Examensarbeten 2015:10

Fakulteten för skogsvetenskap
Institutionen för skogens ekologi och skötsel

Rehabilitation in a tropical secondary rain forest in Malaysian Borneo

- Early effects of canopy properties on light conditions at the forest floor

Foto: Joakim Jansson

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Rehabilitation in a tropical secondary rain forest in Malaysian Borneo

- Early effects of canopy properties on light conditions at the forest floor

Rehabilitering av sekundär tropisk regnskog på Malaysiska Borneo
- Tidiga effekter av krontakets sammansättning på ljusförhållanden vid marken

Joakim Jansson

Nyckelord / *Keywords:*
Tropisk sekundär regnskog, Dipterocarpaceae, krontäckning, ljus, densiometer, luckor, hemisfäriska foton /*Tropical secondary rainforest, Dipterocarpaceae, canopy, openness, light gaps, visible sky, hemispherical photographs, crown illumination, index, densiometer*

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Sammanfattning

Tropisk regnskog i Sydostasien är ett av de områden som hyser störst biodiversitet i världen, av vilken stora ytor är hotat. Ön Borneo drabbades av en katastrof åren 1982-1983 efter att väderfenomenet El Niño orsakat torka med vidsträckta skogsbränder som följd. Detta lämnade stora ytor av Borneos skogar i ett undermåligt, sekundärt tillstånd. På grund av detta startades INIKEA projektet med syfte att rehabilitera skogar i regionen kring Tawau vid östkusten av delstaten Sabah i Malaysia. I denna studie undersökte jag resultatet av rehabiliteringsarbetet på krontaket i tre olika skogstyper genom att ta hemisfäriska foton med en digital systemkamera (DSLR). Vidare undersökte jag ytterligare tre metoder för att se deras lämplighet i denna typ av skog. Dessa var en sfärisk densiometer, det så kallade Crown Illumination Index (CII) och hemisfäriska foton tagna av en smartphone-kamera. Resultatet visade att skogstypen hade signifikant effekt på variablerna visible sky och Leaf Area Index (LAI) medan rehabiliteringsmetoden hade signifikant effekt på variablerna Direct Site Factor (DSF) och Global Site Factor (GSF). Smartphone fotona hade signifikant korrelation med sina motsvarande DSLR foton samt visade statistisk signifikans på variablerna visible sky och LAI. Densiometern och CII har sina styrkor i att de är enkla, snabba och lätta att bära, de är dock föremål för subjektivitet. Densiometern visade störst likhet med DSF och GSF medan CII visade signifikant korrelation med alla variabler förutom LAI.

Nyckelord: *Tropisk sekundär regnskog*, *Dipterocarpaceae, Krontäckning, Ljus, Densiometer, luckor, hemisfäriska foton*

Summary

Tropical rainforests of South East Asia holds some of the biggest biodiversity in the world, with big parts of it being under threat. The island of Borneo was stricken by disaster in 1982-83, when following a weather phenomenon the El Niño Southern Oscillation, vast droughts and subsequent fires ravaged its forests. This left major parts of Borneo’s forest in a secondary state and as a result the INIKEA rehabilitation project was initiated in the Tawau region on the east coast in the state of Sabah, Malaysia. In this study I examined the outcome of the rehabilitation work on the forest canopy in three different forest types. This was done by means of hemispherical photographing using a DSLR camera. Further, three other methods was examined to see their suitability in this type of forest. These were a spherical densiometer, the Crown Illumination Index (CII), and hemispherical photographs taken by a smartphone camera. The results showed that forest type had a significant effect on the amount of visible sky and Leaf Area Index (LAI) while type of rehabilitation treatment had a significant effect on Direct Site Factor (DSF) and Global Site Factor (GSF). The smartphone photographs had a significant correlation with their DSLR counterparts, and also showed a statistical significance for visible sky and LAI signifying that it may be a tool in the future, should certain considerations be made. The densiometer and CII holds advantages in being easy, quick and non-cumbersome but are instead prone to subjectivity. The densiometer had best similarities with DSF and GSF and the CII showed significant correlation with all variables except for LAI.

Keywords: *Tropical secondary rainforest*, *Dipterocarpaceae, Canopy, Openness, Light, Gaps, Visible sky, hemispherical photographs, Crown Illumination Index, Densiometer*

Table of Contents

1. Introduction

Tropical rain forest is one of the major vegetation types of the globe (Richards 1996, Whitmore 1998) which is defined by Corlett and Primack (2011) as “tall, dense, evergreen forests that form the natural vegetation cover of the wet tropics, where the climate is always hot and the dry season is short or absent”. These tropical rain forests make up 44% of the world’s forest cover (FAO 2010). Forests below an altitude of 900-1200 meters are considered lowland forests (Corlett and Primack 2011) and these lowland forests of the wet tropics are the most biodiverse of all terrestrial ecosystems (Turner 1996). A region which largely comprise of this biota is South East Asia which is known as “Sundaland”. It is the third largest rainforest area in the world and is made up by the forests in the Malay Peninsula and the islands Borneo, Sumatra and Java (Corlett and Primack 2011). Many consider “Sundaland” to be one of the regions in the world with the absolute highest biodiversity, now with major parts of it being under threat (Butchart *et al.* 2004, Myers *et al.* 2000, Sodhi *et al.* 2004). The biodiversity is exposed to a level of deforestation and timber extraction that surpasses the Amazon or African rainforests (Cleary *et al.* 2007, Hansen *et al.* 2008, Sodhi *et al.* 2004).

Within the Sundaland region, an area that is affected by heavy logging is the forests on the island of Borneo (Corlett and Primack 2011), which inhabit one of the tallest tropical rainforests in the world (Whitmore 1984). The most common tree species, by numbers, in these forests are in the family *Dipterocarpaceae*. (The name stems from Latin and means “Two-winged fruits” which refers to the tree’s fruits.) Dipterocarps make up the major part of the forests in Borneo, Sumatra, Java, the Malay Peninsula and the wetter parts of the Philippines. According to Priadjati (2002) the family consists of 500 species and the genus *Shorea* is the most abundant in terms of species. It is also important economically as the “Dipterocarps are an important timber species, and timber extraction rates on Borneo are among the highest globally” (Collins *et al.* 1991). Degradation of dipterocarp forests will not only have consequences for the ecosystems on Borneo and in regional economies but also globally, according to Curran *et al.* (2004).

Whitmore (1984 - referenced through Kuusipalo et al. 1997 -) recounts that logging and the activities involved with it damages the forest and creates openings. Successional fast growing species cover these clearings and natural gaps by what Bazzaz and Pickett (1980) call "key in on disturbance”. These fast growing tree species, such as *Macaranga* - a light demanding genus - and climber plants outgrows and keep the comparatively slow-growing dipterocarp seedlings suppressed (Kuusipalo *et al.* 1997). Swaine and Whitmore (1988) define this as pioneer and climax species where Dipterocarps are a climax species which by (Riddoch *et al.* 1991) mean that they are able to survive as seedlings in deep shade. Young plants are thus commonly found below a canopy (Swaine and Whitmore 1988) where dipterocarp seedlings, according to Kuusipalo *et al.* (1997), may “survive for several years under severe shading of the canopy, without commencing any significant height growth until the opening up of the gap”.

Thus with high level of disturbance an abundance of species of *Macaranga* follows (Slik *et al.* 2003), which outcompetes the desired dipterocarps. Davies *et al.* (1998) describes that it is “not uncommon to find five to eight pioneer Macaranga species colonizing a single large forest gap

Another predicament that affected the forests on Borneo was when they stricken by disaster as an effect of the so called El Niño Southern Oscillation in 1982-83 (Wright *et al.* 1999). The ENSO phenomenon consist of oscillation of the atmospheric pressure across the equatorial Pacific with draughts commonly following (Rasmusson *et al.* 1990) (Corlett and Primack 2011). During the 1982-83 event, Borneo had low rainfall which led to disastrous large scale wildfires in its tropical forests with prominent tree mortality in selectively logged forests in Borneo (Wright *et al.* 1999). In total during this event an estimated 1 million ha of forest were burnt in the Malaysian State of Sabah (Woods 1989).

Because of these factors, Bornean forests are in a substandard state. Major parts of the forests are known as secondary forests which mean that the forests have been altered beyond normal effects of natural processes (ITTO 2002) with enough significant disturbance to set of successional processes (FAO 2003). This has made the Yayasan Sabah Group and the board of IKEA take action to rehabilitate said forests. They have since 1998 attempted to rehabilitate parts of the degraded forest in the region of Tawau, located on the east coast of Sabah (Alloysius *et al.* 2010). The project, which is known as INIKEA, is focused on enrichment planting of various tree species but mainly species belonging to *Dipterocarpaceae.* The planting techniques used in the project are line-planting and gap-cluster planting. A third rehabilitation method is also used, namely liberation of plants already available onsite. This means that instead of planting, already available dipterocarp seedlings onsite is localised and the surrounding vegetation is cleared DiNicola *et al.* (1997) recommend using enrichment planting techniques in areas that have been disturbed severely by conventional industrial logging. Lamb *et al.* (2005) speculates that "failure to apply some type of treatment will likely cause regeneration of lower value pioneer species as natural recovery is difficult where the system has crossed an ecological threshold and reached a new steady state".

Romell *et al.* (2008) recounts for some enrichment planting studies in the past, such as (Appanah and Weinland 1993) that suggested that enrichment planting could be used in degraded forests once dominated by dipterocarps to accelerate their recovery. Kuusipalo *et al.* (1997) showed that in liberated gaps, opened 6 years after a logging event, dipterocarps accounted for more of the total basal area than in the untreated area as well as a higher survival, and a diameter twice as the untreated plots. Liberation also improved the quality of dipterocarp trees in terms of stem and crown form. Rehabilitation of degraded forests has proven to have potential for improving biodiversity. Birds are an equitable indicator of biodiversity across taxa (Ansell *et al.* 2011) and in a study by Edwards *et al.* (2009), species richness and diversity increased among insectivore birds in a forest reserve in Sabah as a result of rehabilitation,

The forest canopy is a major factor that regulates ecological and ecophysiological process within a forest ecosystem (Nadkarni *et al.* 2011) hence it affects plant growth and survival which determining the nature of the vegetation. (Jennings *et al.* 1999) As such an essential factor for the plant species in a tropical forest is the solar radiation that manages to pass through the forest canopy. According to Denslow (1987), openings in the forest canopy is important for the establishment and growth of rainforest trees as many of the ecological processes, e.g. succession and natural regeneration take place in this environment (e.g.Bazzaz 1979, Küppers *et al.* 1996). Nadkarni *et al.* (2011) puts it this way, "Canopy drives the future growth of vegetation communities" and as Turner (1990) states "successful regeneration of canopy-top species is thought to require canopy gaps in all forests". Openings in the canopy allow light to reach the forest floor which may increase growth in species that are tolerant of shade (e.g King 1991, Nicholson 1960). Thus seedlings may grow into saplings and subsequently trees.

A commonly used method for assessing solar radiation conditions in forest stands is by hemispherical photographing, which is less damaging to the forest than conventional methods such as stripping the trees of all its leaves in order to measure variables like Leaf Area Index (e.g. Chianucci and Cutini 2012, Hale and Edwards 2002). Hemispherical photography has been used since the 1960s in forest ecology (Evans and Coombe 1959) and is a very valuable tool and source of information as it delivers a lasting record. With this method it is possible to measure a number of variables that describe the conditions below the canopy where you find yourself standing such as the magnitude, location, and dispersal of canopy gaps.

