Non-Tree Carbon Stocks in Mixed Dipterocarp Forests Sarawak Malaysia

A method towards better carbon stock estimations based on canopy cover and basal area in logged dipterocarp forests

Submitted by
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ABSTRACT

The project, during the second phase of the geospatial assessment of the forest resources of Sarawak, anticipates working on the inventory of biomass and carbons stocks in the permanent forest estate (PFE) of Sarawak and some selected forest management units (FMUs), as well as Sarawak's totally protected areas (TPAs) and areas licensed for planted forests (LPFs). The Geospatial project is to determine carbon stocks of all forested areas in Sarawak based on remote sensing and field verification.

In addition to the ''Sarawak Forest Geospatial project phase II'' conducted by VHL for SFC, this research is set up to be able to make better estimations of non-tree carbon mass in mixed dipterocarp forest based on the basal area of trees and the canopy density. The non-tree carbon mass contains all living and dead organic floral biomass besides trees that is present in the forest.

During this research carbon pools such as litter, understory vegetation, lianas and dead wood have been measured as well as trees and canopy cover. With all this data gathered form the sample plots and additional literature studies, the carbon content in dipterocarp forest per basal area class and canopy cover index has been quantified.

Keywords: Sarawak, Malaysia, Mixed Dipterocarp forest, Biomass, Non-tree Carbon stock, Liana carbon stock, Canopy cover

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EXECUTIVE SUMMARY

The Malaysian state Sarawak is coping with forest loss and forest degradation. The main reasons are due to unsustainable logging and conversion to oil palm plantations. Forest degradation and conversion leads to a of loss of stored carbon in the forest which increases the effect of global warming. Therefore, it is important determine the amount of carbon each forest type holds, and what the effect of logging is on the carbon stocks. Carbon measurements of both trees and non-tree mass can improve accuracy of estimated forest carbon stocks. Followed by remote sensing tools and canopy cover measurements it can contribute to better conservation and restoration of those forests. Those forests are high in carbon and considered valuable in flora and fauna richness and could help programs like REDD+, that aims to offset carbon emissions and preserve nature, by selecting areas that are considered of high conservation values.

Mixed dipterocarp forest, the most abundant forest type, was assessed on non-tree carbon mass and canopy cover. Non-tree carbon mass are all other carbon pools present in the forest besides trees (lianas, understory vegetation, litter, dead wood and palms). The goal of this research can be divided in two. The first was to investigate the impact of logging on the non-tree carbon mass in mixed dipterocarp forest. Assumed, this would increase when logging occurred.

This was done by surveying biomass of lianas and palms. All lianas in each subplot were measured and carbon content was calculated. As well, litter sampling, understory sampling and measurement of dead trees in the forest was done. Litter and understory samples, five quadrats per plot were measured, and wet-to-dry ratio was calculated. Standing dead trees were measured throughout the plot. Fallen dead wood was measured on a transect along de centreline. All this data was later converted from biomass to carbon mass using the corresponding species-specific data when possible and previously developed allometric equations that were available.

The second goal was to find out whether the canopy cover percentage can predict the amount of carbon stored inside these forests. The average canopy cover was used to calculate the canopy cover per plot.

The average non-tree carbon mass in mixed dipterocarp forest consists 10% (17 tC/ha) of the total carbon stock in the forest (dead trees included in NTCM). However, in forests with basal area between 10-30 m2/ha, NTCM can shift up to 17%. In forests with higher basal area the non-tree carbon mass reduces to 5% where basal area is 40-50 m2/ha. A correlation between basal area of the trees and the liana carbon stocks showed that the number of lianas as well as the carbon stock of lianas increase with higher basal area of trees. For the other carbon pools and total NTCM there was no significant correlation with the tree basal area. For palms there is no relationship of carbon stocks with tree basal area or canopy cover. Understory vegetation carbon mass showed almost no change between different basal area classes. However, litter carbon mass increases slightly when BA increases as well. Canopy cover index showed the strongest correlation with lianas. No significant correlations could be found for the canopy cover and NTCM, total carbon stocks. Therefore, it is uncertain whether GLAMA is suitable in tropical forests.

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LIST OF ABBREVIATIONS

AGB	Above Ground Biomass
BA	Basal Area
BGB	Below Ground Biomass
C	Carbon
CaCo	Canopy Cover
cm	Centimetre
DBH	Diameter Breast Height (Height: 130 cm)
DW	Dry Weight
FD	Fallen Dead Wood
FMU	Forest Management Unit
FW	Fresh Weight
g	Gram
ha	Hectare
HCV	High Conservation Value
HDF	Hill Dipterocarp Forest
Kg	Kilogram
LDF	Low Dipterocarp Forest
LPF	License for Planted Forest
LTM	Low Tropical Montane Forest
m	Meter
MDF	Mixed Dipterocarp Forest
Modif. CaCo Index	Modified Canopy Cover Index
NTCM	Non-Tree Carbon Mass
PFE	Permanent Forest Estate
REDD	Reduce Emissions from Deforestation and forest Degradation
SD	Standing Dead Wood
SFC	Sarawak Forestry Corporation
t	Ton (1.000 kg)
TAGB	Total Above Ground Biomass
TPA	Totally Protected Area
U	Understory
UDF	Upper Dipterocarp Forest
VHL	Van Hall Larenstein University of Applied Sciences

1. INTRODUCTION

Tropical forests are the most diverse and complex ecosystems on earth (Lee et al., 2002) and serve many benefits in ecosystem services such as regulation of carbon dioxide and water in the atmosphere. Tropical forests contain the highest amount of above ground biomass (AGB), therefore they are incredibly important to offset carbon emissions. In stable and natural conditions (primary forest), those ecosystems are in balance with the atmosphere, neither adding nor removing greenhouse gasses. Human interventions such as burning fossil fuels, deforestation, forest degradation and fragmentation set those ecosystems and climate under pressure (Ghazoul & Sheil, 2010).

Sarawak (Malaysia), together with Sabah (Malaysia), Kalimantan (Indonesia) and Brunei make the island of Borneo. It has the largest intact tropical forest cover in south-east Asia (Wilkie, 2007). The forests of Sarawak can be classified in five main types. The most abundant type is mixed dipterocarp forest covering about 5.4 million hectares. Other forest types are peat swamp forest, mangrove forest, kerangas/heath forest and montane forest (Osman, Othman, Karim, Amir, & Mazlan, 2014)

According to the forestry department, nearly all forested areas are part of the permanent forest estate (PFE) and should stay forested in the future (Government of Sarawak, 2017). But large-scale commercial timber industry is a major income producer in tropical regions like Sarawak and employs over 80.000 people. Therefore, logging is still allowed under certain regulations (Government of Sarawak, 2017). Most logging concessions are in hands of the six largest timber companies; Samling Timber, Shin Yang, WTK, KTS, Rimbunan Hijau and Ta Ann. In total these concessions cover an area around 3.7 million ha. Since 2019, all timber companies must follow the guidelines of Reduced Impact Logging (RIL), a method that provides strict regulations on forest harvesting operations as well as responsible harvesting practices (Sarawak Forestry Corporation; Forest Department, 2018a). This ensures that the natural forest is managed sustainably and minimizes environmental impacts (Sarawak Forestry Corporation; Forest Department, 2018b).

However, as a result of unsustainable logging practices, the total forest cover has relatively high percentage of land that is classified as forest but that is severely degraded (Bryan et al., 2013). For example, only 3-8% of forest area in Sarawak is considered primary forest (Bryan et al., 2013). Compared to Brunei, its neighbouring country, that still holds about 54% of its land with intact forests. It has built its wealth from oil and gas extraction and has largely excluded industrial logging from its borders. This approach of excluding logging, has been much more successful at forest conservation than logging in Sarawak and Sabah.(Bryan et al., 2013)

Unfortunately, common logging practices cause a lot of damage to the soil, species composition and to the abundance of large trees that are of major importance to many animals and plants in the tropical forests (Lindenmayer et al., 2014). Besides, deforested or heavily logged forests are typically drier than primary tropical forests. This increases the risk on fires, that have a major impact on the global carbon cycle (Jandl et al., 2007). Also, encourages timber extraction and logged-over forest to further conversion to other land uses (Ghazoul & Sheil, 2010). In Borneo, oil palm is considered the largest contributor to deforestation (HOB, 2012), with an annual increase of 70% between 1990 and 2008 (Goh, Kamlun, Anis, Adnan, & Phua, 2008). Oil palm nowadays has replaced most of the peat swamp forests in Sarawak, in total an area of 1,56 million ha of oil palm plantations (Wong, 2018).

All of this influences the current forest ability to regulate water and greenhouse gasses as well as the rich flora and fauna these forests inhabit (Ghazoul & Sheil, 2010). To reduce the greenhouse gas emissions, many countries, including Malaysia, signed the Kyoto Protocol (Ki-moon, n.d.), and the program Reduce Emissions from Deforestation and forest Degradation (REDD) was set up.

Mapping carbon stocks in very specific types of forest regions helps to a more sustainable use of those environments and contribute to the REDD program (Basuki, van Laake, Skidmore, & Hussin, 2009). It will achieve a better insight of the forests to protect in the context of climate change mitigation by identifying areas of high-biomass, old growth canopies and areas considered ecologically viable for recovery (Lindenmayer et al., 2014). Using alternative income sources, such as carbon offset projects, Malaysia might increase their efforts to protect remaining primary forest, reduce the need for intensive logging to increase carbon stocks on previously logged forests (Bryan et al., 2013). Also, carbon stock mapping could benefit other types of mapping for decision-making, such as for biodiversity protection, although high carbon stocks are not always correlated with high species diversity (Asner et al., 2018).

Assuming only timber is extracted from the forest the composition of species and dynamics will change (Johns, 1988). The number of lianas and palms will increase, and number of trees will decrease. Often this is not included in regrowth models of forests (P. Addo-Fordjour, Rahmad, & Shahrul, 2016). It is considered to be time consuming and have a little influence on the total carbon stocks the non-tree carbon mass (NTCM) is estimated to be 0,9-1,8% of the total carbon stock in the forest (Goodman et al., 2013). However, forest specific data and influence of logging on non-tree carbon mass NTCM is lacking. Hence, lianas and palms can have a large influence on the regrowth of commercial valuable timber species and indirectly on restocking of carbon. It is important to determine differences of abundance of those plant groups in different forest conditions to predict further development of the forest (Patrick Addo-Fordjour & Rahmad, 2013).

