaves and bark were obtainable were coded with “ls” followed by its original number (in order of collection). Lianas where only bark was available has been numbered with “lsuk”. For example, ls03 refers to liana species number 3 of which leaves and bark were gathered in the sample. A database was set up to store all the photos made during the field work. A field herbarium was established to collect and preserve all gathered samples. This herbarium together with a mobile version of this database was used in the field to compare gathered samples with newly measured liana. Whenever a species could not be matched with a previously collected sample (or the photos), a new sample would be collected. All samples were identified by a botanist in Danum Valley. A list of the gathered species is found in Appendix 4.

2.3 Data analysis

2.3.1 Determining biomass

Determining the volume of lianas will be done using the DBH measurements. The equation used for this calculation is the same as previously used by Addo-Fordjour and Rahmad (2013) on a similar research in Malaysia. The equation is as follows:

$$\text{Log}_{10}\text{ (total biomass)} = c + a(\log_{10}\text{DBH}) \qquad | \ R^2\text{(adjusted)} = 0.986$$

In this formula, the *a* and *c* are both coefficients, what means that they are a consistent factor. In most researches, these coefficients have different values. In figure 3 there is a table with different researches and the thereby different coefficients (Patrick Addo-Fordjour & Rahmad, 2013).

Equation	c	α
Gehring et al. [21]	−1.547	2.640
Gerwing and Farias [20]	0.147	2.184
Putz [29]	0.036	1.806
Hozumi et al.* [22]	−1.347	2.391
Beekman [30]	−1.459	2.566
Schnitzer et al. [3]	−1.484	2.657

Figure 3: Six previously published allometric equations used in comparing the current allometric equation by Addo-Fordjour and Rahmad (2013).

This formula, using only DBH, is chosen above other biomass calculating formulas as a non-destructive measuring method was chosen. Although a formula with both length and DBH would have been better, collecting length data would have been done through estimations, leaving significant errors in the data.

In this case, the coefficients used are the same as in the research from Addo-Fordjour and Rahmad (2013) in which the coefficients were: c = 0.490 $\pm$ 0.021 and a = 1.090 $\pm$ 0.027. Although also data on climbing bamboos and dead lianas was collected these measurements were left out of the biomass calculations.

2.3.2 Determining carbon stock

To determine the carbon stock of lianas, a carbon fraction rate is used. To convert Above Ground Biomass (AGB) to Carbon (C), AGB was multiplied by the %C content of the component in question. In previous studies fraction rates were between 46% and 47.35% (Van der Heijden, Powers, & Schnitzer, 2015; Durán, Gianoli, & Dura, 2013; Donato, 2012). Mean carbon content was assumed to be for trees, palms and lianas (including roots) 47% for palms in a wet forest in Mexico (R. F Hughes, Kauffman, & Jaramillo, 1999).

For this research, a fraction rate off 47.35% by Van der Heijden, Powers, and Schnitzer (2015) is used to determine how much carbon is stored in lianas.

2.3.4 Statistical analysis

Statistical analyses were executed with IBM SPSS Statistics 23 to prove whether correlations could be found between carbon stock, species composition, logging and level of fragmentation. Data was analysed used the Linear regression analysis tool. In each test the R squared change and descriptive test are run all using a confidence interval of 95%. Additionally, the Durbin-Watson and collinearity diagnostics test are run to test for auto-correlation. In Excel 2013 further data analysis was done through t-tests (t-Test: Two-Sample Assuming Equal Variances) and ANOVA tests (ANOVA: Single Factor).

3. Results

The data was collected during roughly two months, from the 4th of June to the 30th of July 2016. In these two months, 14 sites were visited, 46 plots (19 plots of 20 by 20 meter and 27 plots of 50 by 50 meter) were measured covering 3.46 hectare. In total 1.919 lianas were measured of which 915 were identified. 85 liana species were found belonging to 20 different families. All plots results including; number of liana species (N-species), number of lianas per hectare (N-lianas/ha), liana biomass per hectare and liana carbon per hectare are presented in Appendix 5.

3.1 Forest analysis

3.1.1 Forest inventory

Table 3 shows the data collected from the 14 sites. An average value per forest type is added to compare the data between each forest type. To calculate the liana abundance, N/ha, the number of measured lianas per plot was divided by the plot size, which makes it comparable with other plots.

On the location of the Water Catchment intensive climber cutting management had been applied. Beforehand, five plots were intended to be measured. Unfortunately, this had to be reduced to two plots because the forest was overgrown with climbing bamboos and dense vegetation which made the forest inaccessible. Practically all present lianas were cut and dead, making the site unsuitable to compare gathered data with. An inventory was still made for the dead biomass but is left out of all further analysis. The average shown below the HCV does therefore not contain the value of the Water Catchment. When looking at the table the average number of lianas per hectare in the Water Catchment are much higher, 1.788 lianas per hectare, than the other sites. Also, the canopy height and the average DBH is lower than those of other sites.

In table 3 there is a difference visible in average numbers of lianas per hectare (N/ha). The HCV areas (N/ha: 629) contain at least 64 lianas per hectare more than the VJR (N/ha: 565) and 96 lianas per hectare more than the CF (N/ha: 533). However, there is only a relatively small difference observable of 32 lianas per hectare when the VJR are compared with the CF. The opposite occurs when looking at the number of species (N-species). The Continuous forest contains an average higher number of species (30) than the VJRs (23,7). In the HCV areas, the average number of liana species is twice as low as in the CF, 30 species to 15 species.

When looking at the DBH, there are almost no differences between the three forest types. Remarkable, though, is that the average DBH of the VJRs (3,5 cm) are bigger than the averages of the DBH from the HCV (3,4) and CF (3,3), which are basically the same. Taken only the 25 highest DBH measurements most of these measurements were recorded in the VJRs (N:12, Avg_DBH: 14,7) followed by the HCV (N:7, Avg_DBH: 13.4) and the CF (N:6, Avg_DBH: 14,2). Nevertheless, in all of the three forest types large lianas were present. The 25 highest DBH measurements are shown in Appendix 6.

Due to the fact that the plots located in the HCV areas were on unplantable regions with an average slope of 39%, they are found in the roughest terrain. The VJR sites (Avg. slope 17%) are found in locations with only half of the gradient, while the CF is in between both (Avg. slope 28%).

Table 3 Liana inventory overview of the 12 unlogged and logged forest fragments and 2 continuous forest sites

Sites	Area (ha)	Plots	Logged	Average Number of liana/ha	Average liana DBH (cm)	Average tree height (m)	Slope (%)	N-liana species
High Conservation Value Areas								
Jatu	12	2	Yes	825	4,0	8,7	45	21
Meranti	30	2	Yes	300	3,3	8,2	44	16
Yeong Peng	57	3	Yes	608	2,7	11	20	23
Rekasar	85	3	Yes	1.015	3,3	8,9	44	9
Sabasar	88	3	Yes	397	3,5	8,4	40	6
Water Catchment	120	2	Yes	1.788	2,2	6,3	14	0
Average	**65**	**2,5**	**-**	**629**	**3,4**	**9**	**39**	**15**
Virgin Jungle Reserves								
Sapi A	45	2	No	750	2,5	7,2	34	21
Keruak	220	3	No	493	3,8	11,6	18	20
Materis	250	3	No	617	4,3	11,3	6	21
Sapi C	500	4	No	338	3,6	11,3	11	20
Ulu Sapa Payau	720	4	No	471	3,0	8,9	11	28
Lungmanis	3.529	5	No	721	4,0	8,5	24	32
Average	**877**	**3,5**	**-**	**565**	**3,5**	**9,8**	**17**	**23,7**
Continuous forest								
Malua A	∞	5	Yes	481	3,6	14,7	32	26
Malua B	∞	5	Yes	584	3,0	13,8	24	34
Average	∞	**5**	**-**	**533**	**3,3**	**14,2**	**28**	**30,0**

3.1.2 Biomass and carbon stock calculations

DBH measurements are used to calculate the biomass using the formula Log^{10} (total biomass) = 0,490 + 1,090 (log^{10}DBH). In order to convert biomass into carbon stock, the biomass was multiplied by 0,4735 which is the carbon content in lianas. As mentioned above in 3.1.1 Forest inventory the Water Catchment was left out of further analysis because of intensive climber cutting management. The same has been done for the biomass and carbon analysis. Because, some data was collected in the Water Catchment, a calculation from these findings was made and included in Table 4. Nevertheless, these calculations were not included in the averages because the data is incomparable with the data from the other sites.

The highest average biomass was found in the VJRs with an average of 7.580,20 Kg/ha. This is a fraction higher than the biomass of the HCVs (7.467,02 Kg/ha) but considerably higher than the biomass of the CF (6.275,05 kg/ha). However, the highest biomass per site was found in Jatu with 12.062,18 Kg/ha, while the lowest biomass was found in Meranti, 3.498,41 Kg/ha. Since biomass is directly connected with the carbon stock (47,35%), differences are the same for carbon content as they were for biomass. The only difference is that the carbon values are almost half of the biomass values.

Table 4 Average liana biomass and liana carbon stock for the 16 study sites.