1.1 Study objectives

The tropical rainforests are important in even more ways, as they play a vital role in keeping our planet liveable and the biological importance of the forests in Southeast Asia are universally undisputed (E.g. (Edwards *et al.* 2011, Sodhi *et al.* 2010)) at the same time as they are more threatened than ever. Thus how rehabilitation methods affect the composition of a tropical rainforest have been studied (E.g.(Ådjers *et al.* 1995)) but as said in a IUFRO report (IUFRO 2007) in attention to the Forest Plantation Program in Malaysia "There is generally a lack of adequate knowledge in the propagation and silvicultural management of indigenous species".

Therefore, this study's intention is to explore the outcome of silvicultural treatments on canopies in a Macaranga-dominated secondary forest using hemispherical photography. Variables such as canopy openness and below-canopy light conditions are examined in further detail. The standard equipment for taking such photographs is SLR cameras (single-lens reflex camera, a camera in which the viewfinder image is projected via a tilted mirror) which are expensive in the higher quality range, even with a move into digital technology. The equipment is also quite heavy to carry in field and requires some knowledge in able to get reliable result.

Thus two specific questions with following hypothesis were addressed:

1. What effect does rehabilitation methods have on the canopy transmissivity of solar radiation in a secondary tropical rainforest??
    - My hypothesis is that with increased disturbances and thus more intensified rehabilitation method applied; the forest canopy will have more gaps generating lighter conditions in the forest stands. The least disturbed forest type may be brighter on an average, alternatively have the same average as other forest types but with a greater variation because of gaps.

2. How does a digital SLR camera compare to simpler more portable and less expensive methods for inventory of canopy cover?
    - Two different cameras for taking hemispherical photographs and two subjective measurements are examined. My hypothesis is that the digital SLR camera shows no linear relation to the alternative methods.

2. Method

2.1 Study site

The 1 million hectare Yayasan Sabah (YS) logging enterprise, located in Sabah, Malaysia (Figure 1), holds in the words of Lambert and Collar (2002) “the most important remaining area of lowland forest in Borneo “. Together with the company IKEA the YS started the INIKEA Forest Rehabilitation Project in the degraded forests of the Kalabakan region located in the northeast of Borneo in 1998. The total area which is being rehabilitated under the INIKEA project is 18500 hectare. All of which is located in the lowlands.

Figure 1. Map of Borneo with the location of the INIKEA Forestry Centre in Luasong.

The fieldwork was conducted inside the premises of the INIKEA project in an area comprising of 73 hectares. This area lies 25 km west of Luasong Forestry Centre (latitude 4.6N, longitude 117.2E), which in turn west of the town Tawau, and holds the plots on which this study is based upon (Appendix, figure 8). The major vegetation in this area is the pioneer species Macaranga spp. with an abundance of climbers, vines and members in the family *Zingiberaceae* (Gingers) and other herbaceous vegetation are common on the forest floor (Alloysius *et al.* 2010). The climate of the region is classified as tropical wet (Af in Köppen classification) and in the neighbouring Danum Valley the daytime temperatures varies between 22.0˚and 32.7℃ and the mean precipitation being 2890 mm per year (Romell et al, 2008)

Large areas in this region have been affected by wildfires which have been predominant during El Niño drought years. In 1983, 4.5 million hectares of forest were burnt in Borneo (Woods 1989).

2.2 Experimental design & Sampling

21 individual plots are distributed in blocks over an area of 82 hectares. Each plot holds 4 sub-plots which are grouped in rectangles or squares (Appendix, Figure 8). Each of these 4 sub-plots contains a specific treatment, namely Gap-Cluster planting, Line Planting, Liberation and one control. The locations of the sub-plots within the plots are in turn randomized.

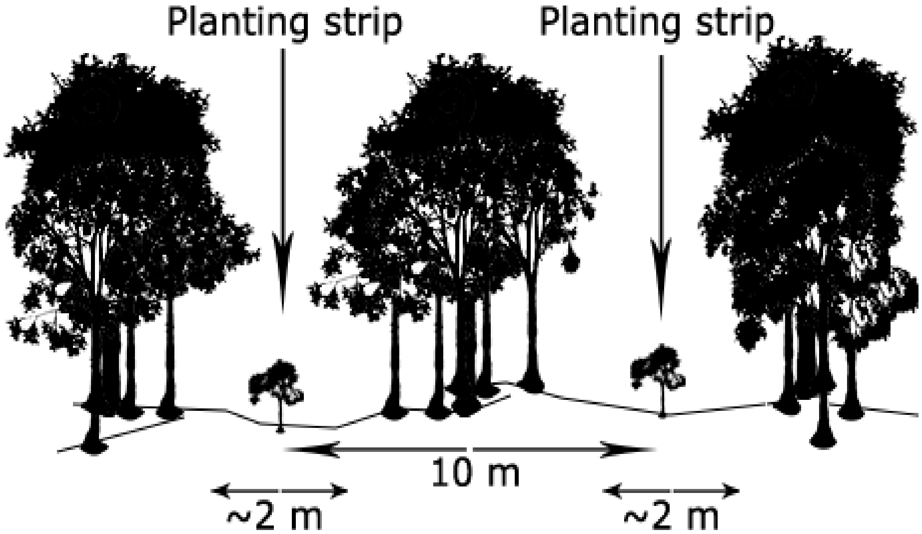

Figure 3. The line planting design. Picture remade from (Alloysius *et al.* 2010)

The design of the two planting methods used in the INIKEA project (Line-planting and Gap-cluster planting) may be found in Alloysius *et al.* (2010). In short, Line-planting is done with 2-meter wide planting strips, in which a seedling is planted every 3 m, at 10 m intervals (Figure 2). With Gap-cluster planting, four gaps within 20 m x 20 m quadrats are created. Each gap is located inside a 10 m x 10 m imaginary sub-quadrat. A cluster of four seedlings, each of different species is planted inside every gap (Figure 3).

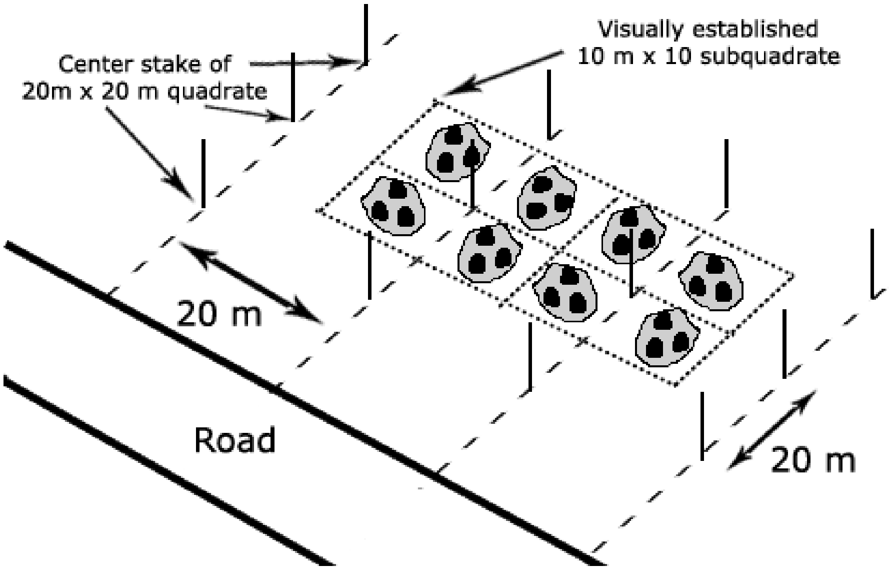

Figure 2. Gap cluster planting design. Picture remade from (Alloysius et al. 2010)

The 21 plots are classified in 3 blocks equivalent to forest types. These forest types share the names of the rehabilitation treatments, namely Liberation, Gap-Cluster and Line planting. This is due to the idea that the corresponding method is thought to be the best for that forest type. This in turn is because they have suffered from varying amounts of disturbance. From now on the forest types will be called 1 (Liberation), 2 (Gap-Cluster) and 3 (Line planting) with an increasing amount of disturbance going from type 1 to 3. The basal area per hectare in the forest types are: Type 1, 35.2 m^2/ha Type 2, 43.2 m^2/ha and Type 3 25.4 m^2/ha (Figure 4).

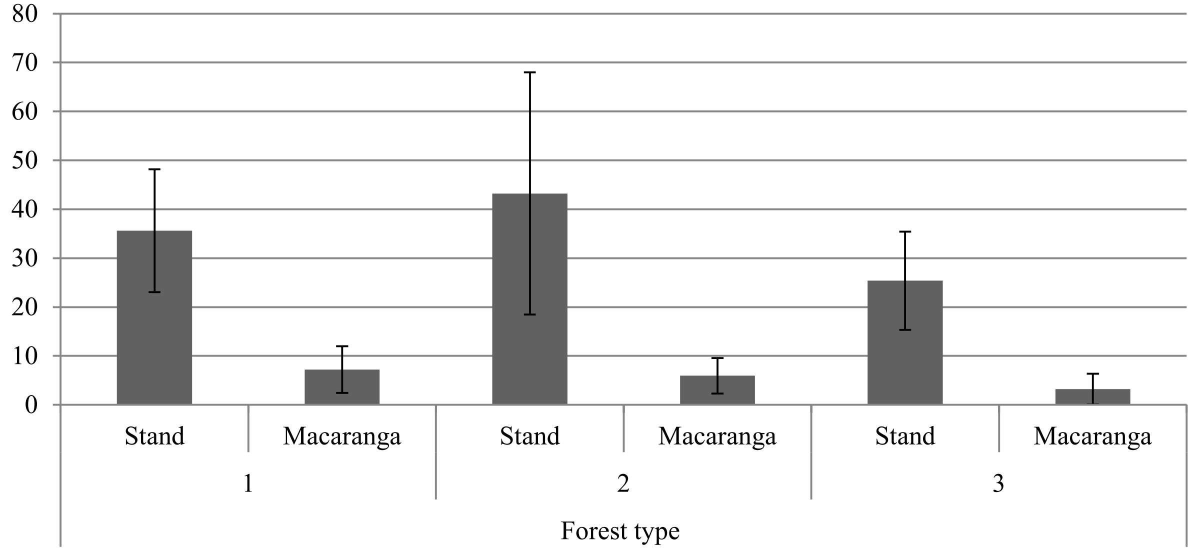

Figure 4. Mean and S.E. if basal area per hectare in the three forest types in a restoration experiment close to Luasong, Sabah, Malaysia. The figure shows the basal area of the whole stands and the basal area of the Macaranga in each stand.

2.3 Hemispherical photographs acquisition

The hemispherical photographing method makes use of a fisheye-lens with a field of view of 180°. The camera points upwards from the ground to the canopy (Rich 1990). As the sky is very bright in contrast to the canopy the camera may not be able to capture the whole scene and the subsequent photograph does not include all of the information in either lowlight and highlight areas, or both (Robertson *et al.* 1999). The minimization of this loss of information is crucial for hemispherical photography as it would overestimate the proportion of sky and thus produce bias. The key for this is to secure the correct exposure setting (Beckschäfer *et al.* 2013) and the subsequent process of thresholding. The thresholding differentiate sky from foliage in the photograph by turning the photos into a high contrast black and white image in which the sky is white and the canopy is black.