This thesis study focusses exclusively on mixed dipterocarp forest (0-700m) (*Figure 1 Sarawak forest types* (Osman et al., 2014)). Dipterocarp forests occur from sea level to an altitude of 900 meters. Mixed dipterocarp forests can be separated in three different types. Low dipterocarp forest (LDF) ranging from sea level up to an altitude of 300 meters, hill dipterocarp forest (HDF) between an altitude of 300 meters and 700 meters and upper dipterocarp forest (UDF) at an altitude of 700 up to 900 meters. In Sarawak lowland and hill dipterocarp forests together are known as mixed dipterocarp forests (MDF) ("The Malaysian Rainforest," 2014).Mixed dipterocarp forests in Sarawak contain over 2000 species of trees. Many of those species are present in large areas. However, density is often below one mature tree per hectare (Demies[1], Samejima[2], Sayok[3], & Noweg[3], 2019). This forest type characterizes with a dominance of trees from the family of *Dipterocarpaceae,* mostly Shorea species. Other important families are, *Burseraceae*, *Anacardiaceae* and *Euphorbiaceae* (Lee et al., 2002).

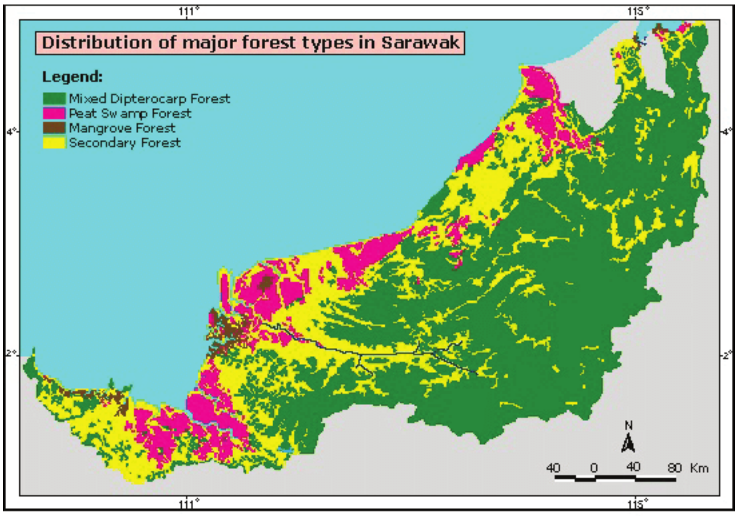

Figure 1 Sarawak forest types

1.1 Problem analysis

Carbon stock mapping can accelerate the identification, protection and recovery for forests that are considered to have a high conservation value (HCV) (Asner et al., 2018). Currently carbon stocks are often determined based on forest types and satellite images (Hairiah et al., 2010) Relying only on moderate resolution imagery of forests in this region would result in an 260% overestimate of remaining intact forests. The monitoring of carbon emissions based on moderate resolution satellite images that cannot define areas of forest degradation are likely to produce underestimates of the amount of forest to protect if used in global carbon accounting or REDD schemes (Bryan et al., 2013).

Field verification can improve estimation of carbon stocks in the forest. Assuming basal area is an accurate indicator for logging intensity in the forest. Therefore, basal area could influence the amount of NTCM in those forests.

Accurate estimations of palm and liana biomass in tropical forests are lacking. The scarcity of liana allometric equations is partly due to the difficulty in accessing the whole length of lianas from trees (Patrick Addo-Fordjour & Rahmad, 2013). According to previous research, assumptions of liana abundance in forests of Sarawak can be done, in terms of gradually declining percentages with fallow and age of the forest, where in primary forest lianas are of only minor importance (Gehring, Park, & Denich, 2004). Since lianas are disturbance adapted group of plants, they are likely to increase in abundance because of increasing disturbance in tropical forests, and therefore their biomass could even be higher. So, the importance of lianas in the forest would continue to increase with time, ignoring lianas in biomass assessment of forests could lead to underestimation of forest biomass and carbon stocks (Patrick Addo-Fordjour & Rahmad, 2013) (Walker et al., 2018).

Palm abundance in those forests is often unknown. Since palms do not have commercial timber value, it is often not assessed when carbon or biomass measurements are done for commercial logging purposes. The forest data, where only trees have been measured are mostly used to calculate carbon stocks. Though, palms can make a difference in the amount of carbon stored in those forests and could contain a higher percentage the total carbon stock in a forest after logging.

Mapping the forest canopy cover, and measure the carbon stocks in those forests, a more accurate estimation can be made if classified correctly. This method can improve the precision and accelerate the process of defining carbon stocks in different forest types, based on the cover percentage and the characteristics of the forest.

1.2 Objective and research questions

The main objective of this research followed from the problem analysis are:

Objective:
Identify the influence of basal area and canopy cover for lianas, palms, dead wood, understory vegetation and litter in the forest, to improve estimations of carbon stocks in mixed dipterocarp forest.

Research question 1:
What is the effect of logging on liana and palm abundance and carbon stock in MDF in Sarawak Malaysia?

Sub research question 1.1:
What is the amount of carbon (t/ha) in MDF of non-tree carbon mass (NTCM) per basal area class?
Sub-research question 1.2:
What is the amount of palm and liana carbon of the total carbon stock in MDF with a different basal area?
Sub-research question 1.3:
How can lianas and palms biomass be measured in MDF?

Research question 2:
Can carbon stocks be precisely identified based on canopy cover percentage in MDF in Sarawak Malaysia?

Sub- research question 2.1:
What is the amount of carbon (t/ha) in MDF with different canopy densities?

Hypothesis 1:
Liana abundance will increase, and palm abundance will stay the same after logging in MDF in Sarawak Malaysia. However, lianas and palms will both increase in overall percentage of the total forest biomass.
Hypothesis 2:
The total amount of AGB of trees declines and NTCM increases if the canopy cover percentage and the basal area reduces after logging.

2. MATERIALS AND METHODS

The following methods have been set up. A clear description of the measured plots for this research will be given. Followed up by a precise formulation of measuring different NTCM stocks. Assumed canopy cover and basal area is the major factor that influences NTCM, precise measuring and classification methods will be explained.

2.1 Plot set-up

All field data will be gathered in allocated plots of 0,1 ha (*Figure 2 Plot locations)* (*SFC geospatial activities and planning*, n.d.). These plots are divided in subplots of (A) 20x50 meter, (B) 20x10 meter and (C) 5x5 meter (*Figure 3 Plot layout)*. The plots used in this research are allocated by VHL and SFC for the 'Sarawak Forest Geospatial Project Phase II'. For Calculation of number of sample plots required for estimation of carbon stock within the project boundary, plot estimation formulas are automated in the WINROCK sample plot calculator following the methods of UNFCC, 2010, 2013, (Winrock Source Book & Winrock Plot estimator)**.**

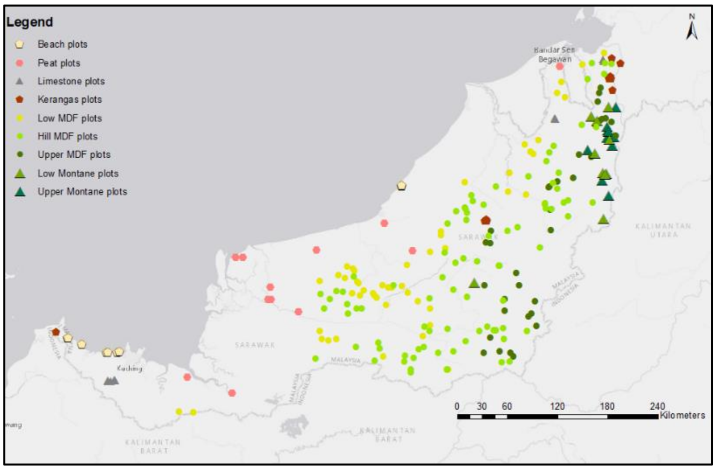

Figure 2 Plot locations

Plots are established in the field as near as possible to the allocated plot location. If plots are not accessible it must be relocated to an area with the same forest characteristics (forest type, logging intensity, elevation, slope etc.). the baseline at 0 meters of the plot will be the coordinate of the allocated plot. From there the plot will continue 50 meters in northern direction.

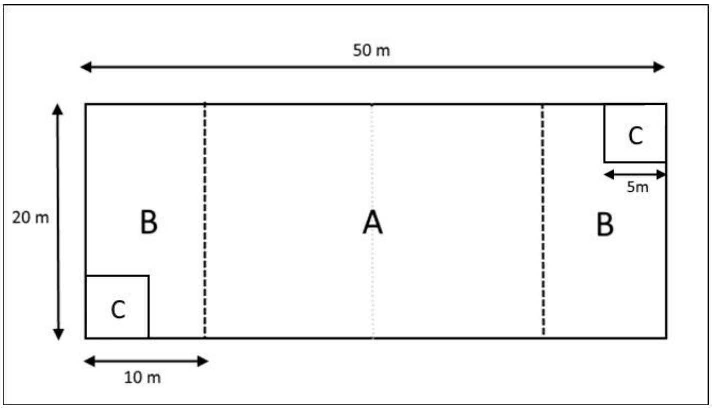

Figure 3 Plot layout

Out of all plots, a total 15 plots allocated for the Geospatial project are recorded for this research (*Table 1 Sample plots used for NTCM assessment*). These plots are in the FMUs and LPF of Shin Yang Trading Sdn. Bhd. and Samling Timber Sdn. Bhd. An additional 3 primary forest plots, located in Semenggoh Wildlife Reserve, are recorded to guarantee enough data of intact forest areas.

Table 1 Sample plots measured for NTCM assessment

Licence No.	Locality	Plot ID
LPF 0018	Shin Yang Trading LPF Bintulu	207, Extra1, Extra2
T0404	Samling Timber FMU Miri	55, 70
T0411	Samling Timber FMU Miri	70, 78, 212
T0412	Samling Timber FMU Miri	21, 57, 86
T0413	Samling Timber FMU Miri	51
T3228	Shin Yang Trading LPF Bintulu	219, 220, 225
	SFC Semenggoh Wildlife Reserve	Sem1, Sem2, Sem3

Before all measurements, general plot characteristics will be recorded. This includes GPS-points at each corner of the plot, forest type, forest condition, elevation, slope (percentage and aspect), soil type, date and team leader.