	Liana biomass (Kg/ha)	Liana carbon (Kg/C/ha)
High Conservation Areas		
Jatu	12.062,2	5.711,4
Meranti	3.498,4	1.656,5
Yeong Peng	5.200,8	2.462,6
Rekasar	5.568,4	2.636,6
Sabasar	11.005,3	5.211,1
Water Catchment	16.177,9	7.660,3
Average	**7.467**	**3.535,6**
Virgin Jungle Reserves		
Sapi A	6.861,9	3.249,1
Keruak	8.026,2	3.800,4
Materis	9.748,2	4.615,8
Sapi C	4.413,9	2.089,9
Ulu Sapa Payau	5.249,9	2.485,8
Lungmanis	11.181,2	5.294,3
Average	**7.580,2**	**3.589,2**
Continuous forest		
Malua A	6.119,4	2.897,5
Malua B	6.430,7	3.044,9
Average	**6.275,1**	**2.971,2**

3.2 Fragmentation size and logging impact on carbon stock

Results from calculated carbon stocks per plot, shown in Appendix 5, were analysed for correlations. With IBM SPSS Statistics linear regression analyses were conducted in order to find any statistic significant relation. In the data analysis no data was transformed, neither was any other data measurements left out of these regressions except for the Water Catchment.

First, an analysis was done to examine if there is a relation between fragment size, logging and carbon stock. Figure 4 shows a scatterplot with two trendlines representing 10,60% (unlogged) and 5,2 % (logged) of the data. The unlogged forest line (blue) shows that the carbon stock (y-axis) increases when the forest fragments size (x-axis) increases. The line for logged forest (red) shows the opposite, the carbon stock decreases when forest fragment size increases. With the linear regression analysis no significant relation between forest fragment size and carbon stock is shown (R^2 = 0,017, P = 0,40). Also no correlation could be found between logging and carbon stock (R^2 = 0,001, p = 0,838). The linear regression analysis results are shown in Appendix 7.

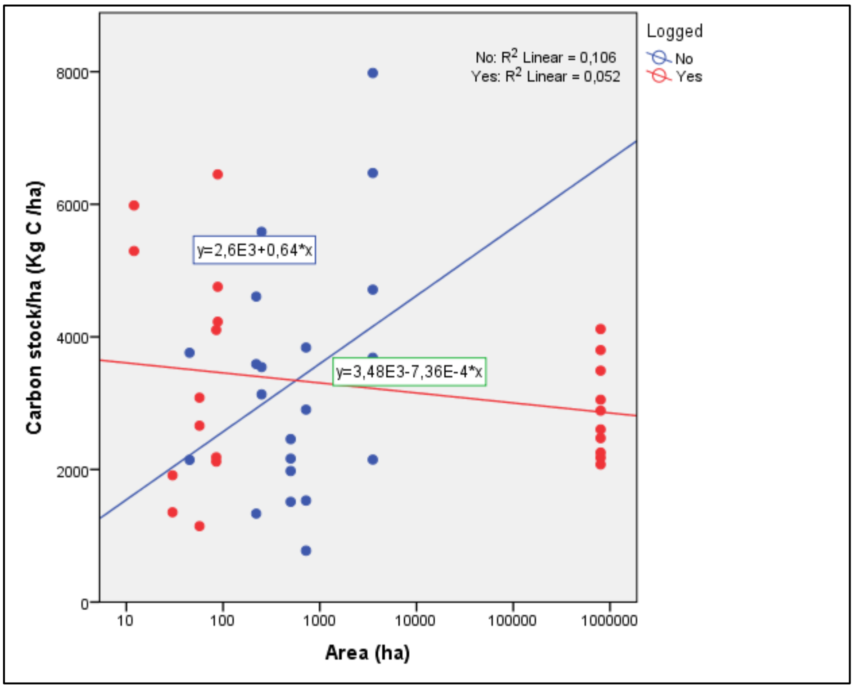

Figure 4 Scatterplot showing two regression lines for liana carbon stocks in both logged (red) and unlogged (blue) forest fragments of various sizes.

3.2.1 Logging impacts

Because no significant correlation between forest fragment size and logging was found using the linear regression analysis (Appendix 7b), further analysis was done using Excel t-Test and Excel ANOVA tests. By using these tests, the only independent factor is logging, which can now be analysed separately. For these test, site Jatu 1 (J1) and the Water Catchment were left out of the analysis, all other plots were included. J1 has been left out because the logging history of this plot was uncertain. The plot was located on a steep slope and no logging evidence was detectable as large trees were still present.

With Excel t-Test, the differences between logged and unlogged forest were analysed. The t-Test showed a p-value of 0,838, what illustrates that there is no significant difference between logged and unlogged plots (see Appendix 7B for t-Test results).

As previously been done by Yeong, (2016) the forest was not categorised by logged or unlogged forest, but by forest class; HCV, VJR and CF disregarding the forest fragment size. It is now possible to do a single factor ANOVA test on the three selected groups. First, a p-value of 0,675 indicated no significance between all three of the forest types. In Table 5 individual ANOVA tests show no significance was found for any of the three forest types. Full test results are found in Appendix 7B.

Table 5: Single factor ANOVA results, showing p-values for correlations between liana carbon stocks and logging history.

	HCV - VJR	**VJR - CF**	**HCV - CF**
P - value	0,806	0,472	0,335

3.2.2 Fragmentation impacts

In this part, the logging history is left out of the analysis as the focus is on fragmentation effects. Analysis of relations between fragments size and liana carbon stock is done with SPSS linear regression analysis. In this analysis all plots were included, except the Water Catchment.

Unfortunately, the linear regression presented a p-value of 0.40; no significance could be found. The R-squared value was 0.017, meaning that 1.7% of the data could be confirmed following this linear formula (figure 5). The line shows a downward trend, or negative correlation, between carbon stock and fragment size (area). What means that when fragment size increases the liana carbon stock would decrease. While the formula shows this trend, this cannot be guaranteed since there is no significance found in any of the tests. The full test results are given in Appendix 7C.

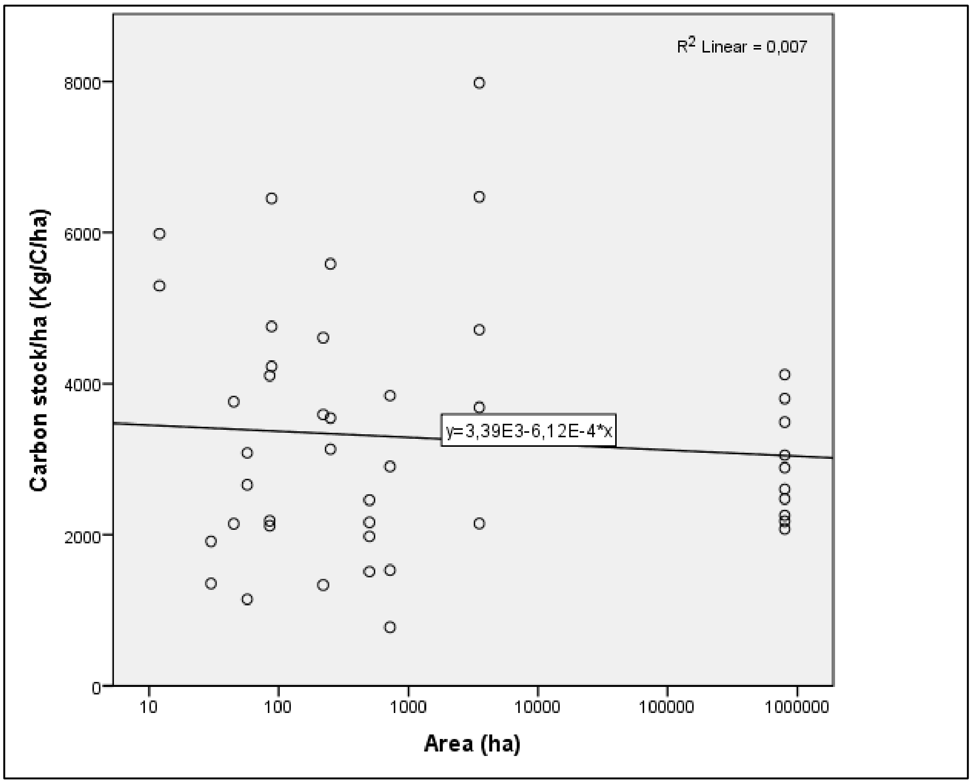

Figure 5: Linear regression displaying the correlation between forest fragment size and liana carbon stock

3.3 Fragmentation and logging effects on liana abundance and species richness

In total 1.919 lianas were measured in 46 plots, 915 lianas were identified by a botanist in The Danum Valley Field Centre. 85 different liana species were found of which 74 could be identified to family names, genus or even species level. The remaining 11 species were numbered Unknown 1 to 11, see Appendix 4 for the entire species list. In total, 51 species were found in the HCV areas, 66 species in the VJR and 39 in the CF. This should not be confused with the average number of species shown in Table 1. Table 1 displays the average number of liana species found per site instead of the total number of liana species per forest type.

With the SPSS linear regression tool is examined whether a significant difference can be found between the HCV, VJR and CF in relation to liana abundance and species composition. Furthermore, the same comparison is made between logged and unlogged forest, analysed with Excel t-Tests and the three forest types which were analysed with Excel ANOVA tests.

The 11 most commonly found liana species are shown in Table 7. Because all lianas are measured in 0,04-hectare plots, it was possible to calculate the average number of lianas per hectare. It needs to be noted that only the lianas in subplot B were identified. All 1004 lianas measured in subplot A, including the 143 lianas measured in the Water Catchment, were never identified. These records are therefore not added to the number of identified liana species.

With 59 measurements liana species *Unknown 2* was the most abundant species. Species *Unknown 2* also has the highest average number of lianas per hectare. While *Spatholobus sp. 6 Fabaceaea* is the second most abundant species, the average number of lianas for *Spatholobus sp. 6 Fabaceaea* per hectare is only 75. This can be clarified as *Spatholobus sp. 6 Fabaceaea* is present in 14 different plots.