The camera used was a Canon EOS 50D, with an Sigma Circular Fish-eye 4.5 mm 1:2.8 objective with field of view of 180°, attached. The camera was secured in a self-levelling frame (SLM-8 from Delta-T Service) which in turn was mounted on a Manfrotto telescope stand (680B9). The built in compass of the frame ensures that all photos are facing the same direction, north. Another useful feature of the frame is the ability of putting a cloak over the flash and via two separate fibre-optic wires lead light from the flash to top of the frame and two diodes. This result in to small dots of light in the photograph taken, the one to the left indicates the direction north and the one to the right, south.

The smartphone camera was the camera of an iPhone 5 with a Rollei Fish-Eye objective (0.28x Tele fish) attached to a casing. Furthermore the app “Iris camera” was used. It has the feature of showing a histogram of the tonal distribution live as well as locking the exposure to a fixed point. This was proven useful and was the reason for using this particular app. By locking the exposure to an open patch of sky in the canopy the risk of overexposure may be minimized. In order to get a level photo when using the smartphone, it was put lying on its front, pointing the camera upwards on top of the lens cap of the Canon camera while it was mounted on its self-levelling stand.

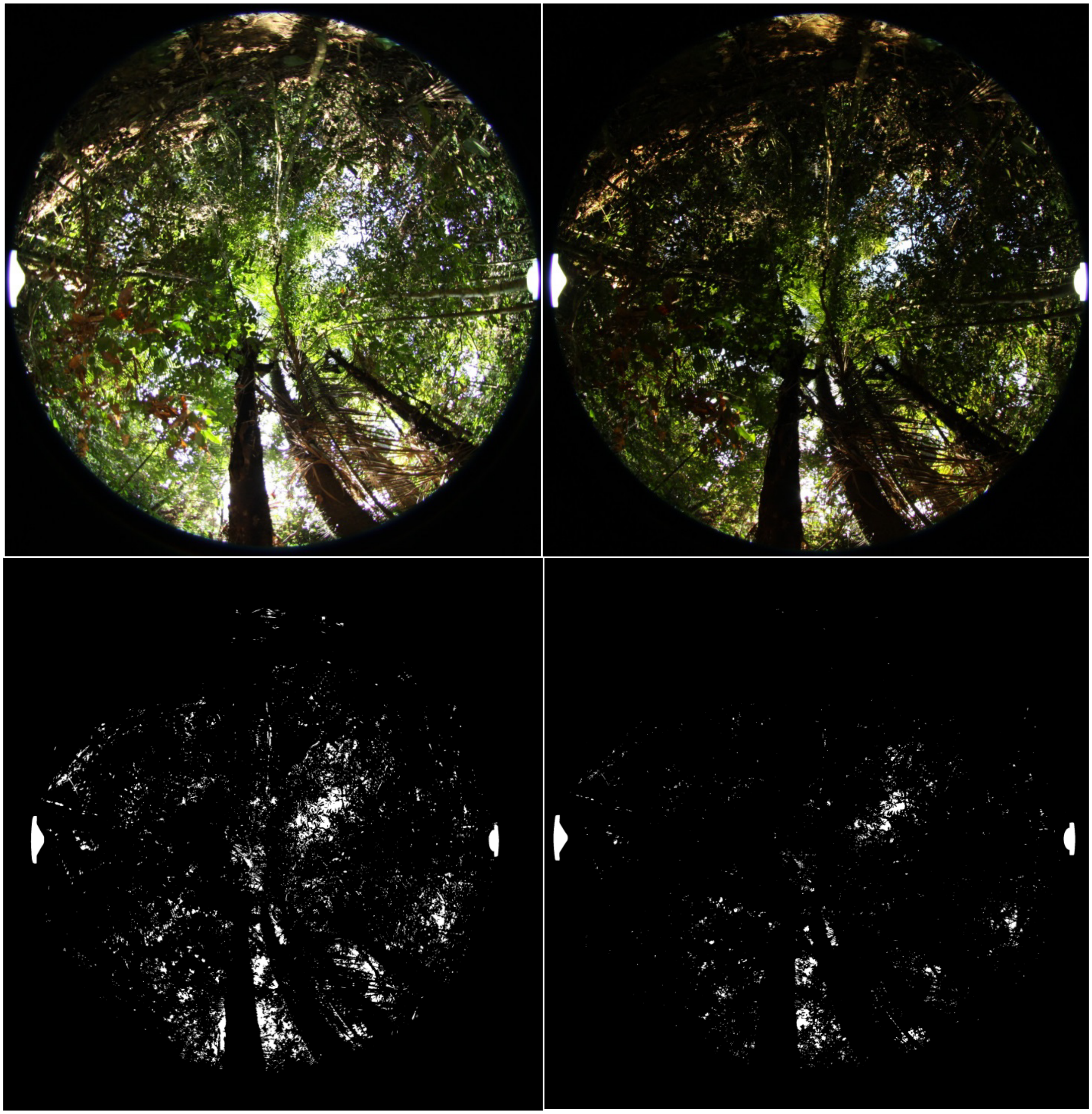

Figure 5 Hemispherical photos taken at plot 13, sub-plot line planting. The photo to the upper left was taken with auto exposure (Setting C1) while the photo on the upper right was taken with a 2.0 reduction of the exposure value to achieve an appropriate exposure of the canopy for threshold classification (Setting C2). Visible in both photos are the LED’s indicating north (left diode) and south (right diode).The photos below show the same photographs after they have underwent a threshold classification.

The basic setting for the Canon Camera was mode "P" (Programmed Auto) with ISO400. Two custom modes was stored and subsequently used, these were called C1 and C2. The difference between the two is that the latter had a 2.0 reduction of the exposure value. Settings available for the Canon were not available for the smartphone. Photographs were taken in the 4 subplots of each main plot (a total of 21). A total of 3 photos were taken at each sub-plot. 2 by using the Canon EOS 50D (Figure 5), one with mode C1 and one with C2, and 1 using the Smartphone. This gives a total of 252 pictures. Photographs taken by the Canon camera were stored in JPEG format (4752 × 3168 pixels resolution) and in also RAW format. The reason for taking 2 photos with different exposure settings with the Canon camera was to explore and make assure that the photos were taken with correct exposure.

The photographing period took place between 28th of August to the 12th of September. The photographs were taken in between the planting lines respectively gap-clusters in the centre of each of the sub-plot at 1, 3 meters height. I strived to take photographs in dawns earliest light in order to minimize the risk of direct sunlight entering the lens. This was generally between 6 am and 8 am. This is necessary because photos that are taken with direct sunlight entering the camera will likely become overexposed. The sun also shines on the leaves and stems of the trees which make them gleam, this is turn has the effect of when analysing the photos it is difficult to this accurately differentiate foliage from canopy openings. In the words of (Rich 1989) "The ideal condition for taking hemispherical canopy photographs is an evenly overcast sky. In the absence of an overcast sky, photographs are best taken early or late in the day, when view of the sun is likely to be blocked by the canopy".

2.4 Alternative methods data acquisition

A method for describing a tree's light environment is the crown illumination index (CII) which was first devised by Dawkins (1958) as the "crown position index" and adapted further by (Clark and Clark 1992). These estimations are done subjectively and are based on a classification system including 7 classes (table 1).

Table 1 Values and definition of the Crown Illumination Index as defined by Clark and Clark (1992)

Index value	Definition
5	Crown completely exposed (to vertical light and to lateral light within the 90˚ inverted cone encompassing the crown)
4	Full overhead light (≥90% of the vertical projection of the crown exposed to vertical light; lateral light blocked within some or all of the 900 inverted cone encompassing the crown
3	Some overhead light (10-90% of the vertical projection of the crown exposed to vertical light)
2.5	High lateral light
2.0	Medium lateral light
1.5	Low lateral light
1	No direct light (crown not lit directly either vertically or laterally)

The spherical densiometer was conceived by Lemmon (1956) as an low-cost and simple tool for estimating canopy cover. "It consists of a convex or concave mirror etched with a grid of 24 squares, within each of which the observer scores canopy cover at four equally spaced points."

(Englund *et al.* 2000). By multiplying the score with a factor of 1.04 you receive the variable Canopy cover which is the equivalent of Visible Sky. From now on I will be consistent with this nomenclature in order to make the distinction between the two. The CII and Densiometer readings were estimated on each of the 84 sub-plots.

2.5 Photograph processing, Calculations & Data analyses

For analysing the hemispherical photos, the software HemiView 2.1 SR4 by Delta-T Devices was used to calculate a number of variables (Table 2). The input data for this software may be image files of various formats, including BMP and JPEG. The process includes aligning a "horizon circle marked with cardinal points and magnetic North", over the photographs (Rich *et al.* 1998). This allows the software to process the images with the hemispherical co-ordinate system. When this is done the software, turns the photos into a high contrast black and white image in which the sky is white and the canopy is black (Figure 5.) This process is called threshold and is done manually which makes it a somewhat subjective process. The calculations uses algorithms to estimate gap fraction, contributions of direct and diffuse solar radiation from each sky direction, site factors, and leaf area index (Table 2). Gap fraction is explained in the HemiView manual as:

> "Gap fraction is the proportion of visible sky within a given sky sector, where a sky sector is defined by a range of zenith and azimuth angles. All calculations, whether for solar radiation regimes or for canopy characterisation, ultimately depend upon dividing the sky into sectors and calculating gap fraction for each sky sector. A gap fraction of zero (0) means that the sky is completely blocked (obscured) in that sky sector. A gap fraction of one (1) means that the sky is completely visible (not obscured) in that sky sector. Site factors are indices of the proportion of radiation reaching a given location. Values range from 0 to 1, with 0 being no radiation (complete sky obstruction) and 1 being the radiation for an open location (complete sky visibility = no sky obstruction."
>
> (Rich *et al.* 1998 p. 14-15)

In order to achieve the correct data output, HemiView requires a number of features set up correctly. These are the site at which the photograph was taken, the lens which was used, the day of the year and the solar model to be used. My settings comprised of adjusting the site to the coordinates of the Luasong forest reserve, the lens was the Sigma Circular Fish-eye 4.5 mm 1:2.8 and the solar model was set to the simple solar model. The day of year was set from 240 to 255 (28th of August to the 12th of September), depending on which day the specific photo was taken. For more information on how the software calculates the different variables, assumptions and more, see the HemiView manual available online.