Forest condition will be recorded as follows based on own field observations, since it is not possible to define based on remote sensing:

- Primary (Unlogged)
  This includes national parks, steep slopes where no regular logging practices and helicopter logging has occurred or areas without any other type of human disturbance.
- Lightly logged
  This includes some areas where only a few trees have been extracted but the overall dynamics of the forest are mostly intact. Probably some areas where helicopter logging has been done or forest that has been used by local communities that has not been cleared in the past for slash and burn.
- Logged
  Forest that has been logged following the regular guidelines, skid trails are present. Clear difference from previous conditions; Tree DBH distribution is affected, canopy height dynamics has become more flattened. However, forest canopy looks still relatively dense (depending on time since logging). Forest still might recover when given enough time.
- Heavily logged
  Logged or logged-over forest with a low number of trees above the DBH-logging limit (Dipterocarps DBH >50 cm Non dipterocarps DBH>45 cm). Lot of skid trails present in the forest. Roads, skid trails and tree felling have clearly damaged other (smaller) trees in the forest. Overall canopy of the forest has been clearly affected and is now less dense. Soil has been disturbed a lot. Unlikely that the forest will recover over time.

Soil type will be recorded as:

- Sandy
- Clay
- Loam
- Alluvial

2.2 Measuring biomass

Aboveground plant biomass comprises all woody stems, branches and leaves of living trees, creepers, climbers, palms and epiphytes as well as understory plants and herbaceous growth (Hairiah et al., 2010). Below ground biomass comprises all roots and leached organic material in the soil (Hairiah et al., 2010). In the table below (*Table 2: Tools*) a description of needed materials will be given to gather all field data.

Table 2: Tools

Tool	What to measure	Unit
Measuring tape (50m)	Set out plot and measure length of fallen dead wood	m
Calliper (20 cm)	Measure Non-round liana diameter.	cm
DBH-tape	Measure trees, palms and liana DHB	cm
Flagging tape	Define (sub)plot boundaries	
GPS	Define plot locations	
Hanging scale (digital)	Weigh FW and DW of (sub)samples	g
Measuring tape	Measure length of fallen dead wood	cm
Mobile phone/tablet (Canopy App)	Define canopy cover	%
Oven	Dry subsamples	
Pruning shears	collect all understory plants inside sample plot	
Quadrat 0,50 m x 0,50 m (0,25 m2)/	Define sample plot	
Rangefinder	Define Height of the tree	m
Small Shovel	Collect litter layer	

2.2.1 Living trees

Living trees are the largest contributors to the carbon stock of a forest. The standard procedure will be applied to measure biomass.

Method

- Trees with a DBH >30 cm will be measured throughout the plot A (20x50 meters).
- Trees with a DBH between 10 and 30 cm will be measured in the two subplots B (10x20 meters).
- Saplings with a DBH between 2 and 10 cm will be measured inside the two subplots C (5x5 meters).
- All tree heights throughout the plot and subplots will be measured using a rangefinder.
- Tree species will be identified to improve accuracy.
- Record all data into the Field data sheet (*Appendix I: Field data sheet Trees, Lianas, Palms, Standing dead wood*)

Wood densities will be collected from the global wood density database. If species is unknown an average density of known species that are found in the field will be used.

2.2.2 Palms

Palms (*Arecaceae*) is a family of plants that can occur as climbers (rattan), tree-like and stemless form. Only tree-like palms will be measured. Other growth varieties will be included in the understory.

Method

- Palm DBH will be measured throughout the plot.
- Palms with a stem height >130cm and DBH >5cm will be measured. Smaller palms will be included in the understory measurements.
- All palm heights throughout the plot and subplots will be measured using a rangefinder.
- Palm Heights are measured from the base to the top of the stem.
- Multi-stem palms: All stems must be measured if the number of stems <10. If the multi-stem palm contains more than 10 stems and all stems have around the same diameter, measure 10 stems, take an average DBH and count the number of stems.
- Palm species will be identified.
- Estimate the palm leaf biomass. Leaf biomass is between 10– 65%.
- Record all data in field form Palms (*Appendix I: Field data sheet Trees, Lianas, Palms, Standing dead wood*)

Wood density of palms varies considerably by species and within the stem of the same species, and it can range from about 0.25 to almost 1.0 t/m^3 (Rich, 1987). The biomass of the leaves also must be added, which in total may range from 10 to 65% of the stem biomass (Frangi, Lugo, Forest, Frangi, & Service, 1985). Therefore, palm leaf biomass will be estimated in the field. Since palm stems are almost cylindrical. Stem height will be multiplied by the basal area (Goodman et al., 2013).

2.2.3 Lianas

Lianas have been shown to have large effect on trees in primary tropical forests and on forests after logging (Putz & Chai, 1987) (Schnitzer, Rutishauser, & Aguilar, 2008)**.** Aboveground competition is the dominant effect that lianas have on trees therefore biomass assessments of lianas may be important to create an estimation about the development of the forest and its carbon stock. Since the biomass of lianas varies significantly between land cover types (Hairiah et al., 2010).

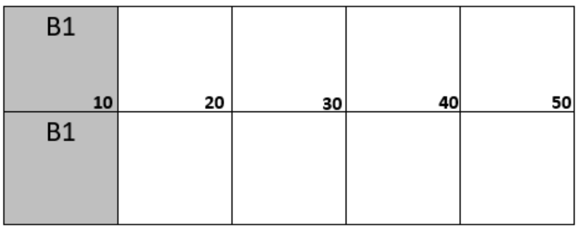

Figure 4 Liana subplot

Method

- Lianas will be measured in subplot B1 of 10x20 meter (*Figure 4 Liana subplot)*
- Only emerging lianas should be measured. Lianas creeping on the soil surface should be included in the understory measurements.
- Only ascending lianas where DBH >1cm will be measured (Schnitzer et al., 2008).
- For non-round liana stems, measure the minimum diameter (Gehring et al., 2004). Pre-tests had shown the minimum diameter to be better correlated with shoot length than the maximum diameter (Gehring et al., 2004).
- Lianas tend to grow in many ways into the host tree in the figure below (*Figure 5: Liana diameter measurement*) the locations of where to measure the diameter of those lianas (Schnitzer et al., 2008).
- Liana species/genus/family will be identified if possible.
- Record all data into the field data sheet (*Appendix I: Field data sheet Trees, Lianas, Palms, Standing dead wood*))

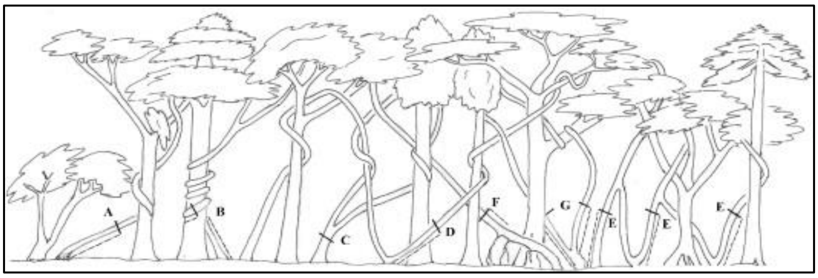

Figure 5 Liana diameter measurement

Measuring liana length in the field is impossible without harvesting them. Therefore, it is almost not possible to use allometric equations including liana length. The allometric equations which used only liana diameter as the predictor are recommended for use in liana biomass determination (Patrick Addo-Fordjour & Rahmad, 2013). The equation below has been proven to be best applicable in defining AGB of Lianas in tropical forests when only the diameter is known (Patrick Addo-Fordjour & Rahmad, 2013).

Log10(Total Biomass) = c+α(Log10D)
c = 0,490 ± 0,021
α=1,090 ± 0,027
D= Liana diameter
CF=1.002

2.2.4 Understory

The understory consists all plants under the main canopy. Some species commonly found are ferns, epiphytes, grasses, bananas and saplings of the emergent species (Chave et al., 2014). Understory sampling must be carried out destructively (Hairiah et al., 2010).

Method

- Collect all understory vegetation inside the quadrat of 0.50 m × 0.50 m (0.25 m2) every 10 m on the 5m-line of the plot. The first sample should be taken at 5 meters from the edge of the plot. In total 5 samples per plot should be collected (*Figure 6: Understory sample plots*).

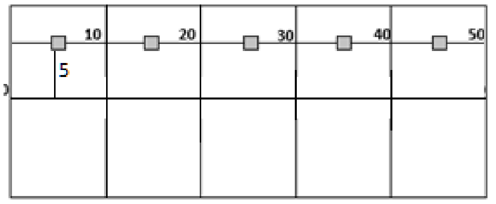

Figure 6 Understory sample plots

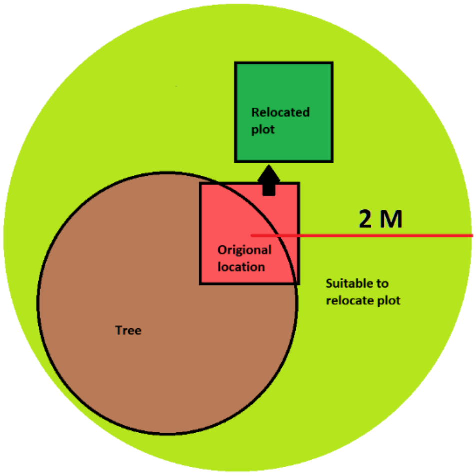

Figure 7 Relocate sample plot

- If a tree stem covers more than 10% of the sample plot the quadrat is moved to another location within a 2 m radius from the original place. Preferably as close as possible to the original location (*Figure 7 Relocate sample plot*).
- When fieldworkers have walked through the location of sampling it is recommended to choose a place that is still intact (as it was before the fieldworkers entered the plot) as close as possible to the original location. Even when instructed it is not always possible for fieldwork members to avoid these locations when other measurements must be done too. For example, chopping a path through understory vegetation and avoiding rattan.
- Weigh the empty plastic bag and write down on field data sheet.
- Collect all aboveground vegetation and cut on the soil surface. Do not pull the plant out of the soil, roots are not measured in the understory vegetation.
- Cut all vegetation in the quadrat and place it in a plastic bag.
- Small palms DBH<5cm should be cut and weighed too. Cut those as low to the soil surface as possible.
- Weigh directly to get fresh weight (FW) in the field (g/0.25 m2) write down total weight. (sample + plastic bag).
- When collecting next sample just add to previous sample(s) and weigh total weight. Specific weight of the sample will be calculated later.
- Weigh small plastic bag and write down on the field data sheet. Chop and mix all 5 samples. Take subsample of 100-150 grams (without weight of plastic bag), put subsample in the small plastic bag.
- Label the subsample with the plot identification number, subsample identification number, and weight of subsample. **Example: P1U106 (P1=PlotID, U=Understory, 106= weight of subsample)**
- Record all data into the field data sheet (*Appendix II: Field data sheet: Understory, Litter, Canopy, Fallen Dead Wood*).
- Place sample in the oven at 85 C for at least 48 hours, weigh its dry weight (DW).
- Calculate wet-to-dry ratio. This ratio will be used to estimate the total dry weight of litter found within the sample plot.