Table 5: Top 11 common liana species of the inventory

ID-Species	Number of lianas measured	Number of plots	Average DBH (cm)	Average number of liana per hectare
Unknown 2**	59	11	3,3	134
Spatholobus sp. 6 Fabaceae	42	14	3,4	75
Uncaria sp. 4 Rubiaceae	41	9	3,4	114
Artabotrys sp. 1 Annonaceae	40	17	3,0	59
Uncaria sp. 6 Rubiaceae	34	9	4,6	94
Bauhinia sp. 1 Fabaceae	33	9	3,1	92
Spatholobus sp. 7 Fabaceae	32	9	3,1	89
Uvaria sp. 7 Annonaceae	28	7	3,4	100
Sphenodesme sp. 1 Lamiaceae	27	9	3,5	75
Strychnos sp. 2 Loginiaceae	26	7	3,1	93
Uncaria sp. 13 Rubiaceae	26	5	3,1	130

** 11 species were unable to identify and numbered Unknown 1 to Unknown 11. This is species Unknown 2, which is recognised to be a different species than the other 10 unknown species.

3.3.1 Effects of fragment size and logging on species richness

With SPSS is examined whether relations could be found between logging, fragment size and number of species. In this analysis, the Water Catchment was left out because it did not contain representative vegetation when compared with vegetation of other sites. In the beginning the research was still in the earliest developing stage, therefore, results found in SB3, YP2 and YP6 cannot considered comparable and representable for further analysis. All plots that were left out are SB3, YP2, YP6, WC1, and WC3.

In total 85 liana species were found belonging to 20 different families. For 74 species at least the family name was known, the remaining 11 species are numbered as unknown species. The 3 most common species are Facabeae (223), Rubiaceae (183) and Annonaceae (168). A species distribution table including the number of lianas for each liana species is included in Appendix 8A. Also included is a distribution table for the three different forest types (Appendix 8B)

The results of the SPSS linear regression analysis show no relations between the number of liana species and the area size (R^2 = 0,012, p-value = 0,499). Full results are in Appendix 9. The trendline presented in figure 6 represents 0.4% of the data which is very low. The line indicates that there is an increase in liana species when forest fragment (area) size increase. Unfortunately, this is not statistically proven.

Additionally, Excel ANOVA and t-Tests were run in which the data was distributed into the three forest types. Still no significant difference was found, see Appendix 9 for the test results.

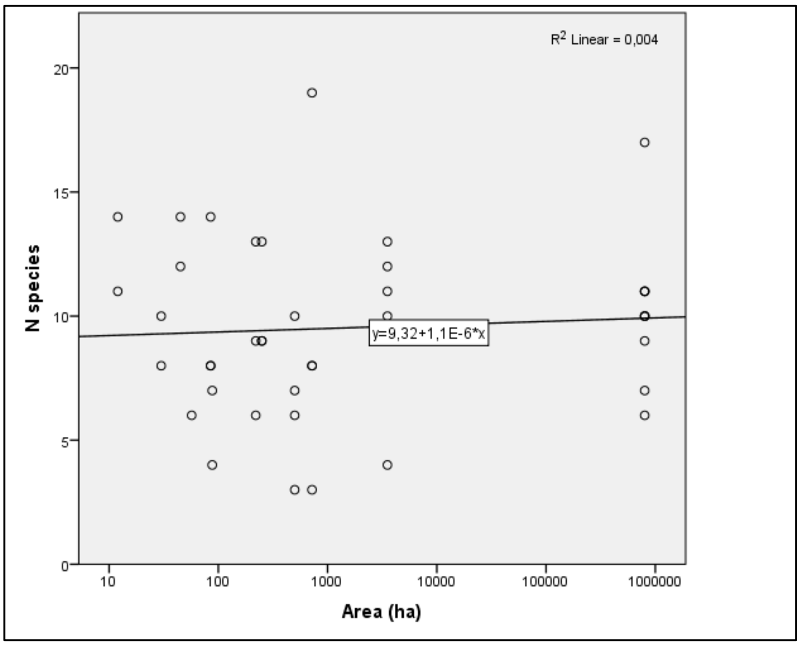

Figure 6: Linear regression displaying the correlation between forest fragment size and liana species richness (N species)

3.3.2 Liana abundance

The same analysing method is used to find relations between fragments size, logging and liana abundance. For this analysis, only the plots of the Water Catchment (W1 and W3) have been excluded.

The SPSS linear statistical analyse has shown that no correlation could be found, $R^2 = 0.007$, p-value = 0.5911. Even when the data is analysed with Excel ANOVA test no significance could be found. The complete analyse results from SPSS and Excel can be found in Appendix 10.

A negative trendline comparing the number of lianas with the area size is found with SPSS, see figure 7. This suggest that when forest fragment size increases the number of lianas decrease. Nevertheless, this line represents 0,9% of the data which is very low to draw any conclusions on.

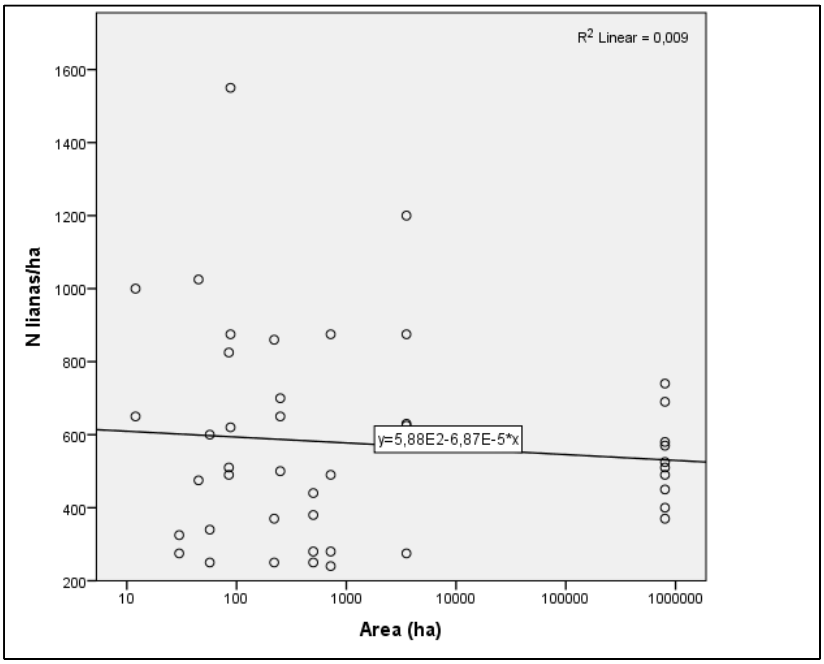

Figure 7: Linear regression displaying the correlation between forest fragment size and liana abundance (N lianas/ha)

4. Discussion

The effects of logging and forest fragmentation on liana carbon stock observed among three forest types indicates that there are no significant difference measurable between liana carbon stock from small forest fragments to large continuous forest. Neither does it indicate a significant difference in liana abundance or species composition.

In this research 19 plots of 20 by 20 meter and 27 plots of 50 by 50 meter were measured covering a total of 3,46 hectare. The sites were preselected from previous studies, comprising 6 High Conservation Value areas, 6 Virgin Jungle Reserves and 2 Continuous Forest sites. 1.919 lianas were measured of which 915 were identified. 85 liana species of which 74 were identified up to family names were found. When total study size is compared with Addo-Fordjour, Rahmad, and Shahrul, (2016) (30 plots of 40 by 40 meters) and Lü, Tang, Feng, and Li, (2009) (3 plots of 1 hectare) the area covered in this research is similar, especially concerning the limited time spend in Malaysia. The procedure of using the protocol by Gerwing and colleagues, (2006) and Schnitzer and colleagues, (2008) is a standard protocol used in most researches for liana DBH measuring. Following this protocol the minimum measuring DBH was set at $\geq$ 1 cm to increase the precision of liana abundance and species composition.

Clark and colleagues, (2001) stated that in general carbon stock determinations done by measuring biomass increment over a longer time period through repeated measurements. Considering only two months of field work were possible in this research, no repeated measurements could be done. The absence of data on liana increment reduces the reliability of the data for the reason that biomass is now estimated instead of calculated. Nonetheless, the gathered data still represents the estimated present biomass.

4.1 Liana abundance:

The numbers of lianas per hectare in this study are relatively similar compared with other studies. In this study, an average of 629 liana stems per hectare in the High Conservation Areas, 565 liana stems per hectare for the Virgin Jungle Reserves and 533 liana stems per hectare in the Continuous Forest was found (Table 3). For instance, in Asian tropical forests, an average of 440 liana stems, with 1–10 cm DBH per hectare, were found on Sarawak by (Proctor, Anderson, Chai, & Vallack, 1983). Putz and Chai, (1987) found an average of 348 stems in Sarawak valleys and 164 ($\geq$ 2 cm DBH) in hilltop sites. In other tropical forest 2 471 liana stems ($\geq$ 2 cm DBH) per hectare were found in Bolivia by Perez-Salicrup and colleagues, (1998) and 606 ($\geq$ 2 cm DBH) in Panama (DeWalt & Chave, 2004).

However, most of those findings were measured from a DBH $\geq$ 2 cm while our measurements were done from a DBH $\geq$ 1 cm. As already mentioned in 2.2.3 DBH measurements decreasing the minimum DBH can lead to an increase in number of lianas. In wet and dry evergreen forests in India, measured species richness increased by 12 to 29 percent and stem density increased by 22 to 71 percent when the cut-off was 1 cm instead of 2 cm, (Parthasarathy et al., 2004). In a forest in Ecuador, measured species richness increased by 22 percent and stem density increased by 31 percent (65–150 stems/ha), when 1–2 cm stems were included (Burnham, 2002).