The HemiView variables were sorted in a spreadsheet and further analysed in the statistical software MINITAB (2009). A general linear model (GLM) was used to investigate the first question of the study, "What effect does rehabilitation methods have on the canopy transmissivity of solar radiation in a secondary tropical rainforest?" The model is written as following (with an explanation of the model variables found in table 3):

$$Y_{ijl} = \tau_i + \beta_j + (\tau\beta)_{ij} + \varepsilon_{ijl} \qquad Var\left(\varepsilon_{ijl}\right) = \sigma^2$$

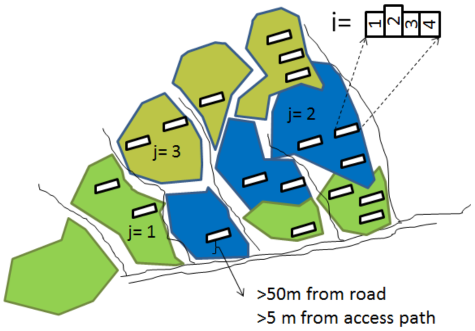

Figure 6. Idealized image of the study area, in complement to table 3. j is forest types and i is Treatments

Table 2 Description of Variables calculated by HemiView

Variable	Description
Visible sky	Overall proportion of the sky hemisphere that is visible.
Indirect Site Factor (ISF)	The proportion of diffuse solar radiation reaching a given location, relative to a location with no sky obstructions.
Direct Site Factor (DSF)	The proportion of direct solar radiation reaching a given location, relative to that in a location with no sky obstructions.
Global Site Factor (GSF)	The proportion of global radiation under a plant canopy relative to that in the open (Sometimes referred to Total Site Factor)
Leaf Area Index (LAI)	The amount of leaf surface area per unit ground area.
Ground Cover (GndCover)	An estimate of the ground cover, defined as the vertically projected canopy area per unit ground area.

Table 3 Description of Variables in statistical model

Variable	Description
τ_i	Treatment *i* main effect
β_j	Forest types *j* main effect
$(\tau\beta)_{ij}$	Treatment by forest type interaction effect
$I = 1, 2, 3, 4$	Treatments (Main blocks)
$j = 1, 2, 3$	Forest types
$l = 1, 2, 3 \ldots 7$	Replications (sub-blocks)

Initial analysis of residual plots revealed the data to be nonlinear as such all data underwent a logarithmic transformation. I present graphs in this paper in non-logarithmic values, except where noted, while all analyses are based on logarithmic values.

3. Results

3.1 Model

The general linear model showed that the factor “Forest type” has a statistical significance on variables Visible sky, ISF and LAI, but no significance on DSF and GSF (Table 4). With the factor “Treatment” the situation is the opposite with variables DSF and GSF showing a statistical significance while Visible sky, ISF and LAI does not. The interaction between factors “Forest type” and “Treatment” only show significance on variable LAI and an indication towards Visible sky to show significance. Running the model with photos deemed to be too overexposed omitted, raised the R^2-values with 1-3 % for all variables except for Ground Cover which was doubled to 35.6% and was also proven to have a statistical significance on the interaction between forest type and treatment with a p-value = 0.017 (Appendix, table 1)

Table 4. P-Values for factors and variables in the General Linear Model calculated using logarithmic values (except for GndCover). Visible sky R^2 = 24.36 %, ISF R^2 = 22.78 %, DSF R^2 = 23.43 %, GSF R^2 = 23.48 %, LAI R^2 = 25.83 %, GndCover R^2 = 18.22 %. Significant P-values are shown in bold.

Factor	Visible Sky	ISF	DSF	GSF	LAI	GndCover
Forest type	**0.036**	0.089	0.184	0.171	**0.019**	0.949
Treatment	0.181	0.129	**0.04**	**0.043**	0.873	0.161
Forest type * Treatment	0.097	0.126	0.148	0.145	**0.021**	0.117

Using Tukey Method and 95% confidence interval, for the variables Visible sky and LAI, forest type 3 (a) is significantly different from type 1 (b), but not type 2 (ab). Variables ISF, DSF, GSF and GndCover show no significant difference between forest types (a). No significant difference was found between treatments.

The sub-plots that in which no treatment have been undertaken, i.e. control, forest type 3 have the highest mean for all variables (Figure 6, 7, 8 & 9) except LAI (Figure 11) and forest type1 the lowest with type 2 in between the two. For the three treatments, Gap-Cluster and Line planting are consistently lower than Liberation for all variables except for LAI. Liberation in forest type 1 shows an increase in LAI in comparison with the other treatments (figure 11).

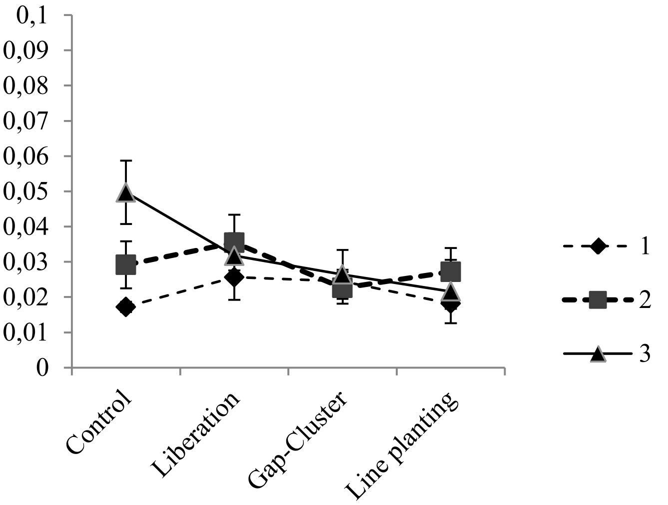

Figure 7 Interaction plot for **Visible sky** between means of forest types 1, 2 and 3. Y-axis shows amount of visible sky on a scale 0.00 to 1.00. X-axis shows the 3 rehabilitation methods, plus control.

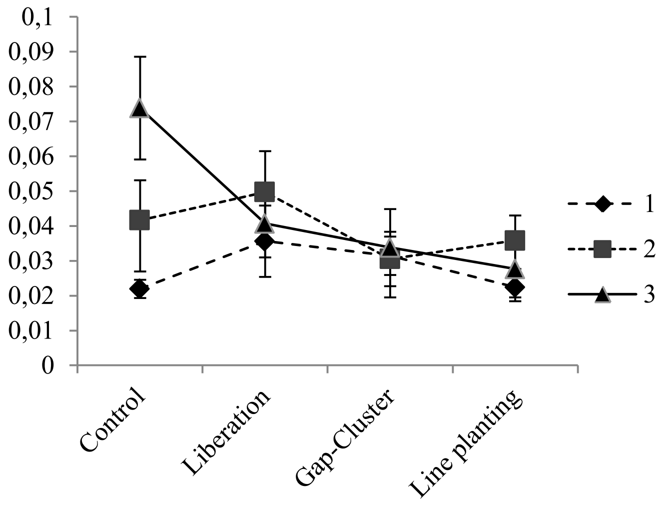

Figure 8 Interaction plot for **ISF** between means of forest types 1, 2 and 3. Y-axis shows amount of ISF on a scale 0.00 to 1.00. X-axis shows the 3 rehabilitation methods, plus control.

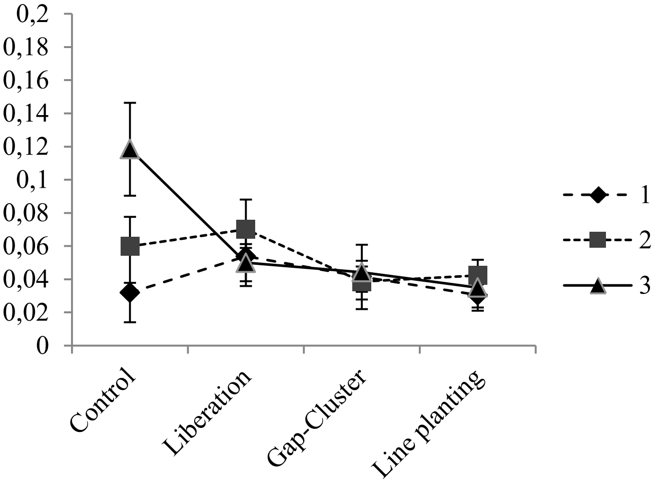

Figure 99. Interaction plot for **DSF** between means of forest types 1, 2 and 3. Y-axis shows amount of DSF on a scale 0.00 to 1.00. X-axis shows the 3 rehabilitation methods, plus control.

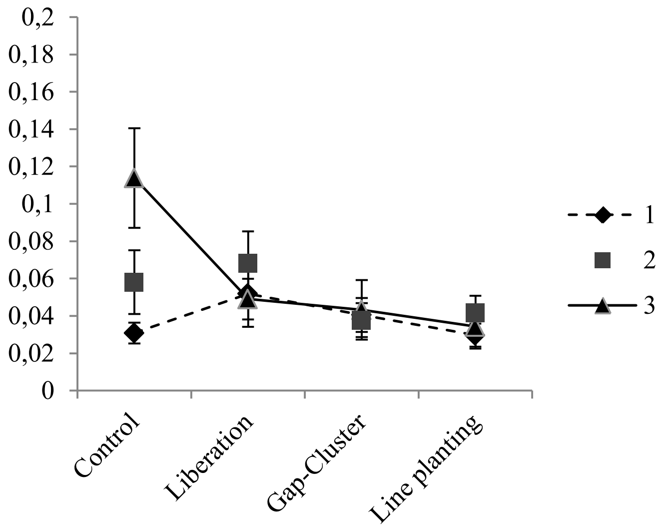

Figure 90 Interaction plot for **GSF** between means of forest types 1, 2 and 3. Y-axis shows amount of GSF on a scale 0.00 to 1.00. X-axis shows the 3 rehabilitation methods, plus control.

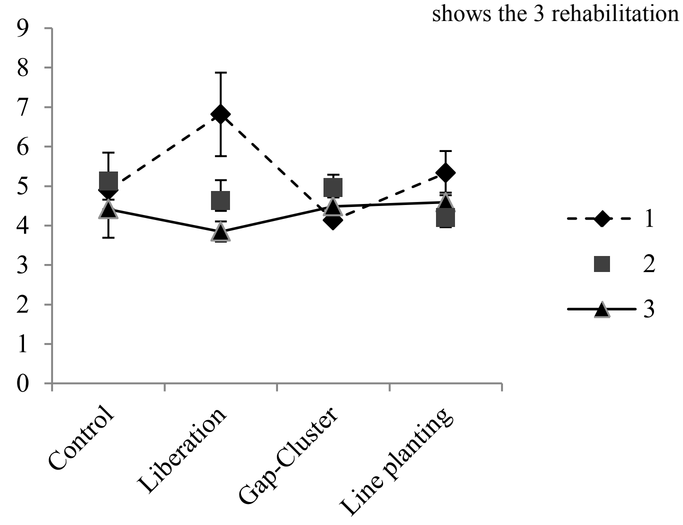

Figure 9 Interaction plot for **LAI** between means of forest types 1, 2 and 3. Y-axis shows amount of visible sky. X-axis shows the 3 rehabilitation methods, plus control.

3.2 Comparison of methods

Plotting Canon values against its smartphone counterpart (Appendix, figure 1) show positive linear correlation between variable XX. Using Spearman's rank test this was proven with a P-value <0,001and the following r_s was obtained for visible sky 0.495 (R^2=46.4), ISF 0.552 (R^2=56.5), DSF 0.652 (R^2=68.3), GSF 0.652 (R^2=67.9), LAI 0.435 (R^2=52.5), and Ground Cover 0.732 (R^2=61.1). Higher correlations was found with Pearson's correlation (Appendix, table 5)

Running the GLM with smartphone photos showed a statistical significance on variables Visible sky (p-value = 0.024, R^2=19.36) and LAI (p-value = 0.018, R^2=16.52) for forest type (Appendix, table 2). If the same procedure is repeated as with the canon photos, photos deemed to be too overexposed omitted, doubles the R^2 – values and show a statistical significance on the interaction between forest type and treatment (Appendix, table 3).