2.2.5 Dead trees

Dead trees may take about 10 years to decompose, and the necromass is about 10% of total aboveground carbon stock in a healthy natural forest. Logging tends to focus on the more valuable trees, damaging many others. After logging, the necromass may be 30–40% of the aboveground carbon stock (Walker et al., 2018). Hence makes measuring dead wood important to precisely calculate carbon stocks in the selected forest.

Method

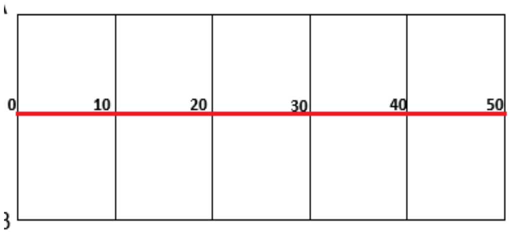

Figure 8 Transect dead trees

- Standing dead trees with a DBH >10 cm will be measured throughout the plot, using a pi-tape and rangefinder.
- Dead tree stumps height >130 cm should be included in the field data sheet of Appendix I (*Appendix I: Field data sheet Trees, Lianas, Palms, Standing dead wood*). Tree stumps on the transect, with a height <130 cm are included

in the field data sheet of Appendix II (*Appendix II: Field data sheet: Understory, Litter, Canopy, Fallen Dead Wood*).

- A piece of fallen dead wood should only be measured if: more than 50% of the log is aboveground, and the sampling line crosses through at least 50% of the diameter of the piece.
- Fallen dead wood will be measured on a 50 m transect on the baseline of the sample plot (*Figure 8: Transect dead trees*).
- All fallen dead wood with a diameter >5 cm and/or >50 cm length will be measured. Using a calliper or measuring tape.
- Tree species will be identified, if possible.
- Record all transect data into the field data sheet (*Appendix II: Field data sheet: Understory, Litter, Canopy, Fallen Dead Wood*)

Total area measured for the transect is for trees where DBH>5cm and DBH<30 cm 5 meters from each side of the transect. So all measured dead wood compromises an area of 10x50 m. Trees where DBH>30 cm will be measured if it crosses the transect and accounts for the total plot 20x50 meters.
Biomass of standing and fallen dead tree volume will be calculated as cylinders, since the specific tree biomass equations are not suitable to be applied.

2.2.6 Litter

The litter layer is defined as all dead organic surface material on top of the mineral soil. Some of this material will still be recognizable (dead leaves, twigs, dead grasses, and small branches) and some will be unidentifiable decomposed fragments of organic material. Note that dead wood with a diameter of less than 10 cm and a length less than 50 cm is included in the litter layer (Walker et al., 2018). The carbon stock of litter fall in a tropical rain forest is typically about 10 t/ha/yr , with a mean residence time in the litter layer of about 1 year (Jandl et al., 2007). However, in every tropical forest this can differ per location. Therefore, it is important to measure the carbon stocks.

Method (Hairiah et al., 2010)

- Collect all litter inside the quadrat of 0.50 m × 0.50 m (0.25 m2) every 10 m along the centreline of the plot. The first sample should be taken at 5 meters from the edge of the plot. In total 5 samples per plot should be collected (*Figure 9 Litter sample plots*).

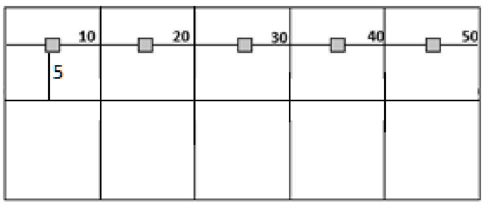

Figure 9 Litter sample plots

- If a tree stem covers more than 10% of the sample plot the quadrat is moved to another location within a 2 m radius from the original place. Preferably as close as possible to the original location (*Figure 7 Relocate sample plot*).
- When fieldworkers have walked through the location of sampling it is recommended to choose a place that is still intact (as it was before the fieldworkers entered the plot) as close as possible to the original location. Even when instructed it is not always possible for fieldwork members to avoid these locations when other measurements must be done too. For example, chopping a path through understory vegetation and avoiding rattan.
- Weigh the empty plastic bag and write down on field data sheet.
- Take a coarse litter sample, (any tree necromass < 10 cm diameter and/or < 50 cm length, undecomposed plant materials or crop residues, all unburned leaves and branches).
- Collect the fine litter in the organic layer (0–5 cm above mineral soil layer) including all woody roots.
- Weigh directly to get fresh weight (FW) in the field (g/0.25 m2) write down total weight. (sample + plastic bag).
- When collecting next sample just add to previous sample(s) and weigh total weight. Specific weight of the sample will be calculated later. Write down total weight.

- Weigh small plastic bag and write down on the field data sheet. Chop and mix all 5 samples. Take subsample of 100-150 grams (without weight of plastic bag), put subsample in the small plastic bag.
- Label the subsample with the plot identification number, subsample identification number, and weight of subsample. **Example: P1L106 (P1=PlotID, L=Litter, 106= Weight of subsample)**
- Record all data into the field data sheet (*Appendix II: Field data sheet: Understory, Litter, Canopy, Fallen Dead Wood*).
- Place sample in the oven at 85 C for at least 48 hours, weigh its dry weight (DW).
- Calculate wet-to-dry ratio. This ratio will be used to estimate the total dry weight of litter found within the sample plot.

2.2.7 Below ground biomass

Below ground biomass sampling will not be done since it is very time consuming. Ratios are known to apply to get an accurate enough estimation of carbon content in the soil.

For mixed tropical forests a ratio of 4:1 is used for aboveground to belowground biomass. In very wet forests the ratio can shift upwards to 10:1 (Hairiah et al., 2010). These ratios will be according to the forest type be applied on the measured AGB of those forests.
Belowground biomass for trees can be calculated following (Mokany et al. (2006))

$$BGBtrees = AGB\text{trees (t/ha)} * 0{,}235$$

2.3 Biomass to carbon

The carbon content of individual trees, and hence patches of forest depends for an important part on knowledge of the tissue density of a given tree. (Chave et al., 2005). Ignoring variations in wood density may result in poor overall predictions of AGB (Baker et al., 2004).

Therefore, carbon stocks will be calculated using the found wood densities, if no species-specific wood densities were found then generic allometric equations will be used (Chave et al., 2014). The carbon stock of a single tree can be estimated by multiplying the carbon content conversion factor by the biomass Average wood density is assumed to be 0.6 (g/cm3) for all trees. And average carbon content is 0,5 for unidentified species. Therefore, this factor will be used for unknown tree species.
Use a default value of 0.46 to calculate carbon content for the understory and litter layer. (Hairiah et al., 2010).

- For living trees, Dead trees and palms its corresponding value will be used to calculate the biomass and carbon content. A wood density of 0,6 (g/cm3) and carbon conversion factor of 0,5 will be applied if the species cannot be identified.
- For the understory, the default value of 0,46 will be applied to calculate carbon content.
- For lianas, the default value of 0,5 will be applied to calculate the carbon content.
- For the litter layer, the default value of 0,46 will be applied to calculate the carbon content.
- For the BGB of everything except trees, the default value of 0,46 will be applied to calculate the carbon content.
- All values will be summed up to calculate the total carbon stock (t/ha) per plot.

2.4 Canopy cover

To measure the canopy of the forest the sample plots are divided into 10 equal subplots of 10x10 meter (*Figure 10: Plot layout for canopy cover measurement*). In every subplot a minimum of one measurement of the canopy cover will be done using Gap Light Analysis Mobile App (GLAMA). In total every plot will have a minimum of 20 measurements to calculate the average canopy density. Preferable, every measurement will be done in the centre of each subplot. When a tree is located at this position another location inside this subplot will be chosen during fieldwork. When more time available, it is recommended to increase the amount canopy measurements.

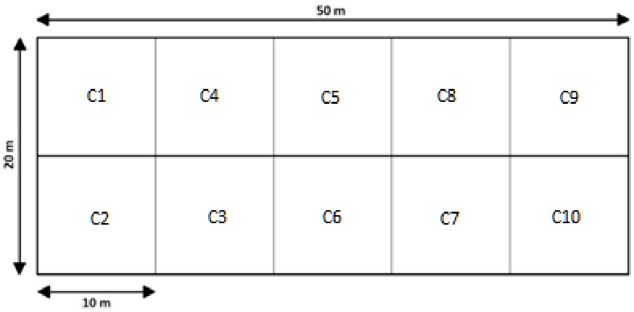

Figure 10 Plot layout for canopy cover measurement

Another method will be applied as well. For this method in total 15 photos will be analysed. The photos are taken at the centreline at the edge of B1 and A, in the centre of the plot in A and at the edge of B2 and A. from these points 5 photos will be taken. One on the exact point and one 5 meters from this point in every direction (north, east, south, west).

The number that will be used, given by GLAMA, is the Modified Canopy Cover Index (Modif. CaCo Index). This gives the best estimation of the perpendicular projection of the canopy cover (Tichy, 2016).

These two methods together will result in a total of 35 measurements. Combining these two methods makes an evenly distributed sampling of the canopy cover throughout the plot.