The supposition that liana abundance, diversity and biomass are substantially higher in disturbed areas, such as in treefall gaps, than in undisturbed closed-canopy forest by Dewalt, Schnitzer, and Denslow, (2000); Schnitzer and Bongers, (2002); Schnitzer and Carson, (2010) this is also visible in our results. Although there is a considerable variation between findings per site, a minimum number of 300 lianas per site for Meranti up to a maximum number of 1015 lianas per hectare for Rekasar. On average the higher numbers of lianas were in the disturbed HCV areas compared with those of the VJR.

The previously logged CF contains a lower number of lianas per hectare than the VJRs do. This might indicate that the CF was not as heavily disturbed by previous logging activities as the HCV areas or that the process of fragmentation plays a role in the number of species in the HCV areas. Unfortunately, this could not be proven according to the collected data in this study.

When the findings are compared with Alkema, (2016) who measured trees DBH $\geq$ 10 cm, lianas percentages are accountable for 25 to 73 % of all stems. The lowest percentages (25-36%) are mostly found in the plots of the Malua A and Malua B sites while the higher percentages (62- 73%) are found in VJRs. In between a mix of HCV and VJR is present. As these percentages only refer to lianas and trees with a DBH $\geq$ 10 cm they do not implicate for all forest stems. Therefore, a lot can change when trees with a DBH below 10 cm are included.

4.2 Liana biomass and carbon stock:

The exact contribution of liana biomass in most tropical forests is currently unknown (Lü et al., 2009; Schnitzer & Bongers, 2002). Our results showed an average liana biomass of 7.467 Kg/ha, contributing to 6,2% of the total biomass for HCV areas. The VJR contained 7.580 Kg/ha (4.1% of the total biomass) and the CF includes 6.275 Kg/ha (2,6% of the total biomass). Putz, (1983) estimated in a forest in Venezuela that lianas contributed for 15.700 kg/ha, 4,5% of the total aboveground biomass. While in eastern Brazilian forests, lianas contributed up to 14% of which the absolute sum was 43.000 kg/ha (Gerwing & Farias, 2000). In a central Panamanian lowland forest Dewalt and colleagues, (2000) concluded that the biomass of lianas was relatively constant with increased stand age, 4.050 to 11.170 kg/ha. Our result show a relatively low amount of biomass, but not significant lower as most other studies do. Besides the contribution of lianas to the total biomass is almost the same.

In this research the formula Log_{10} (total biomass) = c + a(log_{10}DBH) was used for biomass calculation. As both the coefficients as the formula differ per research, recalculations have been done to check how this influences the calculated biomass. In table 6 an overview is given of the different formulas and coefficients used including the resulted total biomass of all measurements. The biomass findings should not to be mistaken with the biomass shown in Table 3 as those are recalculated to biomass per hectare. Gehring and colleagues, (2004) and Gerwing and Farias, (2000) originally used the second formula while Lü and colleagues, (2009) and we used the first formula. The first row is the calculation used in this research, with a total biomass of 23.910,86 kg. Clearly visible is the large impact coefficients have on the biomass in the different formulas. An important difference between the formulas and coefficients is the influence of the DBH size. Looking at the calculations of Gerwing and Farias, (2000), the biomass value of large lianas is much higher compared with ours. While DBH size shows differences, the total biomass of our research is almost the same as that of Gehring et al., 2004.

Table 6: Result from biomass recalculations, using two different formulas and 4 different coefficients.

	Coefficients used*	**c**	**a**	**Biomass**
Log10 (total biomass) = c + a(log10DBH)	Own research	0,49	1,09	23910,86
	Lü et al.	0,1498	1,7895	32265,48
	Gehring et al.	-1,547	2,64	3269,24
	Gerwing and Farias	0,147	2,184	65222,56
Ln(total biomass) = c + a(Ln(DBH))	own coefficients	0,49	1,09	12629,89
	Lü et al.	0,1498	1,7895	26545,78
	Gehring et al	-1,547	2,64	24524,16
	Gerwing and Farias	0,147	2,184	53856,62

* The used coefficients are the same as shown in figure 3

The carbon content of lianas was determined at 47.35%, which was previously used by Van der Heijden, Powers, and Schnitzer (2015). This is between carbon contents used in similar research (46-50%) (Elias & Potvin, 2003; Hughes, Kauffman, & Jaramillo, 1999; Kirby & Potvin, 2007). Although this carbon content is used for all lianas, it needs to be taken into consideration that not all lianas have the same wood density.

Findings by Alkema, (2016) and Beaujon, (2016) show that total AGB, including liana biomass, is 7.483 tonne per hectare on the same sites as measured in this study. Three components are taken into the total biomass: lianas (304 T/ha), trees with a DBH ≥10 cm (6.806 T/ha) and litter (372 T/ha). Lianas contain an average 4% of the total biomass on the sites measured in this study. The highest liana content was found in Sabasar plot 3 where the total biomass consisted for 23% out of lianas. The lowest content of lianas was found in Keruak Virgin Jungle Reserve plot 6 with 0,7% of the total biomass.

The total carbon stock, including the findings from Alkema, (2016) and Beaujon, (2016), is 3524 tonne carbon per hectare. Lianas contain the same percentage of the total carbon stock as was found for biomass (4%). Because the carbon content does not differ much between trees, litter and liana (±47%) the same fluctuations can be found between carbon stock as were found for biomass. Plot 3 in Sabasar still contained the highest percentage of lianas (22,2%) while plot 6 in Keruak Virgin Jungle Reserve still has the lowest percentage (0,7%).

4.3 Species richness:

In this study, no significant difference can be found between disturbed (HCF and CF) forest and undisturbed (VJR) forests. A study conducted by Addo-Fordjour, Rahmad, and Shahrul, (2014) also showed that there was no significant difference in disturbed and undisturbed lowland tropical forest in Malaysia. This research was conducted in a forest 40 years after liana cutting management was applied. It is not clear whether the difference between the two studies is due to the difference in time span or the silvicultural treatments used. But Gerwing & Vidal, (2002) found in their research that liana species richness in an eastern Amazonian forest was lower in disturbed plots than in undisturbed plots. However, this research was conducted eight years after liana cutting was applied and not 40 years as in Addo-Fordjour, Rahmad, and Shahrul, (2014). Other research mention that silvicultural management shows significant differences in species richness, however, the abundance and distribution of lianas significantly depend on abiotic factors such as precipitation, altitude and soil fertility (Gentry, 1991; Schnitzer & Bongers, 2002).

New studies reveal that forest gaps formed through natural occurrences as well as anthropogenic forces increase liana richness substantially (Babweteera, Plumptre, & Obua, 2000; Schnitzer, Mascaro, & Carson, 1991). To illustrate, research by Dewalt and colleagues, (2000) reveals that liana abundance and diversity were significantly greater in young secondary forests, fluctuating from 20 to 40 years old than in older forests which were at least 70 years (Dewalt et al., 2000). Therefore, liana species composition can variate considerably between secondary and primary forests (Yuan, Liu, Tang, & Li, 2009). As this study showed no significant difference between logged and unlogged forest regarding species richness, the differences of abiotic factors per site might have been of influence on the results.

4.4 Limitations

The main limitation of this research was the time limit. Due to several circumstances, a field period of only two month was conducted. In the planning 10 plots were additionally sited in Danum Valley as a baseline for undisturbed continuous forest. Due to the absence of required permissions and limited time, we were forced to leave them out. Although all other measurements were finished nicely on time, a multiple year research with repeated measurements to calculate liana increment was preferred. More plots could have been measured on each site, representing a more reliable overview of the forest vegetation. For instance, we now have sites of 3.500 hectares or more in which five plots are measured representing the entire area.

Despite the status of originally unlogged virgin forest, evidence of timber extraction was found in some locations including Jatu 1. On the other hand, in forest states as logged no evidence of logging was found on the steep riches and slopes. The sites located on the Sabahmas plantation were located on the unplantable steeper areas with a higher elevation than most other sites which were protected forest patches without such steep slopes. With all these different local circumstances it might be questionable to compare these forests with each other. In this case, not only fragmentation or logging influence forest structure, but also site characteristics.

During the field work dense vegetation, steep slopes or canopy caps made it impossible to ensure a steady set-up of the plots. While the locations of the plots were previously determined, the set-up of the plot was not always consistent. The direction of the plot was based on what we found to be the best measurable and contained the most representative vegetation, instead of a constant direction disregarding vegetation density or own interpretation.

Regarding species identification nobody of us required the desirable knowledge and skills to identify liana species. Therefore, a field herbarium and mobile database were made. The collected samples would afterwards be identified by a botanist in Danum Valley. Still, because of large similarities between liana species as well as dissimilarities in the same species (age, growing- location and condition), a large overlap in the collected data might be present. Also, originally was planned to include liana regeneration in this study. The decision was made to exclude liana sapling measurements because no distinguish could be made between liana saplings and tree saplings in the field.

5. Conclusions

This study results reveal that no significant difference can be found between liana carbon stock of small forest fragments compared with liana carbon stock of larger forest fragment. Although a slight decrease is visible in liana biomass and carbon stock when fragment size increase, nothing could be proven with statistical analysis. Also, no significant difference could be found in liana carbon stock of logged or unlogged forest. Therefore, from data collected in this study can be concluded that both fragmentation size as logging has no significant effects on liana carbon stock.

The following step was analysing the effects of fragmentation size and logging on liana abundance. Also no significant difference was present in the data. Neither in the three forest types nor the logged and unlogged forest liana abundance showed any significant difference in liana abundance. However, a higher abundance is present in the HCV areas compared with the VJR and CF. Unfortunately, not enough data was collected to confirm a significant difference.