Table 5. P-Values for factors and alternative methods in the General Linear Model, Canopy openness were calculated using logarithmic values. Using Tukey Method and 95% confidence interval, for Canopy openness forest type 3 (a) is significantly different from forest type 1 (b) but not type 2 (ab). No significant difference between forest types for was found for Crown Illumination Index. Canopy openness R^2=24.08, Crown Illumination Index R^2=11.89%

	Canopy openness (Densiometer)	**Crown Illumination index**
Forest type	**0.011**	0.182
Treatment	0.532	0.532
Forest type x Treatment	0.105	0.676

Using the Densiometer in the GLM showed a statistical significance on forest type and to have the best similarity with variable DSF (R^2=60.0) with GSF following closely at (R^2=59.9) and then ISF (R^2=54.2), VisSky (R^2=47.2) (Table 7). Least similarity had Leaf Area Index with a R^2=0.9. The highest mean for canopy openness was found in forest type 3 in the control (figure 12).

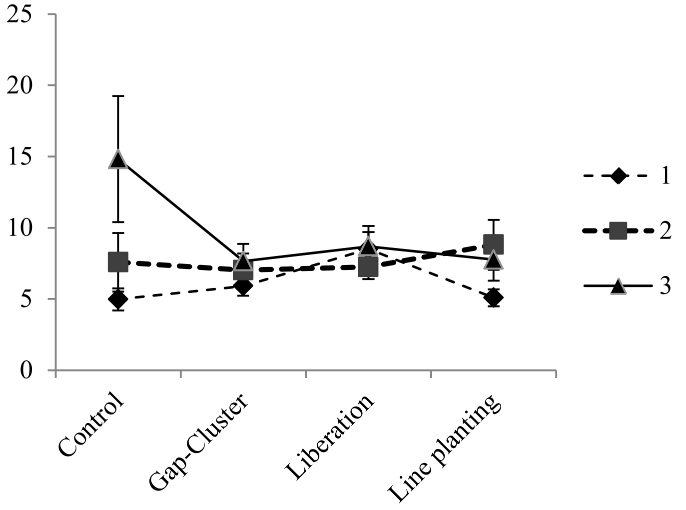

Figure 112. Interaction plot for Canopy openness (densiometer) between means of forest types 1, 2 and 3. Y-axis shows amount canopy openness in percentage on a scale 0 to 100. X-axis shows the 3 rehabilitation methods, plus control.

The Crown Illumination Index showed no statistical significance on any factor, or between forest types or treatments, when running the GLM with it (Table 6). The biggest proportion of sub-plots was classified as having a CII of 1.5 and the least 3 (Table 6). A general pattern is found for all variables, except LAI, that with increased CII respective variables mean also increases (Appendix, table 4, and figure 2, 3, 4, 5 & 6).

Table 6. The distribution of plots in each class of the Crown Illumination index for Treatments and Forest Types. No plot with a CII of 4 or 5 were found.

Treatment	**1**	**1.5**	**2**	**2.5**	**3**	**4**	**5**
Control	4	10	3	3	1	-	-
Gap-Cluster	6	12	1	2	0	-	-
Liberation	7	8	4	2	0	-	-
Line Planting	7	8	5	0	1	-	-

Forest type	**1**	**1.5**	**2**	**2.5**	**3**	**4**	**5**
1	10	13	5	0	0	-	-
2	6	13	5	3	1	-	-
3	8	12	3	4	1	-	-

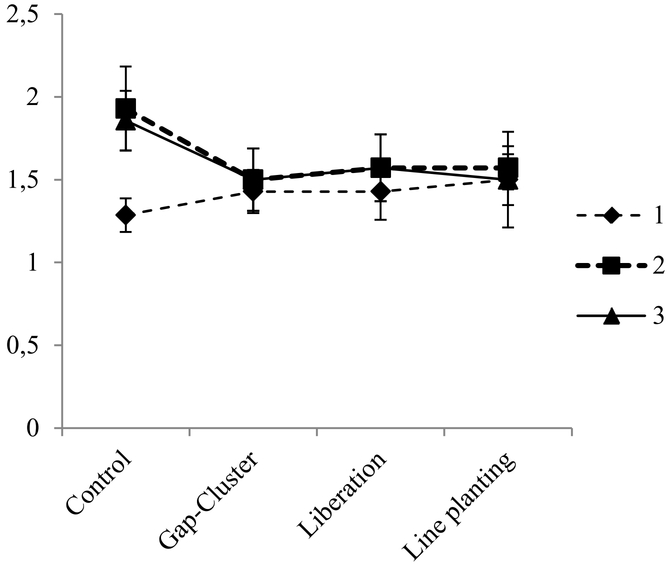

Figure 123. Interaction plot for Crown Illumination Index between means forest types 1, 2 and 3. Y-axis shows level of CII on a scale 1 to 5. X-axis shows the 3 rehabilitation methods, plus control.

4. Discussion

4.1 Effect of rehabilitation on the canopy cover

The general linear model (GLM) show that the forest type have a significant effect on variables Visible Sky, ISF, LAI while Treatment have an significant effect on the variables DSF and GSF. The only variable showing a significant interaction effect between forest type and treatment were LAI. It further shows that for variables visible sky and LAI there is a difference between forest types where type 3 is significantly different between forest type 1. This may indicate that with increased disturbance lighter conditions follows, supporting my hypothesis.

Visible sky is the overall proportion of the sky hemisphere that is visible on a site. In a recent study by Born *et al.* (2014) light measurements were taken in the, from Luasong, nearby reserve Sepilok, also by means of hemispherical photographing. In gaps, the visible sky was measured to be between 8.85 to 11.78% while in more shaded plots it was in the range of 1.63 to 3.44. My visible sky ranged between 0.78 and 8.75 with the highest values in forest type 3 and control (Appendix, table 4). The gaps in the study by Born *et al.* (2014) was established under a 200 m^2 big canopy gap which is twice as big as the gaps used in the gap-cluster technique. The reason that the values of visible sky in my measurement are noticeably lower than Born *et al.* (2014) may be because of this difference in canopy gap size. With larger canopy gaps, naturally more light falls to the forest floor. The extension of this argument would be that my measurements of visible sky correspond better to the shaded plots of Born *et al.* (2014) as my photographs were not taken directly in and on the gap respectively planting line. Kenzo *et al.* (2006) measured visible sky to 5-10% in the understory and 20 % in gaps in the forests of Lambir Hills National Park, in Sarawak. These understory measurements are also in line with my measurements.

In a study by Whitmore *et al.* (1993) they measured that a canopy opening of 140 m^2 had a visible sky of 15.1% while a gap of 73 m^2 had 9.4%. At the same time a significantly smaller gap of 37 m^2 had visible sky of 17.7% which suggest that it is not able to conclude that with a larger gap size the plots visible sky will be higher and vice versa. In a future study it would be interesting to take the photos in the gaps and planting lines to see if what outcome this has on treatments.

Photosynthetically active radiation in (PAR) is the light energy between 400 and 700 nanometres which plans use in the photosynthesis. The amount of PAR is a major element of growth for a forest floor plant (Whitmore *et al.* 1993) and one commonly used unit to characterize this light quantity is Photosynthetic photon flux density, PPFD (Shibles 1976 referenced through Gendron et al. 1998). PAR and global site factor (GSF) showed significant trends across elevation in a study by Ediriweera *et al.* (2008) in a Sri Lankan tropical rainforest as well in a study by Canham (1988) and in a study by Machado and Reich (1999), PPFD was found to show a positive relationship with GSF and visible sky. Whitmore *et al.* (1993) devices a method for calculating PAR with GSF as basis and further argues that the GSF is more closely linked to the radiation than either DSF or ISF and recommend to use it for measurements in ecological studies.

In my study treatment was found to have a significant effect on GSF and the GSF - as well as ISF, DSF & Visible sky - was found to be at its highest in the control of forest type 3 with forest type 2 almost following the same pattern but on a lower level This would mean that the amount of light reaching the forest floor, which is left unused by the canopy, is at its highest in the most disturbed control forest.

Ådjers *et al.* (1995) showed that the growth of dipterocarps planted with line planting depends heavily on the width of the line and thus of overhead light. Denslow (1987) came to the similar conclusion that that most tropical rainforest trees are gap-dependent in that they depend on locally enhanced light levels for growth and reproduction. This has further been shown in an experiment of seedling growth by Brown (1996), three species of dipterocarps grew taller the closer they were to the gap centre and King (1991) found that species which are connected with gaps show a "rapid rise in relative growth rate with increasing light level while species less associated with gaps show a smaller increase in relative growth rate with increasing light level".

With this is in mind I would come to the conclusion that with increased light conditions, increased growth below canopy follows. A curious question follows, the growth of what? Is the light mostly absorbed by species of Dipterocarps, Macaranga or other understory plants such as vines and gingers. An interesting topic to address is the "quality" of light between ISF and DSF. Whitmore et al. (1993) states that "the pattern of radiation across a gap differs for indirect and direct radiation." Indirect sunlight comes from the whole sky while direct sunlight comes straight from the sun. Expanding on this DSF is dependendent on the suns position on the sky while the amount of ISF reaching the forest floor is thus in part determined by the understory vegetation as the understory itself absorbs light and also scatters light by the reflection on leaves . This is supported by Canham et al. (1990) which results show that "there can be significant penetration of light into the understory adjacent to a gap". Numata et al. (2006) theorize that a "high frequency of canopy gaps, therefore, may not always increase the light availability on the forest floor". A factor that might affect the amount of light reaching the forest floor may be the hight of the trees. This is supported in a study by Kenzo *et al.* (2006) in which they found that visible sky increased significantly with tree height in Lambir Hills National Park and as I found a significant correlation between visibly sky and direct and indirect site factor.

With this reasoning I speculate that ISF is a variable that mostly affect understory plants in a gapless forest while DSF is mostly absorbed by the canopy. It would then be expected that in a gap the amount of sunlight reaching the forest floor and thus DSF levels would be higher, but no findings to prove this was found in this study.

Leaf area index is the amount of foliage defined as "the area of leaves above unit area of ground taking only one side of each leaf into account" (Monteith 1973). It is an important variable that influence the exchange of carbon dioxide between the atmosphere and the biosphere (Bonan 1993) and may be used to estimate Net Primary Production, NPP (Waring and Schlesinger 1985). Tropical forests stands for between 32% (Field *et al.* 1998) and 43% (Melillo *et al.* 1993) of the world's NPP and is therefore important for the world carbon budget (Clark *et al.* 2001). The LAI in this study had range reaching from 2.7 to 12.1 $m^2 m^{-2}$, with an overall mean of 4.79 $m^2 m^{-2}$. In Forest type 1 the mean is slightly higher than in type 2 while type 3 is the lowest 3, 5.3 (SE=0.48), 4.73 (SE=0.44), and 4.33 (SE=0.36) $m^2 m^{-2}$ respectively. The LAI are in the same range for all treatments except for an increase in liberation. I find no possible reason for this other than chance. In a study by Kumagai *et al.* (2006) they measured LAI in Lambir National Park, an unlogged mixed dipterocarp forest, in the neighbouring state of Sarawak and found a horizontal variation in LAI ranging from 4.8 to 6.8 $m^2 m^{-2}$ with a mean of 6.2 $m^2 m^{-2}$. Worth to mention is that they did not make use of hemispherical photos for their measurements, but canopy analysers such as LAI-2000.