The average of every plot will be calculated. All data will be recorded in the field data sheet *(Appendix II: Field data sheet: Understory, Litter, Canopy, Fallen Dead Wood*)

2.5 Logging impact on carbon stocks

Diagrams and regression models are used to determine the biomass and abundance of lianas, palms and NTCM in different stages of the forest. Where on the x-axis the BA or BA-Class and on the y-axis the carbon stock or number of palms, lianas, dead trees and NTCM.

2.6 Carbon stocks and canopy cover

To determine if there is a correlation between total carbon stocks and the canopy cover and between NTCM and canopy cover, scatterplots and diagrams will be used. Lianas and palms will also be separately analysed to find out whether they are influenced differently on canopy cover than the rest of the factors that add up to the total NTCM. This analysis will result in the following models:

- Liana carbon stock correlated to the plot average Modif. CaCo Index
- Palm carbon stock correlated to the plot average Modif. CaCo Index
- Total NTCM correlated to the plot average Modif. CaCo Index
- Total carbon stock (NTCM + trees) correlated to the plot average Modif. CaCo Index

3 RESULTS

In total 18 plots have been measured. All different carbon stocks present in the forest have been calculated and are correlated to the tree basal area per plot. These are presented in various scatterplots.

3.1 Total carbon stocks and NTCM

The Tree BA (m2/ha) is subdivided into 4 different classes where each average per carbon pool is shown. As well as the average carbon mass for each different carbon pool of all plots combined (*Table 3 Carbon pools*) (*Figure 11 Carbon pools*).
On average the NTCM is about 10% of the total carbon stocks in the forest. In BA-classes 10-20 and 20-30 the NTCM is largest and can consist up to 16% of the carbon stocks. When BA-increases NTCM reduces to 5% (BA 40-50)

Table 3 Carbon pools; this table shows all average carbon stocks (t/ha) in forests per BA-Class. Measured plots for trees n=15, for and for NTCM n=18. For Lianas per where tree BA-is known n=13 and average n=16

	NTCM (t/ha)								Trees Carbon (t/ha)			Total Carbon (t/ha)
Carbon pool:	Lianas	Palms	Understory vegetation	Litter	Standing dead trees	Fallen dead trees	Soil	Total NTCM	Trees AGB C	Tree BGB C	Total Trees	**Total**
BA 10-20 (n=3)	1.1	0.01	0.7	2.7	0.9	2.8	1.8	10.1	56.4	13.2	69.6	**79.7**
BA 20-30 (n=4)	1.9	0.00	0.5	4.3	10.0	4.5	2.8	24.0	100.5	23.6	124.1	**148.2**
BA 30-40 (n=5)	2.2	0.01	0.6	3.8	3.4	3.1	2.4	15.6	149.6	35.2	184.7	**200.3**
BA 40-50 (n=3)	2.7	0.00	0.8	3.5	1.0	2.3	2.3	12.7	192.8	45.3	238.1	**250.8**
Average all plots (n=15/18)	**2.5**	**0.00**	**0.8**	**4.0**	**3.8**	**2.9**	**2.6**	**16.6**	**126.5**	**29.7**	**156.2**	**172.8**

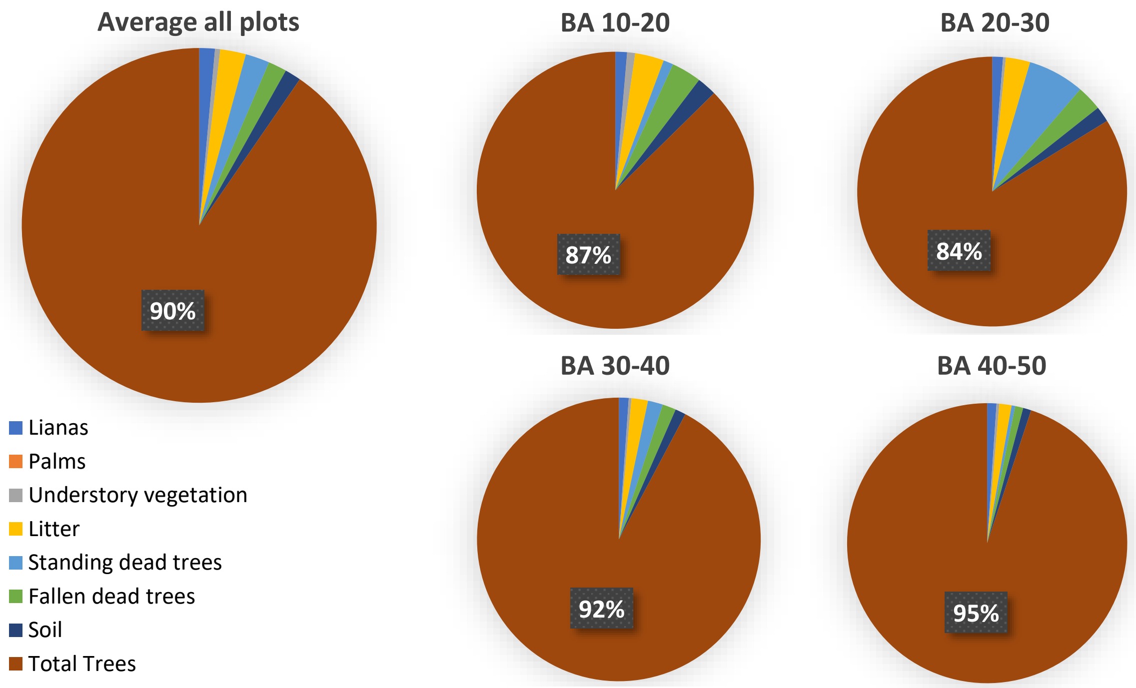

Figure 11 Carbon pools; these pie charts show the amount of NTCM in forests with different BA-Class. The percentage of tree carbon stock is given. visible is that the biggest change in NTCM is between BA-Class 30-40 and 20-30 of 8%

3.1.1 Carbon stock living trees

In the table (Appendix IIII: Carbon data tables, *Table A)* the total carbon mass of all trees per ha have been calculated. Plot Sem1, Sem2 and Sem3 were left out since trees have not been measured in these plots. Wood densities of all known species was used (*Appendix III: Tree data table*).

The table shows an average carbon stock of 156,2 t/ha. However, tree carbon stock per plot ranges between 61,1 t/ha and 318,2 t/ha.

3.1.2 Carbon stock palms

A total of 6 palms were measured distributed over 4 plots. The highest measured carbon stock was 0,04 t/ha

3.1.3 Carbon stock lianas

All calculated data used in the graphs can be found in the appendices (*Appendix IIII: Carbon data tables*, *Table: B, C*)
A moderate correlation between liana carbon and basal area of trees could be found (R^2 =0,4363) (*Figure 12 Liana carbon stock*). For the data analysis 2 plots were not included since those were too much off compared to the rest of the data. This is probably due to another factor that was not present in the other plots, therefore it is not reliable to add to this analysis.

The number of lianas has also been assessed based on the basal area of the specific plot. This showed again more or less the same results as in the graphs were carbon stock has been used (R^2=0,4323) (*Figure 13 Number of lianas*).

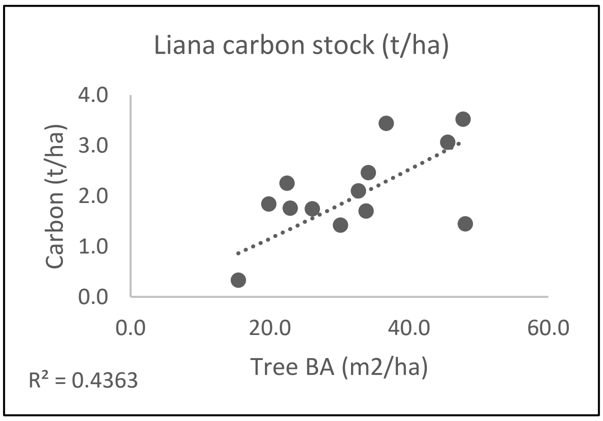

Figure 12 Liana carbon stock; The amount of liana carbon that has been measured correlated to the tree basal area per ha of all trees DBH >10cm.

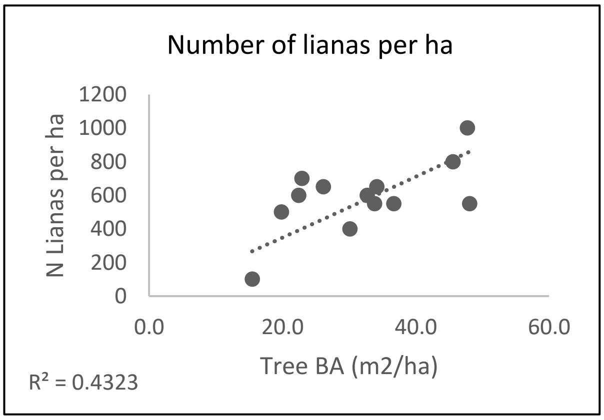

Figure 13 Number of lianas; The number of lianas that have been measured correlated to the tree basal area per ha of all trees DBH>10cm.

Looking at the carbon content and the number of lianas, it is stronger correlated to the basal area of trees with DBH>10 than the basal area of all trees with DBH>30. However, it shows only a moderate correlation between basal area and carbon content and basal area and number of lianas. Correlation was the strongest for Liana Carbon and total basal area of all trees where DBH>10, (R^2=0.3809) (*Figures 14-17*).