The last relation tested was if liana species richness is effected by fragmentation size or logging history. This data also shows no significant relation for species richness. The data does show the opposite as for liana abundance. Which indicates that liana species are more abundant in continuous forest compared with forest fragments. Especially the difference in HCV areas, 15 species, and the CF, 30 species, is considerable. Yet, the same accounts for liana abundance, no significant difference can be confirmed.

6. Recommendations

While no significant differences were found, this research shows some indications of effects on liana carbon stock, abundance or species richness by fragmentation size or logging history. However, to underline these trends more research needs be done. Additional data sampling would be valuable when the number of sites is expended. Additional fragment sizes should be included, covering the cap of fragments sizes between the largest fragments and the continuous forest that was present in this study. It is also recommendable to increase the number of plots per site. In this study 5 plots were indicating the vegetation of sites 700 to 40.000 hectare or more. When more plots are included, there is more data providing a better representation of the forest vegetation.

When forest fragment stated as logged are included, clear observations of the measured plot are required. As found during our field work it may be difficult to distinguish logged with unlogged forest if no clear evidence is present. In order to prevent collecting unusable data it is important to carefully select the plot locations. As was not included in this study the impacts of edge-effects are not taken into consideration. This might be beneficial for additional studies.

Increasing the duration of the study is also recommendable. When using a multiple year study the increment of liana biomass can be investigated. More observation can be done and the data collected of increment can enhance carbon stock calculations.

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7. Appendices

Appendix 1: Plot details

ID-Plot	Site	Location	Station	Area (ha)	Logged	Coordinate	X	Y
J1	Jatu	Rekahalus Plantation	1	12	Yes	N5° 43.870' E117° 29.169'	553828	633510
J3	Jatu	Rekahalus Plantation	3	12	Yes	N5° 43.938' E117° 29.075'	553655	633635
KV1	Keruak Virgin Jungle Reserve	Sukau, Kinabatangan	1	220	No	N5° 30.665' E118° 17.106'	642355	609312
KV3	Keruak Virgin Jungle Reserve	Sukau, Kinabatangan	3	220	No	N5° 30.755' E118° 17.019'	642194	609478
KV6	Keruak Virgin Jungle Reserve	Sukau, Kinabatangan	6	220	No	N5° 30.838' E118° 16.953'	642071	609631
LV1	Lungmanis Virgin Jungle Reserve	Sandakan	1	3529	No	N5° 43.510' E117° 41.139'	575919	632869
LV3	Lungmanis Virgin Jungle Reserve	Sandakan	3	3529	No	N5° 43.577' E117° 41.098'	575844	632993
LV4	Lungmanis Virgin Jungle Reserve	Sandakan	4	3529	No	N5° 43.619' E117° 41.066'	575784	633070
LV5	Lungmanis Virgin Jungle Reserve	Sandakan	5	3529	No	N5° 43.657' E117° 41.039'	575735	633140
LV6	Lungmanis Virgin Jungle Reserve	Sandakan	6	3529	No	N5° 43.695' E117° 41.032'	575722	633210
MA1	Malua A - Near SBE	Malua Forest Reserve	1	33.969	Yes	N5° 05.718' E117° 39.994'	573883	563237
MA4	Malua A - Near SBE	Malua Forest Reserve	4	33.969	Yes	N5° 05.517' E117° 40.011'	573914	562867
MA6	Malua A - Near SBE	Malua Forest Reserve	6	33.969	Yes	N5° 05.434' E117° 40.017'	573926	562714
MA8	Malua A - Near SBE	Malua Forest Reserve	8	33.969	Yes	N5° 05.333' E117° 40.045'	573978	562528
MA10	Malua A - Near SBE	Malua Forest Reserve	10	33.969	Yes	N5° 05.226' E117° 40.061'	574007	562330
MB1	Malua B - Gate	Malua Forest Reserve	1	33.969	Yes	N5° 07.141' E117° 40.497'	574809	565860
MB3	Malua B - Gate	Malua Forest Reserve	3	33.969	Yes	N5° 07.131' E117° 40.396'	574623	565841
MB5	Malua B - Gate	Malua Forest Reserve	5	33.969	Yes	N5° 07.160' E117° 40.296'	574438	565894
MB7	Malua B - Gate	Malua Forest Reserve	7	33.969	Yes	N5° 07.250' E117° 40.233'	574321	566060
MB9	Malua B - Gate	Malua Forest Reserve	9	33.969	Yes	N5° 07.325' E117° 40.159'	574184	566198
MV1	Materis Virgin Jungle Reserve	Sukau, Kinabatangan	1	250	No	N5° 30.731' E118° 01.284'	613140	609378
MV4	Materis Virgin Jungle Reserve	Sukau, Kinabatangan	4	250	No	N5° 30.724' E118° 01.162'	612915	609364
MV6	Materis Virgin Jungle Reserve	Sukau, Kinabatangan	6	250	No	N5° 30.737' E118° 01.055'	612717	609388
M1	Meranti	Rekahalus Plantation	1	30	Yes	N5° 47.056' E117° 30.012'	555379	639381

M3	Meranti	Rekahalus Plantation	3	30	Yes	N5° 47.065' E117° 30.088'	555519	639398
R1	Rekasar	Rekahalus Plantation	1	85	Yes	N5° 47.864' E117° 30.085'	555512	640870
R3	Rekasar	Rekahalus Plantation	3	85	Yes	N5° 47.903' E117° 29.996'	555348	640942
R4	Rekasar	Rekahalus Plantation	4	85	Yes	N5° 47.908' E117° 29.941'	555247	640951
SB3	Sabasar	Sabahmas Plantation	3	88	Yes	N5° 08.357' E118° 26.602'	659986	568241
SB4	Sabasar	Sabahmas Plantation	4	88	Yes	N5° 08.359' E118° 26.646'	660067	568245
SB7	Sabasar	Sabahmas Plantation	7	88	Yes	N5° 08.444' E118° 26.651	640276	562270
SA1	Sapi A Virgin Jungle Reserve	Beluran	1	45	No	N5° 41.812' E117° 24.155'	544578	629711
SA3	Sapi A Virgin Jungle Reserve	Beluran	3	45	No	N5° 41.758' E117° 24.100'	544477	629612
SC1	Sapi C Virgin Jungle Reserve	Beluran	1	500	No	N5° 43.478' E117° 24.724'	545626	632781
SC3	Sapi C Virgin Jungle Reserve	Beluran	3	500	No	N5° 43.572' E117° 24.700'	545582	632955
SC5	Sapi C Virgin Jungle Reserve	Beluran	5	500	No	N5° 43.667' E117° 24.637'	545465	633130
SC7	Sapi C Virgin Jungle Reserve	Beluran	7	500	No	N5° 43.754' E117° 24.640'	545471	633290
U2	Ulu Sapa Payau Virgin Jungle Reserve	Telupid	2	720	No	N5° 39.591' E117° 15.947'	529432	625611
U4	Ulu Sapa Payau Virgin Jungle Reserve	Telupid	4	720	No	N5° 39.501' E117° 15.883'	529314	625445
U6	Ulu Sapa Payau Virgin Jungle Reserve	Telupid	6	720	No	N5° 39.472' E117° 15.819'	529196	625391
U8	Ulu Sapa Payau Virgin Jungle Reserve	Telupid	8	720	No	N5° 39.414' E117° 15.754'	529076	625284
WC1	Water Catchment	Rekahalus Plantation	1	120	Yes	N5° 46.496' E117° 28.837'	553212	638348
WC3	Water Catchment	Rekahalus Plantation	3	120	Yes	N5° 46.425' E117° 28.857'	553249	638217
YP2	Yong Peng	Sabahmas Plantation	2	57	Yes	N5° 08.103' E118° 25.621'	658174	567769
YP6	Yong Peng	Sabahmas Plantation	6	57	Yes	N5° 08.401' E118° 25.549'	658040	568318
YP7	Yong Peng	Sabahmas Plantation	7	57	Yes	N5° 08.317' E118° 25.561'	639068	562127

Appendix 2: Example of the field forms used

Plot ID		**Date**		**Observer**	
X-Coordinate		**Y-Coordinate**		**Canopy height**	
Remarks					

#	**L/T**	**A/D**	**Tree or liana species**	**DBH**	**POM**	**Length**	**COD**	**TOD**	**Remarks**
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									

Field form methodology

L/T	Indicates if the measured plant is a tree or a liana; either **L** or **T**
A/D	Indicator if tree or liana is alive or dead; either **A** or **D**
Tree or liana species	Identified name of the tree species; at least to genus level (e.g. ***Shorea sp***.)
DBH	Measured diameter of the tree at 1.30m from ground; in **cm**
POM	Point of measurement on the liana; **A** until **R**
Length	Tree: Measured or estimated height of tree canopy; in **m** Liana: Measured or estimated total length of liana; in **m**
COD	Cause of death: If dead, cause of death is either; **U** (uprooted), **S** (snapped), **SD** (standing dead) or **O** (other)
TOD	Time of death: Estimated time that has passed since the tree died; either **<1** year or **>1** year

Appendix 3: Detailed description of the DBH measuring protocol from Schnitzer and colleagues (2008)