4.2 *The relation between digital SLR camera, smartphone, densiometer and Crown Illumination Index for assessment of canopy cover*

The result of plotting canon photographs against their smartphone counterparts reveals a positive and significant correlation between them. This suggests that the smartphone camera may very well be a tool in the future of measuring canopy covers. The photos were not perfect though and in order to achieve good quality photographs I propose a pair of things to consider in future usage of a smartphone, see the “data uncertainties” section below for further information. By plotting the results of the two cameras against each other I was also able to find equations that serves as a tool if one wish to transpose the smartphone values to canon values.

The Crown Illumination Index had no significant effect on either forest type, treatment or the interaction between the two but showed to have a significant correlation with all variables except Leaf Area Index. This correlation is consistent with Keeling and Phillips (2007) as well as Clark and Clark (1992) and Davies *et al.* (1998), although former only looked at variables ISF and DSF and the latter at the variable visible sky. In the study by Keeling and Phillips (2007) the CII is calibrated in a Amazonian rainforest by taking hemispherical photographs at each CII class. As stated above they found visible sky, ISF, DSF and GSF to correlate strongly with CII classes while in my study as well as theirs the reason CII could only be weakly defined by LAI. A reason for this may be because of the substantial overlying between each CII class (Appendix, table 4). Another study, done by Davies *et al.* (1998) calibrates CII against percentage visible sky (canopy openness)

Keeling and Phillips (2007) raised a warning finger and stated that the straightforwardness of the CII makes it attractive to ecologists, but continues with that it is “a generic, semi-quantitative scale, with no relation to actual quantified light measurements, and presents problems for analysis using parametric statistical methods”. Though it is a highly subjective method prone to errors if the person carrying it out is not familiar with the classification process, it holds its strength in being low in cost, quick and without need for instruments with difficult instructions it may be conducted by anyone.

The same pros may be said about the densiometer, although slightly less subjective. Its clear design and easy instructions makes it possible even for a person who never seen a densiometer before to accurately measure the canopy cover after a short practice. When running the general linear model with data gathered with the densiometer, canopy openness had a statistical significant effect on the forest type, the same result as the corresponding variable Visible Sky. This indicates that a densiometer may be a valid tool for measuring the amount visible sky. A look at the densiometer interaction plot (figure 11) however, reveals that the estimated canopy cover is considerably higher than its hemiphoto counterpart, threefold for forest type 3. Another interesting notion is that the highest R^2-value, when plotting densiometer against DSLR, was found between canopy openness and DSF, not as one would expect between canopy openness and visible sky.

Several studies examine the suitability of densiometers in measuring canopy cover. Cook *et al.* (1995) for example tested both convex and concave and found them to produce substantial bias in terms of overestimating canopy cover substantially. The test was performed in stands comprised of grand fir and western larch in northeast Oregon which is a considerably different environment than the deciduous wet forests of the tropics. If one regards the measurements derived from the hemiphotos as “true”-values then the conclusion would be that the densiometer has gravely overestimated the canopy cover. This may be due to the fact that the mirror on the densiometer offers a low resolution as well as a miss calibrated user. As conclusion it can be said that as with the CII, the densiometer is a subjective method which would give improved result with proper practice and calibration but may very well be in use for relative comparisons.

4.3 Data uncertainties and future considerations

The sensitivity of hemispherical photographs to exposure and image processing is a matter one do not afford to neglect as hemispherical photography is a process of many steps which all are prone to errors (Rich 1990). Rich identify the biggest pitfalls to be camera positioning and orientation, photographic exposure; and the selection of a threshold, where I believe the issue of photographic exposure is the one to focus on. This is because the positioning of the camera is easy to adjust and while the threshold process is very important it is considerably challenging to accomplish with photographs taken with the wrong exposure. The most important for minimizing the risk of wrong exposure is to take the photos without direct sunlight which interfering which Welles and Norman (1991) state can cause errors of up to 50%

The photographs taken by the Canon camera in this study were of good quality. In order to achieve this I used RAW-format for the photographs, which have high dynamic range, and I set the exposure 2 EV down. Afterwards I controlled the quality by inspecting the tonal distribution histograms of the photographs. I categorized the photos depending on their exposure and their histogram on a scale 1-3 where 1 is underexposed, 2 is slightly overexposed and 3 is very overexposed. A sign of overexposure is if the histogram is skewed to the right. Most photos fell in category 1 (60 out of 84), fewer in 2 (15 out of 84) and the fewest in 3 (9 out of 84). This gives a percentage of "good" photos of just above 70%. All photos were used in the final analysis but analyses with a separation of the photographs based on the exposure were made in an earlier step (Appendix, Table 1). The R^2-values with photographs classified as 2 and 3 excluded are all higher than if I used all photographs. Because of photos fell in the overexposed categories some further considerations could have been taken. In order to achieve high quality for all hemispherical photographs, the photos have to be taken with the correct exposure. Beckschäfer *et al.* (2013) proposes a method for taking hemispherical photographs in which the photographer takes a photo of the sky out in the open and looks at this photo's histogram. The exposure of the subsequent photos of the canopy should then be adjusted based on the first photo. Another method is to take photographs on location and adjust the exposure until you reach a satisfying histogram with no highlights and subsequent loss of information. As newer models of digital cameras have the ability of showing a live histogram, the methods described above can be taken advantage of for achieving high quality hemispherical photographs.

To manually set the level of threshold, in order to separate sky from canopy objects, in the HemiView software is a highly subjective matter and may cause over- or underestimation of the canopy. Different methods have been developed for an automated threshold process (e.g. Beckschäfer *et al.* 2013, Nobis and Hunziker 2005) which have the advantages that there is no change between the photos and it makes the process faster.

A further trick in ensuring good quality result is to extract the blue colour plane of the RGB in the photographs as found in (Beckschäfer *et al.* 2013, Cescatti 2007, Leblanc *et al.* 2005). This is due to that "best separability of sky and vegetation pixels in the blue colour plane results from skies tending to scatter blue light and low scattering of blue light by leaves". When I did my HemiView analysis I used the whole RGB colour plane because of the photos being mostly underexposed, making an extraction of the blue plane redundant. For some photos that were classified as overexposed the method was tested, with only slightly different numbers as a result.

The two flash indicators visible in each photograph taken by the Canon camera are classified as sky by HemiView. To test the effect this had on the result a complete black photo was compared with a black photo with the flash indicators in HemiView. The outcome showed that the flash indicators had little to none effect and as a result no further action was taken. As this small overestimation of the sky is consistent in every photograph it would be possible to apply a statistical correction to the regression.

The photographs taken by the smartphone were of varying quality but overall good. A problem that was identified was that some of the darkest photographs were overexposed. The reason for overexposure could be the function in the application used to lock the exposure to a point on the sky. This function proved to be useful on plots with gaps in the canopy large enough to make use of this feature. If the gaps were too small though, the photographs became slightly overexposed resulting in photos where the outer edges of the canopy blend in with the sky. In order to prevent this in the future I advise to ensure that the application to be used have the correct prerequisites regarding exposure. Further, how reliable the live histogram, which is available in the app used, is may be questioned. Photographs that seemed to have, for the study's purpose, a perfect of the tonal distribution histogram in the app did when looking at the same photos in a raster graphics editor not have the same histogram. When looking at them in such software they tended to be skewed more to the right of the visual spectrum, indicating that they are overexposed.

There was also an issue with the fish-eye lens adapter for the iPhone. Due to the hardware it trims the photographs one the left and right side. This is not a major problem as long the camera is aligned to take photos in a north-south alignment thus the right and left side is becomes east and west. This is because when HemiView analyse photos it makes use of a solar track model. The solar track model is not affected by these trimmed edges and thus the software don't take this in concern and base the analysis on what is visible in the actual photo.

For further exploration if a smartphone can be used for measuring canopy cover I recommend testing more hardware and software. There are various smartphone manufacturers with varying camera quality and suitability for this purpose as well as there are applications. For example there are apps that combine several photographs into one picture with a high dynamic range, known as HDR, which could prove a useful tool. A smartphone application which is made with generally acknowledged methodological and technological considerations would be ideal as a tool out in the field. This app could utilize the proposed equations for corrected values. This could prove to be a cheap, quick and non-cumbersome method which would provide the user with instant feedback and information about the canopy above and would serve as good initial data for a pilot study.

5 Conclusion

The main goals of this study were to investigate the influences of rehabilitation methods have on the canopy cover in a secondary tropical rainforest and if a digital SLR camera is the most efficient method for inventory of canopy cover.

With regard to the first goal this study was able to demonstrate that there are no greater differences for light conditions between treatments. For variables visible sky and LAI there is a difference between forest types where type 3 is significantly different between type 1. This may indicate that with increased disturbance lighter conditions follows, supporting my hypothesis.

The variables visible sky, Indirect Site Factor and Leaf Area Index was found to be related to forest type while Direct Site Factor and Global Site Factor was found to be related to treatment. The only variable showing a significant interaction effect between forest type and treatment were LAI.

With regard to the second goal about the methodological comparison, I found that a digital SLR camera is still the most competent method for inventory of canopy cover but the alternatives hold great promises if properly utilized. Especially the possibility of developing a smartphone application for direct measurement of the forest canopy. The Densiometer presented best similarities with variables DSF and GSF and was also able to predict forest type, the same result as the corresponding variable Visible Sky. This could indicate that a densiometer is a valid tool for measuring the amount visible sky. The Crown Illumination Index showed significant correlation with all variables except for Leaf Area Index

6 Reference list

ALLOYSIUS, D., FALCK, J., WAI, Y. S. & KARLSSON, A. 2010. An attempt to rehabilitate a degraded Tropical Rainforest in Borneo: the biological results and the social benefits of the IKEA investment, an analysis after ten years. *XXIII IUFRO World Congress.* Seoul, Korea: Conservation & Environmental Management Division, Yayasan Sabah Group.

ANSELL, F. A., EDWARDS, D. P. & HAMER, K. C. 2011. Rehabilitation of Logged Rain Forests: Avifaunal Composition, Habitat Structure, and Implications for Biodiversity-Friendly REDD+. *Biotropica,* 43**,** 504-511.

APPANAH, S. & WEINLAND, G. 1993. *Planting quality timber trees in Peninsular Malaysia: a review*, Forest Research Institute Malaysia.

BAZZAZ, F. A. 1979. The Physiological Ecology of Plant Succession. *Annual Review of Ecology and Systematics,* 10**,** 351-371.

BAZZAZ, F. A. & PICKETT, S. T. A. 1980. Physiological Ecology of Tropical Succession: A Comparative Review. *Annual Review of Ecology and Systematics,* 11**,** 287-310.

BECKSCHÄFER, P., SEIDEL, D., KLEINN, C. & XU, J. 2013. On the exposure of hemispherical photographs in forests. *iForest - Biogeosciences and Forestry,* 6**,** 228-237.

BONAN, G. B. 1993. Importance of leaf area index and forest type when estimating photosynthesis in boreal forests. *Remote sensing of Environment,* 43**,** 303-314.

BORN, J., PLUESS, A. R., BURSLEM, D. F. R. P., NILUS, R., MAYCOCK, C. R. & GHAZOUL, J. 2014. Differing Life History Characteristics Support Coexistence of Tree Soil Generalist and Specialist Species in Tropical Rain Forests. *Biotropica,* 46**,** 58-68.