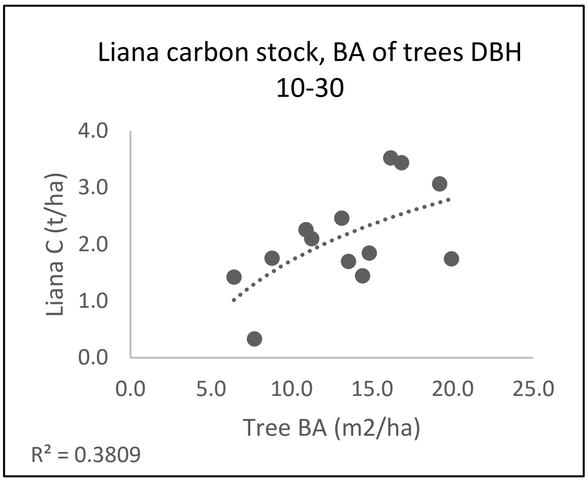

Figure 14 Liana carbon stock BA of trees DBH 10-30

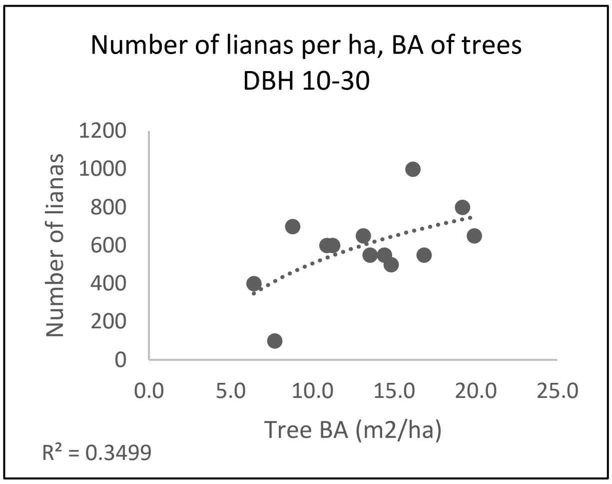

Figure 15 Number of lianas BA of trees DBH 10-30

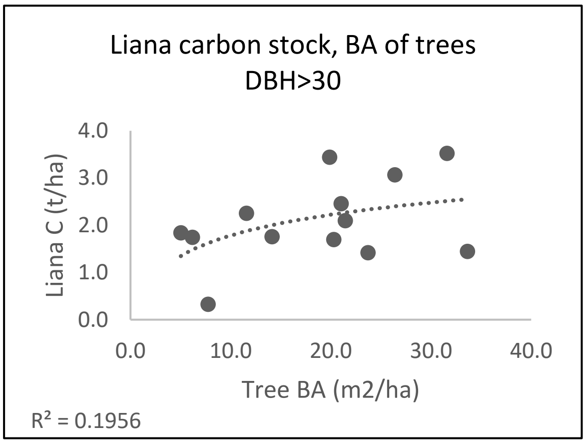

Figure 16 Liana carbon stock BA of trees DBH>30

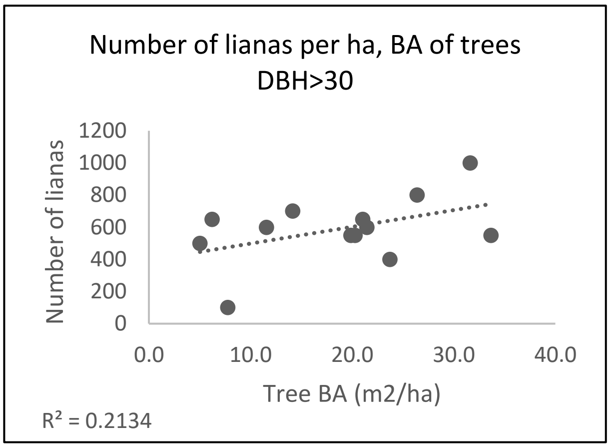

Figure 17 Number of lianas BA of trees DBH>30

3.1.4 Carbon stock understory and litter

In the following table (*Appendix IIII: Carbon data tables, Table D*) and graph the carbon mass of both Understory and Litter have been calculated. However, the trend lines show a weak correlation when the change in carbon stocks of litter and understory vegetation is compared with the tree BA. Understory vegetation showed an almost flat line (R^2=0,0885). For Litter, there is a slight increase of carbon but shows a weak correlation (R^2=0,0664). So, there is no significant difference in litter carbon stocks between forests with a different BA (*Figure 18 Litter and understory carbon*).

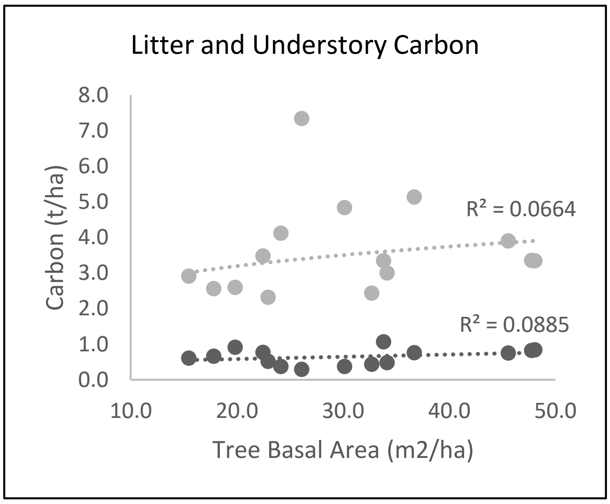

Figure 18 Litter and understory carbon; carbon stock of litter and understory vegetation correlated with the tree basal area per ha

3.1.5 Carbon stock dead trees

The carbon stock of dead trees was calculated. The graph (*Figure 19: fallen dead trees carbon*) shows a decrease of fallen dead trees in forests when BA increases. However, a very weak correlation is present (R^2= 0,0469).

Standing dead trees also show a weak correlation (R^2=0,0866). There is a slight increase in carbon stock and peaks where BA is around 25m2 (*Figure 20 Standing dead trees carbon*)

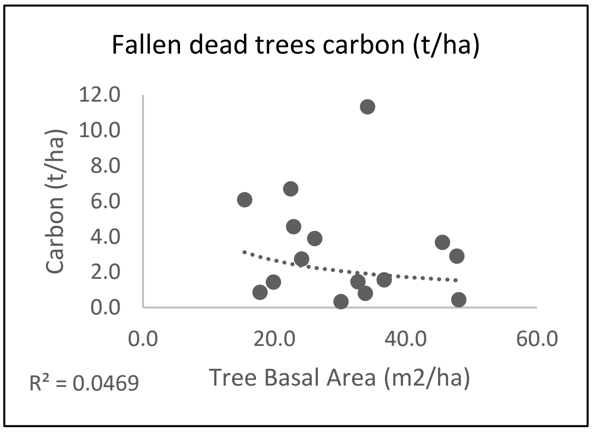

Figure 19 Fallen dead trees carbon

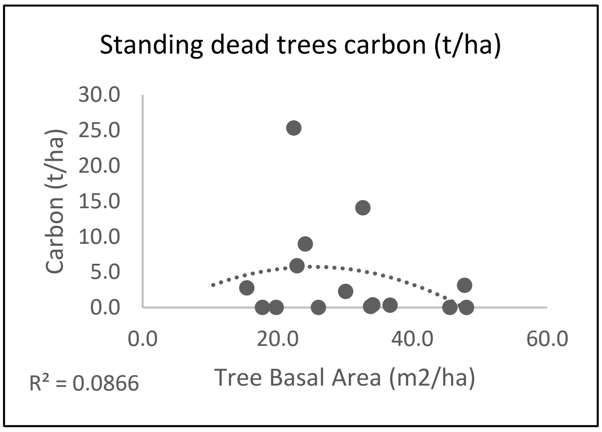

Figure 20 Standing dead trees carbon

3.2 Canopy cover and carbon stocks

The average of 35 measurements of Modif. CaCo Index per plot has been calculated

For the graphs, the tables of (*Appendix V: Canopy cover tables, Table: C, D, E*) have been used. The first analysis is whether basal area is linked to the canopy cover. No correlation is present between basal area of the forest and the canopy cover (R^2= 0,0006) (*Figure 21 Tree basal area and CaCo%*). An explanation for this is that trees tend to use as much space as possible that is available in the canopy. Therefore, even when basal area is low the canopy will still be closed. Only after logging or natural regeneration gaps will appear that influence these factors.

The second factor tht is analysed is if liana carbon stocks are influenced by the canopy cover. The graph shows an negative trendline, when canopy cover increases the liana carbon stock will reduce. However it shows a weak correlation (R^2=0.218) (*Figure 22 Liana carbon and CaCo%*).

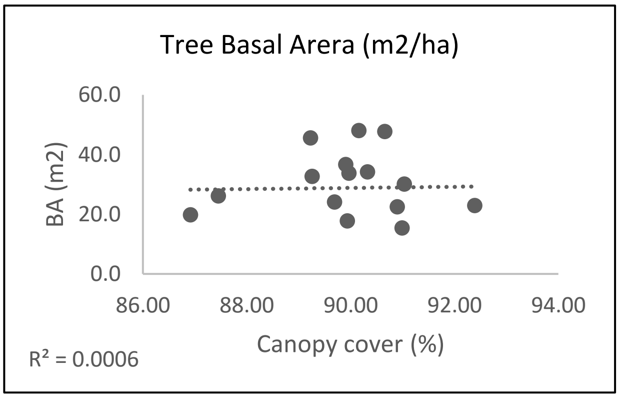

Figure 21 Tree basal area and CaCo%

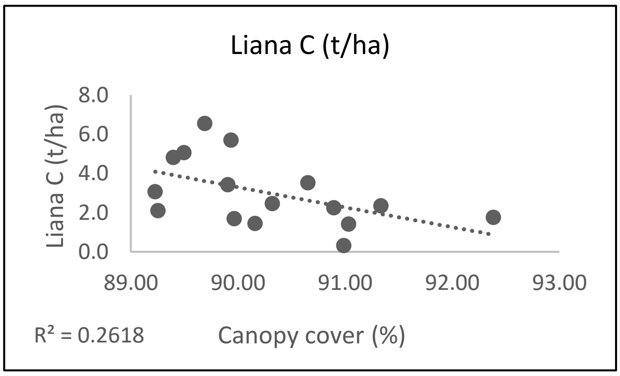

Figure 22 Liana carbon and CaCo%

The total NTCM increases slightly when the CaCo increases, this is in contrast with the liana carbon mass, which reduces if the CaCo increases. Possibly other carbon pools increase with a denser canopy and lianas reduce. However, only a weak correlation is visible (R^2=0,0275) (*Figure 23 Total NTCM and CaCo%*).

Last, the total carbon stocks present in the forest have been analysed in the graph. This shows an increase of carbon mass when canopy cover increases too. However, again no significant relationship between those two factors can be determined (R^2=0,0255) (*Figure 25 Total carbon stock and CaCo%*).