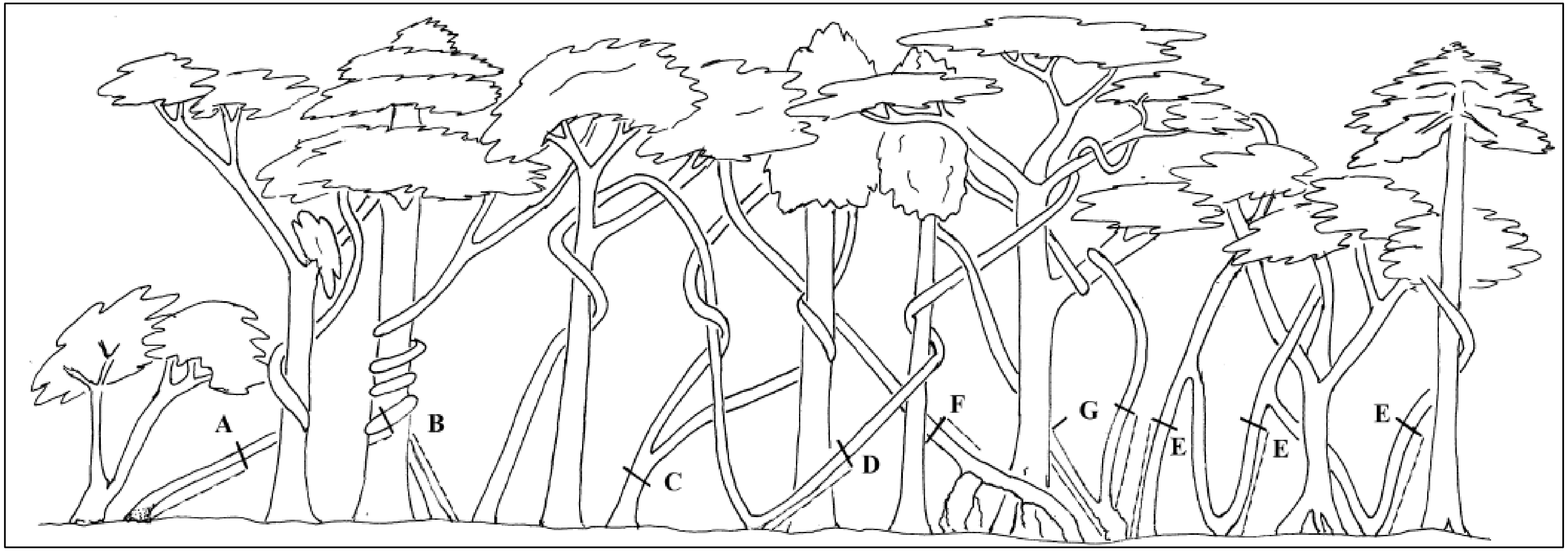

Figure 8: Liana diameter measurement points (A-G) (Schnitzer et a.,2008)

A. Measure the diameter of all lianas (≥1 cm) 130 cm from the main rooting point at the soil surface.
B. Measure twining lianas 130 cm from the rooting point, along the stem of the liana.
C. If lianas branch below 130 cm (but≥40 cm from the roots), measure 20 cm below the branching point.
D. If lianas loop to the ground and root before ascending into the canopy, ignore the loop and measure 130 cm from the last substantial (cannot be easily dislodged) rooting point along the stem that ascends into the canopy.
E. If lianas loop to the ground and root (as in D), but the loops have branches that ascend to the canopy, measure each rooted ascending stem of the individual separately
F. If lianas have aerial roots≥80 cm from the ultimate rooting point of the prostrate stem, measure 50 cm above highest rooted aerial root.
G. If lianas branch ≤40 cm from the rooting point, measure each branch of the individual separately at 130 cm above the main rooting point

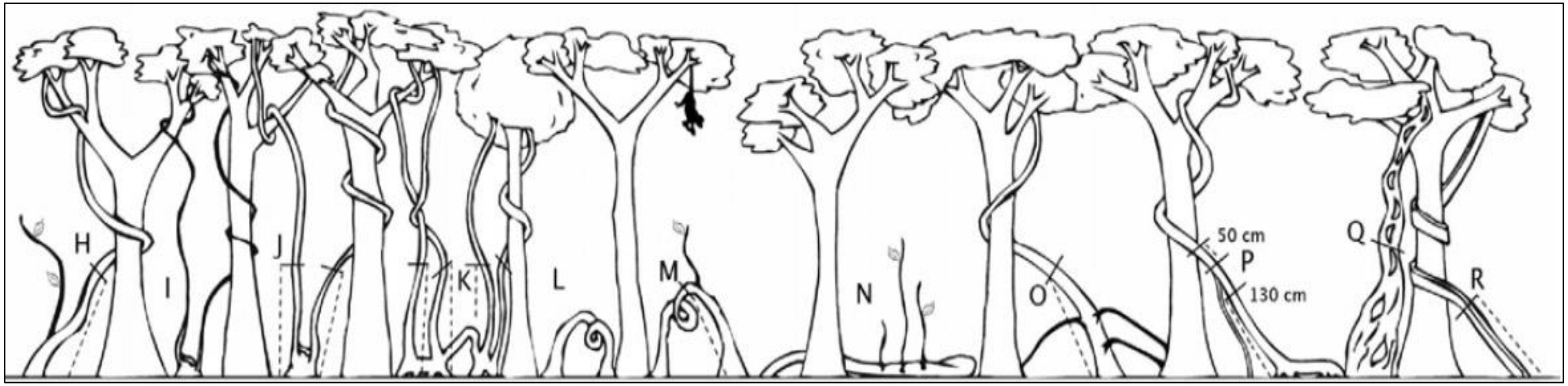

Figure 9: Liana diameter measurement points (H-R) (Schnitzer et a.,2008)

H. Ignore branches <1 cm diameter and measure the principal stem 130 cm from the roots.
I. Exclude lianas that branch below 130 cm from the roots if none of the stems are >1 cm diameter 130 from the roots.
J. If a liana branches within 40 cm of the roots, measure each stem (>1 cm) 130 cm from the rooting point. Note that they are branches of a single individual and tag them as multiple stems (see below).
K. Measure each resprout or branch (>1 cm) 130 cm from the roots of each distinct rooting point.
L. Exclude''ground-to-ground'' lianas, those that do not ascend toward the canopy, but rather loop from one rooting spot to another or that are prostrate on the soil without any resprout or branches, even if they are >1 cm diameter.
M. Include ''ground-to-ground'' lianas if they have a resprout or branch, even if the branch is <1 cm diameter. If the branch is <1 cm, measure the principal stem 130 cm from the roots, ignoring the branch. If the branch is >1 cm and within 130 cm of the roots, the point of measurement should be on the ascending branch.
N. Exclude lianas growing prostrate along the soil if they do not have a stem >1 cm ascending towards the canopy.
O. Exclude multiple branches that originate within 130 from the main roots if they are smaller than 1 cm in diameter.
P. Measure 50 cm above the last aerial root if that root is >80 cm from the final rooting location of the stem before the stem ascends to the canopy.
Q. If the stem is anomalous and not uniform below 130 cm from the roots, measure stem 20 cm above the point where it becomes uniform. If there is no uniform area within reach, measure the stem 130 cm from the roots.
R. If the stem is flat and wide, include the liana if the mean of its wide and narrow axes is >1 cm.

Appendix 4: Liana species list

ID-Species	Species-Name	Species-scientific	Genus	Family
ls01	Uvaria sp. 1 Annonaceae		Uvaria	Annonaceae
ls02	Spatholobus sp. 1 Fabaceae		Spatholobus	Fabaceae
ls03	Uvaria sp. 2 Annonaceae		Uvaria	Annonaceae
ls04	Desmos sp. 1 Annonaceae		Desmos	Annonaceae
ls05	Coscinium sp. 1 Menispermaceae		Coscinium	Menispermaceae
ls06	Agalea Macrophylla Connaraceae	Agalea Macrophylla	Agalea	Connereaceae
ls07	Spatholobus sp. 2 Fabaceae		Spatholobus	Fabaceae
ls08	Spatholobus macropterus Fabaceae		Spatholobus	Fabaceae
ls09	Tetracera sp. 1 Dilleniaceae		Tetracera	Dilleniaceae
ls10	Spatholobus sp. 3 Fabaceae		Spatholobus	Fabaceae
ls11	Celastraceae			celastraceae
ls12	Same as 10			
ls13	Tree species			
ls14	Uncaria sp. 1 Rubiaceae		Uncaria	Rubiaceae
ls15	Spatholobus sp. 4 Fabaceae		Spatholobus	Fabaceae
ls16	Spatholobus sp. 5 Fabaceae		Spatholobus	Fabaceae
ls17	Lodes sp. 1 Icecynaceae		Lodes	Icecynaceae
ls18	Coscinium Stephania Corumbosa Menispermaceae	Coscinium stephania corumbosa	Coscinium	Menispermaceae
ls19	Syzyphus boneensis Rhamnaceae	Syzyphus boneensis	Syzyphus	Rhamnaceae
ls20	Strychnos ignatii Loginiaceae	Strychnos ignatii	Strychnos	Loginiaceae
ls21	Artabotrys sp. 1 Annonaceae		Artabotrys	Annonaceae
ls22	Uvaria sp. 3 Annonaceae		Uvaria	Annonaceae
ls23	Spatholobus sp. 6 Fabaceae		Spatholobus	Fabaceae
ls24	Agelea bonensis connaraceae	Agelaea bonensis	Agelea	Connearaceae
ls25	Agalea sp. 1 Connaraceae		Agelea	Connearaceae
ls26	Uncaria sp. 2 Rubiaceae		Uncaria	Rubiaceae
ls27	Agalea sp. 2 Connaraceae		Agelea	Connearaceae
ls28	Fabaceae			Fabaceae
ls29	Omphalea sp. 1 Euphorbiaceae		Omphalea	Euphorbiaceae
ls30	Ericibe sp. 1 Convolvulaceae		Ericibe	Convolvulaceae
ls31	Bauhinia sp. 1 Fabaceae		Bauhinia	Fabaceae
ls32	Uncaria sp. 3 Rubiaceae		Uncaria	Rubiaceae
ls33	Combretum sp. 1 Combretaceae		Combretum	Combretaceae
ls34	Spatholobus sp. 7 Fabaceae		Spatholobus	Fabaceae
ls35	Dalbergia sp. 1 Fabaceae		Dalbergia	Fabaceae
ls36	Artabotrys sp. 2 Annonaceae		Artabotrys	Annonaceae
ls37	Sphenodesme sp. 1 Lamiaceae		Sphenodesme	Lamiaceae
ls38	Spatholobus sp. 8 Fabaceae		Spatholobus	Fabaceae
ls39	Uvaria sp. 4 Annonaceae		Uvaria	Annonaceae
ls40	Bauhinia kockiana Fabaceae	Bauhinia kockiana	Bauhinia	Fabaceae
ls41	Callerea sp. 1 Fabaceae		Callerea	Fabaceae
lsuk01	Unknown 1			