BROWN, N. 1996. A gradient of seedling growth from the centre of a tropical rain forest canopy gap. *Forest Ecology and Management,* 82**,** 239-244.

BUTCHART, S. H. M., STATTERSFIELD, A. J., BENNUN, L. A., SHUTES, S. M., AKÇAKAYA, H. R., BAILLIE, J. E. M., STUART, S. N., HILTON-TAYLOR, C. & MACE, G. M. 2004. Measuring Global Trends in the Status of Biodiversity: Red List Indices for Birds. *PLoS Biol,* 2**,** e383.

CANHAM, C. D. 1988. An Index For Understory Light Levels in and Around Canopy Gaps. *Ecology,* 69**,** 1634-1638.

CANHAM, C. D., DENSLOW, J. S., PLATT, W. J., RUNKLE, J. R., SPIES, T. A. & WHITE, P. S. 1990. Light regimes beneath closed canopies and tree-fall gaps in temperate and tropical forests. *Canadian Journal of Forest Research,* 20**,** 620-631.

CESCATTI, A. 2007. Indirect estimates of canopy gap fraction based on the linear conversion of hemispherical photographs: Methodology and comparison with standard thresholding techniques. *Agricultural and Forest Meteorology,* 143**,** 1-12.

CHIANUCCI, F. & CUTINI, A. 2012. Digital hemispherical photography for estimating forest canopy properties: current controversies and opportunities. *Iforest-Biogeosciences and Forestry,* 5**,** 290-295.

CLARK, D. A., BROWN, S., KICKLIGHTER, D. W., CHAMBERS, J. Q., THOMLINSON, J. R., NI, J. & HOLLAND, E. A. 2001. Net primary production in tropical forests: An evaluation and synthesis of existing field data. *Ecological Applications,* 11**,** 371-384.

CLARK, D. A. & CLARK, D. B. 1992. Life History Diversity of Canopy and Emergent Trees in a Neotropical Rain Forest. *Ecological Monographs,* 62**,** 315-344.

CLEARY, D. F. R., BOYLE, T. J. B., SETYAWATI, T., ANGGRAENI, C. D., LOON, E. E. V. & MENKEN, S. B. J. 2007. Bird Species and Traits Associated with Logged and Unlogged Forest in Borneo. *Ecological Applications,* 17**,** 1184-1197.

COLLINS, N., SAYER, J. & WHITMORE, T. 1991. The conservation atlas of tropical forests: Asia and the Pacific. International Union for Conservation of Nature and Natural Resources. London: Macmillian Press, London.

COOK, J. G., STUTZMAN, T. W., CLINTON, W. B., BRENNER, K. A. & IRWIN, L. L. 1995. Spherical Densiometers Produce Biased Estimates of Forest Canopy Cover. *Wildlife Society Bulletin,* 23**,** 711-717.

CORLETT, R. & PRIMACK, R. B. 2011. *Tropical rain forests: an ecological and biogeographical comparison*, Wiley-Blackwell.

CURRAN, L. M., TRIGG, S. N., MCDONALD, A. K., ASTIANI, D., HARDIONO, Y. M., SIREGAR, P., CANIAGO, I. & KASISCHKE, E. 2004. Lowland Forest Loss in Protected Areas of Indonesian Borneo. *Science,* 303**,** 1000-1003.

DAVIES, S. J., PALMIOTTO, P. A., ASHTON, P. S., LEE, H. S. & LAFRANKIE, J. V. 1998. Comparative ecology of 11 sympatric species of Macaranga in Borneo: tree distribution in relation to horizontal and vertical resource heterogeneity. *Journal of Ecology,* 86**,** 662-673.

DAWKINS, H. C. 1958. *The management of natural tropical high-forest with special reference to Uganda*, Imperial Forestry Institute, University of Oxford.

DENSLOW, J. S. 1987. Tropical Rainforest Gaps and Tree Species Diversity. *Annual Review of Ecology and Systematics,* 18**,** 431-451.

DINICOLA, A., JONES, D. & GRAY, G. 1997. Opportunities for forestry investment in Asia and the Pacific through carbon offset initiatives. Asia-Pacific Forestry Towards 2010. *In:* FAO (ed.) *Asia-Pacific Forestry Sector Outlook Study Working Paper Series (FAO).* Rome.

EDIRIWEERA, S., SINGHAKUMARA, B. M. P. & ASHTON, M. S. 2008. Variation in canopy structure, light and soil nutrition across elevation of a Sri Lankan tropical rain forest. *Forest Ecology and Management,* 256**,** 1339-1349.

EDWARDS, D. P., ANSELL, F. A., AHMAD, A. H., NILUS, R. & HAMER, K. C. 2009. The value of rehabilitating logged rainforest for birds. *Conservation Biology,* 23**,** 1628-1633.

EDWARDS, D. P., LARSEN, T. H., DOCHERTY, T. D. S., ANSELL, F. A., HSU, W. W., DERHÉ, M. A., HAMER, K. C. & WILCOVE, D. S. 2011. Degraded lands worth protecting: the biological importance of Southeast Asia's repeatedly logged forests. *Proceedings of the Royal Society B: Biological Sciences,* 278**,** 82-90.

ENGLUND, S. R., O'BRIEN, J. J. & CLARK, D. B. 2000. Evaluation of digital and film hemispherical photography and spherical densiometry for measuring forest light environments. *Canadian Journal of Forest Research,* 30**,** 1999-2005.

EVANS, G. C. & COOMBE, D. E. 1959. Hemisperical and Woodland Canopy Photography and the Light Climate. *Journal of Ecology,* 47**,** 103-113.

FAO. 2003. *Tropical secondary forest management in humid Africa: reality and perspectives. "Proceedings of the Workshop on Tropical Secondary Forest Management in Africa: Reality and Perspectives"* [Online]. Rome, Italy: FAO. Available: http://www.fao.org/docrep/006/J0628E/J0628E00.htm [Accessed 13 January 2015].

FAO 2010. Global forest resources assessment 2010 - Main Report

In: FAO (ed.) *Global forest resources assessment.* Rome.

FIELD, C. B., BEHRENFELD, M. J., RANDERSON, J. T. & FALKOWSKI, P. 1998. Primary Production of the Biosphere: Integrating Terrestrial and Oceanic Components. *Science,* 281**,** 237-240.

GENDRON, F., MESSIER, C. & COMEAU, P. G. 1998. Comparison of various methods for estimating the mean growing season percent photosynthetic photon flux density in forests. *Agricultural and Forest Meteorology,* 92**,** 55-70.

HALE, S. E. & EDWARDS, C. 2002. Comparison of film and digital hemispherical photography across a wide range of canopy densities. *Agricultural and Forest Meteorology,* 112**,** 51-56.

HANSEN, M. C., STEHMAN, S. V., POTAPOV, P. V., LOVELAND, T. R., TOWNSHEND, J. R. G., DEFRIES, R. S., PITTMAN, K. W., ARUNARWATI, B., STOLLE, F., STEININGER, M. K., CARROLL, M. & DIMICELI, C. 2008. Humid Tropical Forest Clearing from 2000 to 2005 Quantified by Using Multitemporal and Multiresolution Remotely Sensed Data. *Proceedings of the National Academy of Sciences of the United States of America,* 105**,** 9439-9444.

ITTO 2002. *ITTO guidelines for the restoration, management and rehabilitation of degraded and secondary tropical forests*, Internaitonal Tropical Timber Organization.

IUFRO 2007. Keep Asia Green Volume I Southeast Asia. *In:* LEE, D. K. (ed.). Vienna.

JENNINGS, S., BROWN, N. & SHEIL, D. 1999. Assessing forest canopies and understorey illumination: canopy closure, canopy cover and other measures. *Forestry,* 72**,** 59-74.

KEELING, H. C. & PHILLIPS, O. L. 2007. A calibration method for the crown illumination index for assessing forest light environments. *Forest Ecology and Management,* 242**,** 431-437.

KENZO, T., ICHIE, T., WATANABE, Y., YONEDA, R., NINOMIYA, I. & KOIKE, T. 2006. Changes in photosynthesis and leaf characteristics with tree height in five dipterocarp species in a tropical rain forest. *Tree Physiology,* 26**,** 865-873.

KING, D. A. 1991. Correlations Between Biomass Allocation, Relative Growth Rate and Light Environment in Tropical Forest Saplings. *Functional Ecology,* 5**,** 485-492.

KUMAGAI, T. O., ICHIE, T., YOSHIMURA, M., YAMASHITA, M., KENZO, T., SAITOH, T. M., OHASHI, M., SUZUKI, M., KOIKE, T. & KOMATSU, H. 2006. Modeling CO2 exchange over a Bornean tropical rain forest using measured vertical and horizontal variations in leaf-level physiological parameters and leaf area densities. *Journal of Geophysical Research: Atmospheres,* 111**,** D10107.

KUUSIPALO, J., HADENGGANAN, S., ÅDJERS, G. & SAGALA, A. P. S. 1997. Effect of gap liberation on the performance and growth of dipterocarp trees in a logged-over rainforest. *Forest Ecology and Management,* 92**,** 209-219.

KÜPPERS, M., TIMM, H., ORTH, F., STEGEMANN, J., STÖBER, R., SCHNEIDER, H., PALIWAL, K., KARUNAICHAMY, K. S. T. K. & ORTIZ, R. 1996. Effects of light environment and successional status on lightfleck use by understory trees of temperate and tropical forests. *Tree Physiology,* 16**,** 69-80.

LAMB, D., ERSKINE, P. D. & PARROTTA, J. A. 2005. Restoration of Degraded Tropical Forest Landscapes. *Science,* 310**,** 1628-1632.

LAMBERT, F. & COLLAR, N. 2002. The future for Sundaic lowland forest birds: long-term effects of commercial logging and fragmentation. *Forktail***,** 127-146.

LEBLANC, S. G., CHEN, J. M., FERNANDES, R., DEERING, D. W. & CONLEY, A. 2005. Methodology comparison for canopy structure parameters extraction from digital hemispherical photography in boreal forests. *Agricultural and Forest Meteorology,* 129**,** 187-207.

LEMMON, P. E. 1956. A spherical densiometer for estimating forest overstory density. *Forest Science,* 2**,** 314-320.

MACHADO, J.-L. & REICH, P. B. 1999. Evaluation of several measures of canopy openness as predictors of photosynthetic photon flux density in deeply shaded conifer-dominated forest understory. *Canadian Journal of Forest Research,* 29**,** 1438-1444.

MELILLO, J. M., MCGUIRE, A. D., KICKLIGHTER, D. W., MOORE, B., VOROSMARTY, C. J. & SCHLOSS, A. L. 1993. Global climate change and terrestrial net primary production. *Nature,* 363**,** 234-240.

MONTEITH, J. L. 1973. *Principles of environmental physics,* London, Edward Arnold Limited.

MYERS, N., MITTERMEIER, R. A., MITTERMEIER, C. G., DA FONSECA, G. A. B. & KENT, J. 2000. Biodiversity hotspots for conservation priorities. *Nature,* 403**,** 853-858.

NADKARNI, N., PARKER, G. & LOWMAN, M. 2011. Forest canopy studies as an emerging field of science. *Annals of Forest Science,* 68**,** 217-224.

NICHOLSON, D. 1960. Light requirements of seedlings of five species of Dipterocarpaceae. *Malayan Forester,* 23**,** 344-56.