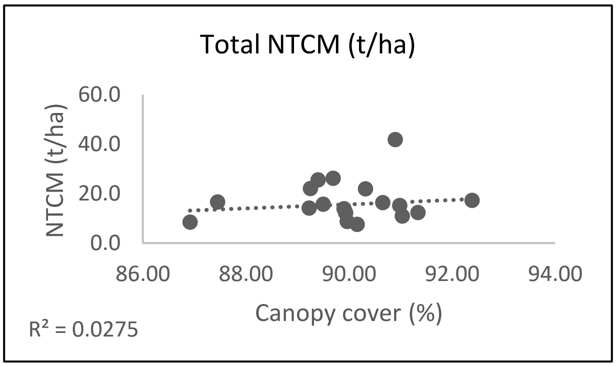

Figure 23 Total NTCM and CaCo%

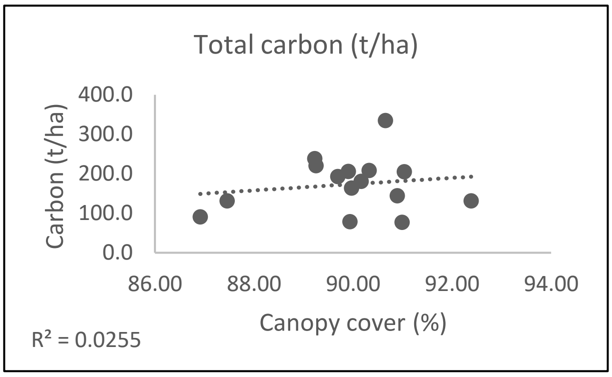

Figure 24 Total carbon stock and CaCo%

4 DISCUSSION

This research was focussed on answering the two main research questions. Can carbon stocks be precisely identified based on canopy cover percentage in MDF in Sarawak Malaysia? What is the effect of logging on liana and palm abundance and carbon stock in MDF in Sarawak Malaysia? During the research several factors could have influenced the outcome of the results. In this chapter first the findings will be given followed by the factors that could have influenced the research.

Results

The results of the data analysis indicated that canopy cover measured with GLAMA does not correlate with the amount of carbon stored in the forest. Therefore, it is not possible to identify carbon stocks in forests using GLAMA. The second result indicated that liana carbon stock correlates with the tree basal area. The higher basal area the higher the liana carbon stock. An insufficient number of palms were recorded to use in the data analysis. On average consists NTCM 10% of the total carbon mass in MDF. However, this increases in highly disturbed forests.

Trees

The first carbon pool that has been calculated were trees. To estimate the amount of carbon wood density is the largest influencing factor that could have affected the total carbon mass. The carbon content of wood may vary considerably between species and between sites (Thomas and Malczewski, 2007). A specific tree species can have denser wood in the one site compared to the other (Verwer & van der Meer, 2010). Site specific data was not integrated in this research, only the wood densities of known species present in the Global Wood Density Database were used (Zanne et al., 2009). For unknown species a wood density of 0,6 was applied. Other factors that could have influenced the outcome is the formula used to calculate the volume of the trees. A factor of 0,7 was used. However, every tree species has its specific growth and may needs a species-specific volume equation for better estimations of the biomass.

Information about time since logging and the amount of timber extracted from the forest was not available. Thus, makes it difficult to incorporate the changes the forest location has undergone and comparisons between previous and current tree biomass at the location could not be made. During analysis of the tree data, only a few large trees (DBH>100 cm) were recorded. These large trees influence the total carbon stock a lot. Converting plot data to hectares estimates that the amount of these large trees is 10 times bigger than measured. However, it is unlikely that this number of large trees are present inside these forests, since all plots were located inside logging concession area. Therefore, carbon stocks of plots where only one or two of these large trees have been measured are possibly lower than calculated.

Plot location

The total carbon stocks per hectare could differ due to slope steepness of the plots. This has not been calculated and adjusted. In the field this takes too much time. Therefore, possibly some 50x50 m plots are bigger or smaller than 0,1 ha. During fieldwork we tried to measure as accurate as possible. However, on some locations this could not be avoided.

Non-tree carbon mass

Liana species could not be identified due to lack of knowledge and time. Also, very little is known about liana species and its wood densities (Patrick Addo-Fordjour & Rahmad, 2013). Therefore, wood densities of different species of lianas could not be integrated into the data analysis and a standard value of 0,46 g/cm3 was used. Besides wood density another explanation that influences liana carbon stock and abundance is cutting lianas to prevent damage to other trees as pre-harvesting practice (Gerwing & Vidal, 2002). This leads to a low number and biomass of lianas in forests where BA is low. Because those forests have recently been logged, lianas did not have time to grow back. Whereas forests with higher BA have been logged longer time ago or have not been logged that heavily, lianas were much more abundant. The allometric equation could also have influenced the outcome of the liana biomass, since only one equation was used for all lianas. While each species could have different growth characteristics thus influencing the total liana biomass (Putz, 1990).

Litter sample collection was done as precise as possible however contamination of soil still could have affected the outcome of the wet-to-dry ratio and the total biomass per sample plot (Frangi et al., 1985). Another factor that influenced the wet-to-dry ratio was the weight scale, the one used in the field was accurate to 5 grams. Subsamples were weighed again in the lab after the fieldwork trips, on a more accurate scale but, decomposition and evaporation might influence the fresh weight.
Dead trees could not always be identified, therefore a standard value for wood density was used. The total bio- and carbon mass could be higher or lower when species specific wood density values are applied. Besides, the fallen dead tree volume was calculated as cylinder. For larger trees this could have created overestimations of biomass and carbon stock. A possible factor that could have underestimated this biomass is that the fallen dead trees were measured on a transect. More accurate estimations can be made if another method of measuring all large fallen dead trees and tree stumps throughout the plot that for example are bigger than 30cm DBH and longer than 2 meters.

Also, some plots contained a lot of large dead trees what might causes overestimations in NTCM since dead wood is the biggest contributor to the carbon stock after living trees.
Depending on the time since logging, it is most likely to have higher estimations of NTCM when forests have recently been logged than when trees have been felled some years before and the dead wood has had some time to decompose (Walker et al., 2018).

Below ground biomass was not assessed and a standard value has been used. For more accurate estimations, area specific samples should be taken and analysed.

Canopy cover
The program GLAMA highly suits temperate forest but not necessarily tropical forest. This was realised when forest canopy percentage results all were between 86-91% even at plots earlier identified as low and medium dense canopy cover. The field sampling strategy must avoid potential bias in canopy characterization that can occur due to patchiness of the forest canopy, especially if images are captured only from openings between trunks. Tropical forest has a much broader canopy than temperate forest hence three GLAMA focal points may even be under one canopy rendering no value variation (Report SFC August 2018).

Remarkable is that liana biomass increases when basal area does too. Assuming higher basal area results in a forest condition that resembles primary forest conditions more, that canopy cover gets denser. So, higher basal area will result in a denser canopy, thus higher liana biomass. Assuming forests with lower basal area have been logged more frequently and/or more recently and preharvest operations (removing lianas before logging) have been done, could explain the increase of liana carbon stock in forests with higher basal area.
However, according to the results of GLAMA, liana biomass decreases when the canopy gets more closed (*Figure 22 Liana carbon and CaCo%*). This proves the assumptions of growth of lianas that are considered a disturbance adapted group according to (Patrick Addo-Fordjour & Rahmad, 2013), thus, increasing biomass after disturbance (reduced canopy density) for example due to logging. But, since it is uncertain if GLAMA is suitable to use in tropical forests, and shows a weaker correlation than lianas linked to tree basal area, it is recommended to use the model of tree basal area to predict liana biomass in future assessments.

5 CONCLUSION

- The average NTCM in MDF is 10% of the total carbon stock in the forest. However, in forests with basal area between 10-30 m2/ha, NTCM can shift up to 16%. In forests with higher basal area the NTCM reduces to 5% where basal area is 40-50 m2/ha.
- Primary forests contain the highest carbon stock. However, NTCM is smallest in those forests.
- Lianas carbon stock and number of lianas increase when the basal area increases.
- Liana carbon stock and number is more correlated to the basal area of trees where DBH 10-30 than to basal area of trees where DBH>30
- Litter carbon stock increases if the basal area does, however no correlation can be proved.
- Understory vegetation stays the same when basal area of trees increases.
- Standing dead tree carbon increases in forests with a basal area around 25m2. Forests with higher basal area, the dead wood carbon stocks decrease.
- Fallen dead wood slightly reduces when tree basal area increases.
- No moderate or strong correlations could be found for canopy cover index and carbons stocks in the forests. Therefore, carbon stock cannot be identified using GLAMA in MDF

6 RECOMMENDATIONS

Recommendations for future research:

- Increase the number of measured plots.
- Develop species specific allometric equations to calculate tree volume for better biomass estimations.
- Adjust plot surface according to slope steepness before calculating biomass per ha.
- Identify liana species and measure wood densities.
- Improve allometric equations for lianas.
- Conduct more research about the influence of lianas on the development of tree growth for logging and/or conservation purposes.
- It is recommended not to use GLAMA for canopy cover assessments, app-improvements for measuring tropical forest canopies are necessary before this would be suitable to use in future research.

Recommendations for forest management, conservation purposes and carbon offset programs:

- For future logging and forest conservation purposes it is recommended to use the correlation found in this research to estimate liana biomass in MDF.

- In terms of climate change and carbon offset programs it is recommended to include non-tree carbon mass assessments in forests to improve estimations of carbon stocks in the forests since those could make a huge difference between actual and estimated carbon stock. This to improve selecting areas with high carbon storage or areas with potential or restocking large amounts of carbon.
- It is recommended to use the models of this research to create better estimations of total forest carbon stocks to improve decision making of areas that have an HCV for carbon offset programs.

- Develop an easy mobile program to identify the canopy cover quickly in the field that is specified for tropical forests.

- Develop a long-term monitoring system for carbon stocks of the LPF's, FMU's, and TPA's in Sarawak where trees as well as lianas will be measured to get insight in the development of logged and unlogged forests and the effect of lianas in restocking of carbon in forests.

- Preserve the last remaining areas of primary rainforest that have never been logged and are almost untouched as TPA. Those have highest carbon stocks and are considered to have a HCV for carbon offset programs and nature conservation.