lsuk02	Mucuna sp. 1 Fabaceae		Mucuna	Fabaceae
lsuk03	Unknown 2			
lsuk04	Uncaria sp. 4 Rubiaceae		Uncaria	Rubiaceae
lsuk05	Unknown 3			
lsuk06	Unknown 4			
lsuk07	Unknown 5			
lsuk08	Unknown 6			
lsuk09	Willughbei sp. 1 Apocynaceae		Willughbei	Apocynaceae
lsuk10	Uvaria sp. 5 Annonaceae		Uvaria	Annonaceae
lsuk11	Uncaria sp. 5 Rubiaceae		Uncaria	Rubiaceae
lsuk12	Coscinium sp. 2 Menispermaceae			Menispermaceae
lsuk13	Artabotrys sp.3 Annonaceae		Artabotrys	Annonaceae
lsuk14	Unknown 7			
lsuk15	Uvaria sp. 6 Annonaceae		Uvaria	Annonaceae
lsuk16	Uncaria sp. 6 Rubiaceae		Uncaria	Rubiaceae
lsuk17	Unknown 8			
lsuk18	Uvaria sp. 7 Annonaceae		Uvaria	Annonaceae
lsuk19	Uncaria sp. 7 Rubiaceae		Uncaria	Rubiaceae
lsuk20	Ficus: (Stranglia fie sp. Moraceae)	Ficus		
lsuk21	Bauhinia sp. 2 Fabaceae		Bauhinia	Fabaceae
lsuk22	Salpinia sp. 1 Fabaceae		Salpinia	Fabaceae
lsuk23	Spatholobus sp. 9 Fabaceae		Spatholobus	Fabaceae
lsuk24	Coscinium fenestratum Menispermaceae	Coscinium fenestratum	Coscinium	Menispermaceae
lsuk25	Uncaria sp. 8 Rubiaceae		Uncaria	Rubiaceae
lsuk26	Caesalpinia sp. 1 Caesalpiniaceae		Caesalpinia	Caesalpiniaceae
lsuk27	Strychnos sp. 1 Loginiaceae		Strychnos	Loginiaceae
lsuk28	Uncaria sp. 9 Rubiaceae		Uncaria	Rubiaceae
lsuk29	Uncaria sp. 10 Rubiaceae		Uncaria	Rubiaceae
lsuk30	Willughbeia sp. 2 Apocynaceae		Willughbeia	Apocynaceae
lsuk31	Agalea sp. 3 Connaraceae		Agelea	Connearaceae
lsuk32	Uncaria sp. 11 Rubiaceae		Uncaria	Rubiaceae
lsuk33	Phytocrene sp. 1 Icecynaceae		Phytocrene	Icecynaceae
lsuk34	Oleaceae			Oleaceae
lsuk35	Strychnos sp. 2 Loginiaceae		Strychnos	Loginiaceae
lsuk36	Artabotrys sp. 4 Annonaceae		Artabotrys	Annonaceae
lsuk37	Unknown 9			
lsuk38	Connarus sp. 1 Connaraceae		Connarus	Connaraceae
lsuk39	Agalea sp. 4 Connaraceae		Agelea	Connearaceae
lsuk40	Uvaria sp. 8 Annonaceae		Uvaria	Annonaceae
lsuk41	Annonaceae			Annonaceae
lsuk42	Willughbeia sp. 3Apocynaceae		Willughbeia	Apocynaceae
lsuk43	Uncaria sp. 12 Rubiaceae		Uncaria	Rubiaceae
lsuk44	Uncaria sp. 13 Rubiaceae		Uncaria	Rubiaceae
lsuk45	Ficus			
lsuk46	Piper sp. 1 Piperaceae		Piper	Piperaceae
lsuk47	Spatholobus sp. 10 Fabaceae		Spatholobus	Fabaceae

lsuk48	Unknown 10			
lsuk49	Unknown 11			

Appendix 5: Liana biomass and carbon stock for each plots

Plot result include: number of liana species (N-species), number of lianas per hectare (N-lianas/ha), liana biomass per hectare and liana carbon per hectare.

ID-plot	N-Species	N-lianas/ha	Liana biomass/ha	Liana carbon/ha
J1	11	650	11182,2	5294,8
J3	14	1000	12634,1	5982,3
KV1	9	370	7582,9	3590,5
KV3	13	860	9731,0	4607,6
KV6	6	250	2818,0	1334,3
LV1	12	1200	13667,9	6471,8
LV3	10	875	16853,2	7980,0
LV4	4	275	4537,1	2148,3
LV5	13	625	9952,7	4712,6
LV6	11	630	7782,9	3685,2
M1	8	325	4038,2	1912,1
M3	10	275	2860,5	1354,4
MA1	6	525	6445,1	3051,7
MA10	9	370	6098,4	2887,6
MA4	10	570	8026,4	3800,5
MA6	10	490	4599,8	2178,0
MA8	11	450	5223,7	2473,4
MB1	17	580	4762,3	2254,9
MB3	7	400	4384,9	2076,2
MB5	11	690	8697,1	4118,1
MB7	10	510	5499,2	2603,9
MB9	11	740	7373,0	3491,1
MV1	13	500	7484,4	3543,9
MV4	9	650	11793,8	5584,4
MV6	9	700	6616,3	3132,8
R1	8	490	4473,7	2118,3
R3	14	510	4614,6	2185,0
R4	8	825	8667,7	4104,2
SA1	14	1025	7942,4	3760,7
SA3	12	475	4530,4	2145,2
SB3	0	1550	13624,0	6451,0
SB4	4	875	10041,9	4754,9
SB7	7	620	8930,5	4228,6
SC1	3	250	4175,5	1977,1
SC3	7	440	5191,7	2458,3
SC5	10	380	4568,6	2163,2
SC7	6	280	3194,6	1512,6
U2	19	875	8107,2	3838,7
U4	8	490	6130,1	2902,6
U6	8	280	3234,4	1531,5
U8	3	240	1637,2	775,2
YP2	1	250	2418,4	1145,1
YP6	1	600	5618,0	2660,1
YP7	6	340	6510,4	3082,7

Appendix 6: The 25 highest DBH measurements

ID	ID-plot	DBH	ID-Species	Biomass (kg/ha)	Carbon Stock (kg/ha)
1	MV4	25.2		104.12	49.30
2	KV1	22.5		92.02	43.57
3	MA10	18.6		74.78	35.41
4	J1	18	Isuk38	72.15	34.16
5	MV4	17.5		69.97	33.13
6	J1	16.7	Is22	66.49	31.48
7	LV6	16	Is38	63.46	30.05
8	MA10	16	Is16	63.46	30.05
9	MB9	15	Is16	59.15	28.01
10	MB7	14.7	Is06	57.86	27.40
11	MV4	14.6		57.43	27.19
12	KV1	14.5		57.00	26.99
13	LV4	14.3	Isuk16	56.15	26.58
14	MV4	14.1		55.29	26.18
15	SC5	13.6	Isuk23	53.16	25.17
16	LV3	13.3	Isuk16	51.88	24.57
17	SB7	12.5	unknown	48.49	22.96
18	MA10	12.4		48.07	22.76
19	SB7	12.2	Isuk05	47.22	22.36
20	LV5	12.2	Isuk41	47.22	22.36
21	M1	12.2	Is16	47.22	22.36
22	MA4	12		46.38	21.96
23	LV6	11.7		45.12	21.36
24	J1	11.5	Isuk38	44.28	20.96
25	YP7	11.5	Isuk02	44.28	20.96

Appendix 7: Statistical tests results on fragment size and logging

7A: Results from multiple regression analysis on fragment size and logging

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	,137[a]	,019	-,029	1616,664600003	1,517

a. Predictors: (Constant), Logging, Area_Size

b. Dependent Variable: TotalC_ha

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2035154,014	2	1017577,007	,389	,680[b]
	Residual	107157781,585	41	2613604,429		
	Total	109192935,599	43			

a. Dependent Variable: TotalC_ha

b. Predictors: (Constant), Logging, Area_Size

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	3327,332	352,786		9,432	,000		
	Area_Size	-,001	,001	-,155	-,858	,396	,733	1,365
	Logging	152,944	570,051	,048	,268	,790	,733	1,365

a. Dependent Variable: TotalC_ha

Collinearity Diagnostics[a]