- Expand the PFE-system to prevent conversion to other land use systems and enhance them via forest management certification and exclude logging in the last remaining intact forests. Only non-forest should be considered as an alternative for new plantations. New oil palm and pulpwood plantations should only be established in areas that are neither forested nor containing values for biodiversity conservation and protection of ecosystem services.

- Develop and implement payment system for environmental services that include conservation financing and sustainable financing such as carbon offset programs.

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APPENDICES

Appendix I: Field data sheet Trees, Lianas, Palms, Standing dead wood
Appendix II: Field data sheet: Understory, Litter, Canopy, Fallen Dead Wood
Appendix III: Tree data tables
Appendix IIII: Carbon data tables
Appendix V: Canopy cover tables

Appendix I: Field data sheet Trees, Lianas, Palms, Standing dead wood

Plot ID:		**Date:**			**Team leader:**		
Locality:					**License No.:**		
GPS coordinate (Corner A):							
Subplot (A / B1, B2)	**Species**	**DBH (cm)**	**Height (m)**		**Canopy size (m)**		**Remarks (Palm) (Liana + R/NR)**
			M	**T**	**X**	**Y**	

Appendix II: Field data sheet: Understory, Litter, Canopy, Fallen Dead Wood

Plot ID:		Date:	Team leader:		
Locality:			License No.:		
Elevation:			Forest type:		
GPS Coordinate (Corner A):					
Understory (U)			Litter (L)		
Sample number	Total FW (kg)	Sub sample FW (kg)	Sample number	Total FW (kg)	Sub sample FW (kg)
1			1		
2			2		
3			3		
4			4		
5			5		

Subsample label: PlotID + Sample No. + U/L + Weight + Date

Canopy Subplot No.:	1 Cover (%)	2 Cover (%)	3 Cover (%)	4 Cover (%)	Average Density (%)
C1					
C2					
C3					
C4					
C5					
C6					
C7					
C8					
C9					
C10					

1 Cover = Center of each 10x10 subplot, 2-,3-,4-Cover = Random in subplot

Dead tree No.	DBH (cm)	Length (m)	Species	Remarks
1				
2				
3				
4				
5				
6				
7				

Dead trees: Diameter>10 cm and/or Length >50 cm

Appendix III: Tree data tables

Species	Wood density
Adinandra dumosa	0.490
Aglaia sp.	0.676
Alangium sp.	0.606
Allanthospermum sp.	0.600
Antidesma sp.	0.691
Aporosa sp.	0.370
Archidendron sp.	0.382
Ardisia sp.	0.568
Artocarpus elasticus	0.350
Artocarpus interger	0.551
Artocarpus kemando	0.448
Artocarpus rigidus	0.549
Artocarpus sp.	0.569
Baccaura macrocarpa	0.540
Baccaurea sp.	0.672
Barringtonia sp.	0.573
Bhesa paniculata	0.590
Blumeodendron kurzii	0.510
Bruinsmia sp.	0.380
Calophyllum sp.	0.536
Campnosperma auriculatum	0.327
Canarium sp.	0.583
Castanopsis hypophoenicea	0.596
Castanopsis sp.	0.596
Chionanthus sp.	0.628
Cinnamomum sp.	0.561
Cleistanthus sp.	0.576
Cratoxylum arborescens	0.433
Cratoxylum cochinchinense	0.670
Croton sp.	0.552
Cyathocalyx sp.	0.510
Dacryodes sp.	0.561
Dillenia sp.	0.572
Diospyros sp.	0.674
Dipterocarpus conformis	0.765
Dipterocarpus sp.	0.604
Dryobalanops lanceolata	0.604
Dryobalanops oblongifolia ssp. oblongifolia	0.615
Drypetes sp.	0.605
Durio sp.	0.750
Dyera costulata	0.616
Elaeocarpus barbulatus	0.553
Elaeocarpus sp.	0.553
Elateriospermum tapos	0.785
Endiandra sp.	0.626
Fagraea sp.	0.612
Ficus brunneoaurata	0.485
Ficus fulva	0.390
Ficus leptogramma	0.485
Ficus sp.	0.485
Fordia sp.	0.600
Garcinia sp.	0.654
Gironniera nervosa	0.450
Glochidion sp.	0.522
Gluta sp.	0.572
Gonystlyus sp.	0.600
Hancea penangensis	0.600
Helicia sp.	0.591
Hopea fluvialis	0.677
Hopea sp.	0.677
Horsfieldia sp.	0.529

Species	Wood density
Hydnocarpus sp.	0.594
Ilex cissoidea	0.360
Knema sp.	0.533
Koilodepas sp.	0.600
Koompassia malaccensis	0.760
Lithocarpus sp.	0.705
Litsea sp.	0.442
Lophopetalum sp.	0.574
Luis sp.	0.600
Macaranga beccariana	0.290
Macaranga conifera	0.330
Macaranga hosei	0.277
Macaranga trachyphylla	0.277
Macaranga triloba	0.320
Macaranga winkleri	0.277
Madhuca sp.	0.635
Magnolia sp.	0.661
Mallotus wrayi	0.623
Myristica sp.	0.600
Nauclea sp.	0.600
Nauclea subdita	0.600
Neolamarckia cadamba	0.600
Nepheliumsp.	0.600
Palaquium sp.	0.600
Parashorea smythiesii	0.600
Pentace sp.	0.600
Pimeleodendron griffithianum	0.600
Platea latifolia	0.600
Pleiocarpidia sp.	0.600
Polyalthia cauliflora	0.600
Polyalthia sp.	0.600
Porterandia anisophylla	0.550
Prunus arborea	0.600
Prunus sp.	0.600
Pternandra	0.600
Quercus sp.	0.600
Santiria sp.	0.600
Saurauia glabra	0.600
Saurauia sp.	0.600
Scaphium macropodum	0.530
Shorea argentifolia	0.520
Shorea leprosula	0.440
Shorea lunduensis	0.600
Shorea macroptera ssp. baillonii	0.425
Shorea parvifolia ssp. parvifolia	0.405
Shorea parvifolia ssp. parvifolia	0.405
Shorea parvifolia ssp. velutinata	0.405
Shorea parvistipulata ssp. parvistipulata	0.400
Shorea patoensis	0.600
Shorea pauciflora	0.533
Shorea pinanga	0.363
Shorea quadrinervis	0.435
Shorea sagittata	0.600
Shorea sp.	0.600
Sindora	0.600
Sterculia	0.600
Symplocos	0.600
Syzygium	0.605
Teijsmanniodendron	0.600
Timonius esherianus	0.600
Trema tomentosa	0.600
Triadica cochinchinensis	0.600

Species	Wood density
Trigonopleura malayana	0.500
Trigonopleura sp.	0.600
Tristaniopsis whiteana	0.600
Unknown	0.600
Vatica sp.	0.600
Vatica umbonata ssp. umbonata	0.600
Vernonia arborea	0.330
Walsura dehiscens	0.868
Xanthophyllum	0.709
Xylopia stenopetala	0.536

Appendix IIII: Carbon data tables

Table A: Tree carbon

PlotID	Total Trees C (t/ha)	Trees AGB C (t/ha)	Trees BGB C (t/ha)
14	113.4	91.8	21.6
21	102.5	83.0	19.5
51	197.8	160.2	37.6
55	61.1	49.5	11.6
57	166.3	134.6	31.6
70	193.5	156.7	36.8
78	186.1	150.7	35.4
86	318.2	257.7	60.6
207	154.7	125.2	29.4
212	191.5	155.1	36.4
219	114.5	92.7	21.8
220	172.6	139.8	32.8
225	81.6	66.0	15.5
Extra1	66.2	53.6	12.6
Extra2	223.3	180.8	42.5
Average	**156.2**	**126.5**	**29.7**

Table B: Liana carbon

Tree Basal Area (m2/ha)	Liana C (t/ha)
15.5	0.3
19.8	1.8
22.5	2.3
22.9	1.8
26.1	1.7
30.1	1.4
32.7	2.1
33.8	1.7
34.2	2.5
36.7	3.4
45.6	3.1
47.8	3.5
48.1	1.4

Table C: Number of lianas

Tree BA (m2/ha)	N Lianas ha
15.5	100
19.8	500
22.5	600
22.9	700
26.1	650
30.1	400
32.7	600
33.8	550
34.2	650
36.7	550
45.6	800
47.8	1000
48.1	550

Table D: Understory and litter carbon stocks

Tree Basal Area (m2/ha)	Understory C (t/ha)	Litter C (t/ha)
22.9	0.5	2.3
22.5	0.8	3.5
32.7	0.4	2.4
15.5	0.6	2.9
24.1	0.4	4.1
30.1	0.4	4.8
34.2	0.5	3.0
47.8	0.8	3.4
33.8	1.1	3.3
36.7	0.8	5.1
26.1	0.3	7.3
48.1	0.8	3.3
19.8	0.9	2.6
17.8	0.7	2.6
45.6	0.8	3.9

Appendix V: Canopy cover tables

Table D: Liana carbon, CaCo%

Average CaCo (%)	Liana C (t/ha)
89.23	3.1
89.25	2.1
89.40	4.8
89.50	5.1
89.69	6.6
89.91	3.4
89.93	5.7
89.97	1.7
90.16	1.4
90.32	2.5
90.65	3.5
90.89	2.3
90.99	0.3
91.03	1.4
91.34	2.4
92.38	1.8

Table E: Total NTCM, CaCo%

Average CaCo (%)	Total NTCM (t/ha)
86.91	8.5
87.45	16.6
89.23	14.2
89.25	280.8
89.40	85.7
89.50	32.5
89.69	312.7
89.91	13.6
89.93	12.2
89.97	8.7
90.16	7.6
90.32	21.6
90.65	70.1
90.89	683.2
90.99	12.4
91.03	8.7
91.34	12.2
92.38	11.5

Table F: Total carbon, CaCo%

Average CaCo (%)	Total C (t/ha)
86.91	1705.9
87.45	2441.8
89.23	5157.2
89.25	4390.9
89.69	3627.4
89.91	3980.3
89.93	1403.6
89.97	3793.7
90.16	5892.5
90.32	3956.4
90.65	7021.1
90.89	2728.8
90.99	1624.5
91.03	4591.1
92.38	2509.4