Model	Dimension	Eigenvalue	Condition Index	Variance Proportions		
				(Constant)	Area_Size	Logging
1	1	2,246	1,000	,07	,07	,06
	2	,526	2,067	,37	,63	,00
	3	,228	3,135	,56	,30	,94

a. Dependent Variable: TotalC_ha

7B: Results from multiple regression analysis on logging

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	,032[a]	,001	-,023	1611,588372922	1,498

a. Predictors: (Constant), Cut

b. Dependent Variable: TotalC_ha

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	109818,082	1	109818,082	,042	,838[b]
	Residual	109083117,517	42	2597217,084		
	Total	109192935,599	43			

a. Dependent Variable: TotalC_ha

b. Predictors: (Constant), Cut

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	3326,497	351,677		9,459	,000		
	Cut	-100,021	486,415	-,032	-,206	,838	1,000	1,000

a. Dependent Variable: TotalC_ha

Collinearity Diagnostics[a]

Model	Dimension	Eigenvalue	Condition Index	Variance Proportions	
				(Constant)	Cut
1	1	1,723	1,000	,14	,14
	2	,277	2,494	,86	,86

a. Dependent Variable: TotalC_ha

t-Test: Two-Sample Assuming Equal Variances		
	Unlogged	*Logged*
Mean	3326.497046	3226.47639
Variance	3241189.018	2011788.053
Observations	21	23
Pooled Variance	2597217.084	
Hypothesized Mean Difference	0	
df	42	
t Stat	0.20562826	
P(T<=t) one-tail	0.419037375	
t Critical one-tail	1.681952357	
P(T<=t) two-tail	0.838074751	
t Critical two-tail	2.018081703	

Anova: All types						
Groups	*Count*	*Sum*	*Average*	*Variance*		
HCV	13	45273.43	3482.571	3145493		
VJR	21	69856.44	3326.497	3241189		
CF	10	28935.53	2893.553	505826.7		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2070797	2	1035398	0.396289	0.675361	3.225684
Within Groups	1.07E+08	41	2612735			
Total	1.09E+08	43				

Anova: HCV - VJR						
Groups	*Count*	*Sum*	*Average*	*Variance*		
HCV	13	45273.43	3482.571	3145493		
VJR	21	69856.44	3326.497	3241189		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	195589.7	1	195589.7	0.061021	0.806468	4.149097
Within Groups	1.03E+08	32	3205303			
Total	1.03E+08	33				

Anova: VJR - CF						
Groups	*Count*	*Sum*	*Average*	*Variance*		
VJR	21	69856.44	3326.497	3241189		
CF	10	28935.53	2893.553	505826.7		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1269758	1	1269758	0.530772	0.472125	4.182964
Within Groups	69376221	29	2392283			
Total	70645979	30				

Anova: HCV - CF						
Groups	Count	Sum	Average	Variance		
HCV	13	45273.43	3482.571	3145493		
CF	10	28935.53	2893.553	505826.7		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1960979	1	1960979	0.973573	0.335024	4.324794
Within Groups	42298359	21	2014208			
Total	44259337	22				

7C: Results from multiple regression analysis on fragment size

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	,130[a]	,017	-,006	1598,704225908	1,529

a. Predictors: (Constant), Area_Size

b. Dependent Variable: TotalC_ha

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1847017,118	1	1847017,118	,723	,400[b]
	Residual	107345918,481	42	2555855,202		
	Total	109192935,599	43			

a. Dependent Variable: TotalC_ha

b. Predictors: (Constant), Area_Size

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	3385,773	274,426		12,338	,000		
	Area_Size	-,001	,001	-,130	-,850	,400	1,000	1,000

a. Dependent Variable: TotalC_ha

Collinearity Diagnostics[a]

Model	Dimension	Eigenvalue	Condition Index	Variance Proportions	
				(Constant)	Area_Size
1	1	1,478	1,000	,26	,26
	2	,522	1,683	,74	,74

a. Dependent Variable: TotalC_ha

Appendix 8: Species distribution tables

8A: Overall liana family distribution

Taxonomy liana family*	Number of measurements
Fabaceae	223
Rubiaceae	183
Annonaceae	168
Loginiaceae	39
Conneraceae	37
Menispermaceae	29
Lamiaceae	27
Apocynaceae	26
Convolvulaceae	11
Combretaceae	10
Euphorbiaceae	9
Icecynaceae	8
Caesalpiniaceae	8
Dilleniaceae	6
Oleaceae	4
celastraceae	4
Rhamnaceae	4
Piperaceae	2

* All unknown liana families are left out of this table

8B: Liana family distribution for each of the three forest types

Taxonomy family	Number of measurements	Percentage
High Conservation Value areas		
Fabaceae	97	26.4%
Rubiaceae	31	8.4%
Conneraceae	16	4.3%
Annonaceae	14	3.8%
Virgin Jungle Reserves		
Annonaceae	99	21.4%
Rubiaceae	96	20.7%
Fabaceae	83	17.9%
Loginiaceae	33	7.1%
Continuous Forest		
Rubiaceae	56	26%
Annonaceae	55	25.6%
Fabaceae	43	20%
Menispermaceae	15	6.9%

Appendix 9: Statistical test results species richness

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	,109[a]	,012	-,014	3,539	2,156

a. Predictors: (Constant), Area_Size

b. Dependent Variable: N_species

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	5,837	1	5,837	,466	,499[b]
	Residual	488,358	39	12,522		
	Total	494,195	40			

a. Dependent Variable: N_species

b. Predictors: (Constant), Area_Size

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	9,321	,636		14,652	,000		
	Area_Size	1,099E-6	,000	,109	,683	,499	1,000	1,000

a. Dependent Variable: N_species

Collinearity Diagnostics[a]

Model	Dimension	Eigenvalue	Condition Index	Variance Proportions	
				(Constant)	Area_Size
1	1	1,495	1,000	,25	,25
	2	,505	1,721	,75	,75

a. Dependent Variable: N_species

t-Test: Two-Sample Assuming Equal Variances		
	Logged	**Unlogged**
Mean	9.6	9.476190476
Variance	9.515789474	15.66190476
Observations	20	21
Pooled Variance	12.66764347	
Hypothesized Mean Difference	0	
df	39	
t Stat	0.111336831	
P(T<=t) one-tail	0.455960143	
t Critical one-tail	1.684875122	
P(T<=t) two-tail	0.911920286	
t Critical two-tail	2.02269092	

Anova: All species						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
HCV	10	90	9	10.66666667		
VJR	21	199	9.476190476	15.66190476		
CF	10	102	10.2	8.622222222		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	7.357026713	2	3.678513357	0.287125245	0.752	3.2448
Within Groups	486.8380952	38	12.81152882			
Total	494.195122	40				

Anova: HCV - VJR						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
HCV	10	90	9	10.66666667		
VJR	21	199	9.476190476	15.66190476		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.53609831	1	1.53609831	0.108853138	0.7438	4.183
Within Groups	409.2380952	29	14.11165846			
Total	410.7741935	30				

Anova: VJR - CF						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
VJR	21	199	9.476190476	15.6619		
CF	10	102	10.2	8.62222		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	3.549001536	1	3.549001536	0.26333	0.6117	4.183
Within Groups	390.8380952	29	13.4771757			
Total	394.3870968	30				

Anova: HCV - CF						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
HCV	10	90	9	10.6667		
CF	10	102	10.2	8.62222		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	7.2	1	7.2	0.74654	0.3989	4.4139
Within Groups	173.6	18	9.644444444			
Total	180.8	19				

Appendix 10: Data analyse results on liana abundance

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	,083[a]	,007	-,017	281,410	1,895

a. Predictors: (Constant), Area_Size

b. Dependent Variable: N_lianas_ha

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	23284,410	1	23284,410	,294	,591[b]
	Residual	3326040,022	42	79191,429		
	Total	3349324,432	43			

a. Dependent Variable: N_lianas_ha

b. Predictors: (Constant), Area_Size

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	587,639	48,305		12,165	,000		
	Area_Size	-6,868E-5	,000	-,083	-,542	,591	1,000	1,000

a. Dependent Variable: N_lianas_ha

Collinearity Diagnostics[a]

Model	Dimension	Eigenvalue	Condition Index	Variance Proportions	
				(Constant)	Area_Size
1	1	1,478	1,000	,26	,26
	2	,522	1,683	,74	,74

a. Dependent Variable: N_lianas_ha

t-Test: Two-Sample Assuming Equal Variances		
	Logged	*Unlogged*
Mean	592.826087	555.7142857
Variance	79647.33202	79098.21429
Observations	23	21
Pooled Variance	79385.84738	
Hypothesized Mean Difference	0	
df	42	
t Stat	0.436402991	
P(T<=t) one-tail	0.332389803	
t Critical one-tail	1.681952357	
P(T<=t) two-tail	0.664779606	
t Critical two-tail	2.018081703	

Anova: All Types						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
HCV	13	8310	639.2308	130266		
VJR	21	11670	555.7143	79098.21		
CF	10	5325	532.5	13851.39		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	79505.34	2	39752.67	0.498456	0.611102	3.225684
Within Groups	3269819	41	79751.69			
Total	3349324	43				

Anova: HCV - VJR						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
HCV	13	8310	639.2308	130266		
VJR	21	11670	555.7143	79098.21		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	56005.17	1	56005.17	0.569818	0.455851	4.149097
Within Groups	3145157	32	98286.14			
Total	3201162	33				

Anova: VJR - CF

SUMMARY

Groups	Count	Sum	Average	Variance
VJR	21	11670	555.7143	79098.21
CF	10	5325	532.5	13851.39

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	3650.634	1	3650.634	0.062034	0.805066	4.182964
Within Groups	1706627	29	58849.2			
Total	1710277	30				

Anova: HCV - CF

SUMMARY

Groups	Count	Sum	Average	Variance
HCV	13	8310	639.2308	130266
CF	10	5325	532.5	13851.39

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	64386.5	1	64386.5	0.801086	0.380913	4.324794
Within Groups	1687855	21	80374.04			
Total	1752241	22				