NOBIS, M. & HUNZIKER, U. 2005. Automatic thresholding for hemispherical canopy-photographs based on edge detection. *Agricultural and Forest Meteorology,* 128**,** 243-250.

NUMATA, S., YASUDA, M., OKUDA, T., KACHI, N. & NUR SUPARDI, M. 2006. Canopy gap dynamics of two different forest stands in a Malaysian lowland rain forest. *Journal of Tropical Forest Science,* 18**,** 109.

PRIADJATI, A. 2002. *Dipterocarpaceae: forest fires and forest recovery.* Tropenbos International.

RASMUSSON, E. M., WANG, X. & ROPELEWSKI, C. F. 1990. The biennial component of ENSO variability. *Journal of Marine Systems,* 1**,** 71-96.

RICH, P. M. 1990. Characterizing plant canopies with hemispherical photographs. *Remote Sensing Reviews,* 5**,** 13-29.

RICH, P. M., WOOD, J., VIEGLAIS, D. A., BUREK, K. & WEBB, N. 1998. *Hemiview User Manual,* Cambridge, UK, Delta-T Devices Ltd.

RICHARDS, P. W. 1996. *The tropical rain forest: an ecological study,* Cambridge, Cambridge University Press.

RIDDOCH, I., GRACE, J., FASEHUN, F. E., RIDDOCH, B. & LADIPO, D. O. 1991. Photosynthesis and Successional Status of Seedlings in a Tropical Semi-Deciduous Rain Forest in Nigeria. *Journal of Ecology,* 79**,** 491-503.

ROBERTSON, M. A., BORMAN, S. & STEVENSON, R. L. Dynamic range improvement through multiple exposures. Image Processing, 1999. ICIP 99. Proceedings. 1999 International Conference on, 1999 1999. 159-163 vol.3.

ROMELL, E., HALLSBY, G., KARLSSON, A. & GARCIA, C. 2008. Artificial canopy gaps in a Macaranga spp. dominated secondary tropical rain forest—Effects on survival and above ground increment of four under-planted dipterocarp species. *Forest Ecology and Management,* 255**,** 1452-1460.

SHIBLES, R. 1976. Terminology Pertaining to Photosynthesis. *Crop Sci.,* 16**,** 437-438.

SLIK, J. W. F., KEßLER, P. J. A. & VAN WELZEN, P. C. 2003. Macaranga and Mallotus species (Euphorbiaceae) as indicators for disturbance in the mixed lowland dipterocarp forest of East Kalimantan (Indonesia). *Ecological Indicators,* 2**,** 311-324.

SODHI, N. S., KOH, L. P., BROOK, B. W. & NG, P. K. L. 2004. Southeast Asian biodiversity: an impending disaster. *Trends in Ecology & Evolution,* 19**,** 654-660.

SODHI, N. S., KOH, L. P., CLEMENTS, R., WANGER, T. C., HILL, J. K., HAMER, K. C., CLOUGH, Y., TSCHARNTKE, T., POSA, M. R. C. & LEE, T. M. 2010. Conserving Southeast Asian forest biodiversity in human-modified landscapes. *Biological Conservation,* 143**,** 2375-2384.

SWAINE, M. D. & WHITMORE, T. C. 1988. On the definition of ecological species groups in tropical rain forests. *Vegetatio,* 75**,** 81-86.

TURNER, I. M. 1990. The Seedling Survivorship and Growth of Three Shorea Species in a Malaysian Tropical Rain Forest. *Journal of Tropical Ecology,* 6**,** 469-478.

TURNER, I. M. 1996. Species Loss in Fragments of Tropical Rain Forest: A Review of the Evidence. *Journal of Applied Ecology,* 33**,** 200-209.

WARING, R. H. & SCHLESINGER, W. H. 1985. *Forest ecosystems : concepts and management,* Orlando, Orlando : Academic Press.

WELLES, J. M. & NORMAN, J. M. 1991. Instrument for Indirect Measurement of Canopy Architecture. *Agron. J.,* 83**,** 818-825.

WHITMORE, T. C. 1984. *Tropical rain forests of the Far East,* Oxford., Oxford University Press.

WHITMORE, T. C. 1998. *An introduction to tropical rain forests*, Oxford University Press.

WHITMORE, T. C., BROWN, N. D., SWAINE, M. D., KENNEDY, D., GOODWIN-BAILEY, C. I. & GONG, W. K. 1993. Use of Hemispherical Photographs in Forest Ecology: Measurement of Gap Size and Radiation Totals in a Bornean Tropical Rain Forest. *Journal of Tropical Ecology,* 9**,** 131-151.

WOODS, P. 1989. Effects of Logging, Drought, and Fire on Structure and Composition of Tropical Forests in Sabah, Malaysia. *Biotropica,* 21**,** 290-298.

WRIGHT, S. J., CARRASCO, C., CALDERÓN, O. & PATON, S. 1999. The El Niño Southern Oscillation, Variable Fruit Production, and Famine in a Tropical Forest. *Ecology,* 80**,** 1632-1647.

ÅDJERS, G., HADENGGANAN, S., KUUSIPALO, J., NURYANTO, K. & VESA, L. 1995. Enrichment planting of dipterocarps in logged-over secondary forests: effect of width, direction and maintenance method of planting line on selected Shorea species. *Forest Ecology and Management,* 73**,** 259-270.

Appendices

Table 1. P-Values for factors and variables in the General Linear Model calculated using logarithmic values (except for GndCover) with photographs deemed to be overexposed excluded. Visible sky $R^2 = 27.89$ %, ISF $R^2 = 26.47$ %, DSF $R^2 = 24.08$ %, GSF $R^2 = 24.43$ %, LAI $R^2 = 24.73$%, GndCover $R^2 = 35.57$%. Significant P-values are shown in bold.

Factor	Visible Sky	ISF	DSF	GSF	LAI	GndCover
Forest type	0.068	0.159	0.305	0.284	0.295	0.493
Treatment	0.701	0.509	0.238	0.248	0.318	0.043
Forest type * Treatment	0.054	0.071	0.187	0.172	0.152	**0.017**

Table 2. P-Values for factors and variables in the General Linear Model using values from smartphone photographs calculated using logarithmic values. Visible sky $R^2 = 19.36$ %, ISF $R^2 = 16.99$ %, DSF $R^2 = 17.11$ %, GSF $R^2 = 17.12$ %, LAI $R^2 = 16.52$ %, Significant P-values are shown in bold.

Factor	Visible Sky	ISF	DSF	GSF	LAI
Forest type	**0.024**	0.108	0.523	0.458	**0.018**
Treatment	0.732	0.663	0.574	0.580	0.695
Forest type * Treatment	0.241	0.217	0.088	0.095	0.640

Table 3. P-Values for factors and variables in the General Linear Model using values from smartphone photographs calculated using logarithmic values with photographs deemed to be overexposed excluded... Visible sky $R^2 = 50.14$ %, ISF $R^2 = 47.16$ %, DSF $R^2 = 40.48$ %, GSF $R^2 = 41.29$ %, LAI $R^2 = 40.63$ %, Significant P-values are shown in bold.

Factor	Visible Sky	ISF	DSF	GSF	LAI
Forest type	0.224	0.595	0.960	0.935	0.147
Treatment	0.280	0.211	0.644	0.584	0.427
Forest type * Treatment	**0.007**	**0.007**	**0.012**	**0.011**	0.208

Table 4 Mean, Standard error of the mean, minimum and maximum values of visible sky, ISF, DSF, GSF and LAI for each CII class. Non-logarithmic values. r_s is the Spearman's rank correlation coefficient. 24 sub-plots were classified as having a Crown Illumination Index of 1. 38 sub-plots were classed as 1.5, 13 sub-plots as 2, 7 sub-plots as 2.5 and 2 sub-plots as 3. No sub-plots with a CII higher than 3 was found in the study.

CII	1	1.5	2	2.5	3	r_s
Visible sky						
Mean	0.01687	0.02667	0.02979	0.05676	0.05115	
S.E	0.00219	0.00179	0.00367	0.0091	0.00544	0.639
Min	0.00783	0.01219	0.01187	0.01823	0.04571	
Max	0.06275	0.06475	0.06151	0.08745	0.05658	
ISF						
Mean	0.01918	0.03501	0.04625	0.0863	0.0835	
S.E	0.00342	0.00259	0.00564	0.014	0.0122	0.695
Min	0.00660	0.01281	0.01304	0.0264	0.0713	
Max	0.09352	0.08604	0.09067	0.1288	0.0957	
DSF						
Mean	0.02480	0.04695	0.06103	0.1258	0.1299	
S.E	0.00525	0.00397	0.03576	0.0277	0.0266	0.681
Min	0.00882	0.01445	0.01124	0.0434	0.1033	
Max	0.14101	0.12608	0.14968	0.2436	0.1566	
GSF						
Mean	0.02423	0.04574	0.05916	0.1217	0.1252	
S.E	0.00506	0.00381	0.00944	0.0262	0.0251	0.684
Min	0.0086	0.01501	0.01142	0.0417	0.1001	
Max	0.13617	0.12201	0.014367	0.232	0.1504	
LAI						
Mean	4.689	4.692	5.222	4.867	4.665	
S.E	0.192	0.264	0.414	0.808	0.458	0.049
Min	3.547	2.863	3.677	2.702	4.207	
Max	6.872	12.074	7.76	9.066	5.122	
GnD Cover						
Mean	0.9404	0.92748	0.8751	0.690	0.647	
S.E	0.0105	0.00750	0.0210	0.120	0.125	-0.725
Min	0.7329	0.76673	0.7193	0.002	0.522	
Max	0.9880	0.98683	0.9700	0.0985	0.647	

Table 5. Pearson's correlation coefficient, P-values and R^2-values for DSLR camera versus Smartphone camera

Pearson correlation	Canon	Visible sky	ISF	DSF	GSF	LAI	GndCover
Smartphone							
Visible sky		0.682	0.699	0.719	0.720	-0.149	-0.630
ISF		0.710	0.751	0.787	0.786	-0.062	-0.719
DSF		0.690	0.750	0.826	0.823	-0.036	-0.803
GSF		0.694	0.753	0.827	0.824	-0.030	-0.800
LAI		-0.302	-0.262	-0.230	-0.232	0.725	-0.009
GndCover		-0.573	-0.651	-0.738	-0.734	-0.228	0.782

P-values	Canon	Visible sky	ISF	DSF	GSF	LAI	GndCover
Smartphone							
Visible sky		0.000	0.000	0.000	0.000	0.176	0.000
ISF		0.000	0.000	0.000	0.000	0.577	0.000
DSF		0.000	0.000	0.000	0.000	0.742	0.000
GSF		0.000	0.000	0.000	0.000	0.789	0.000
LAI		0.005	0.016	0.036	0.033	0.000	0.934
GndCover		0.000	0.000	0.000	0.000	0.037	0.000

R^2-values	Canon	Visible sky	ISF	DSF	GSF	LAI	GndCover
Smartphone							
Visible sky		46.4%	---	---	---	---	---
ISF		50.5%	56.5%	---	---	---	---
DSF		47.5%	56.3%	68.3%	---	---	---
GSF		48.1%	56.8%	68.4%	67.9%	---	---
LAI		9.1%	6.9%	5.3%	5.4%	52.5%	---
GndCover		32.8%	42.4%	54.4%	53.8%	5.2%	61.1%

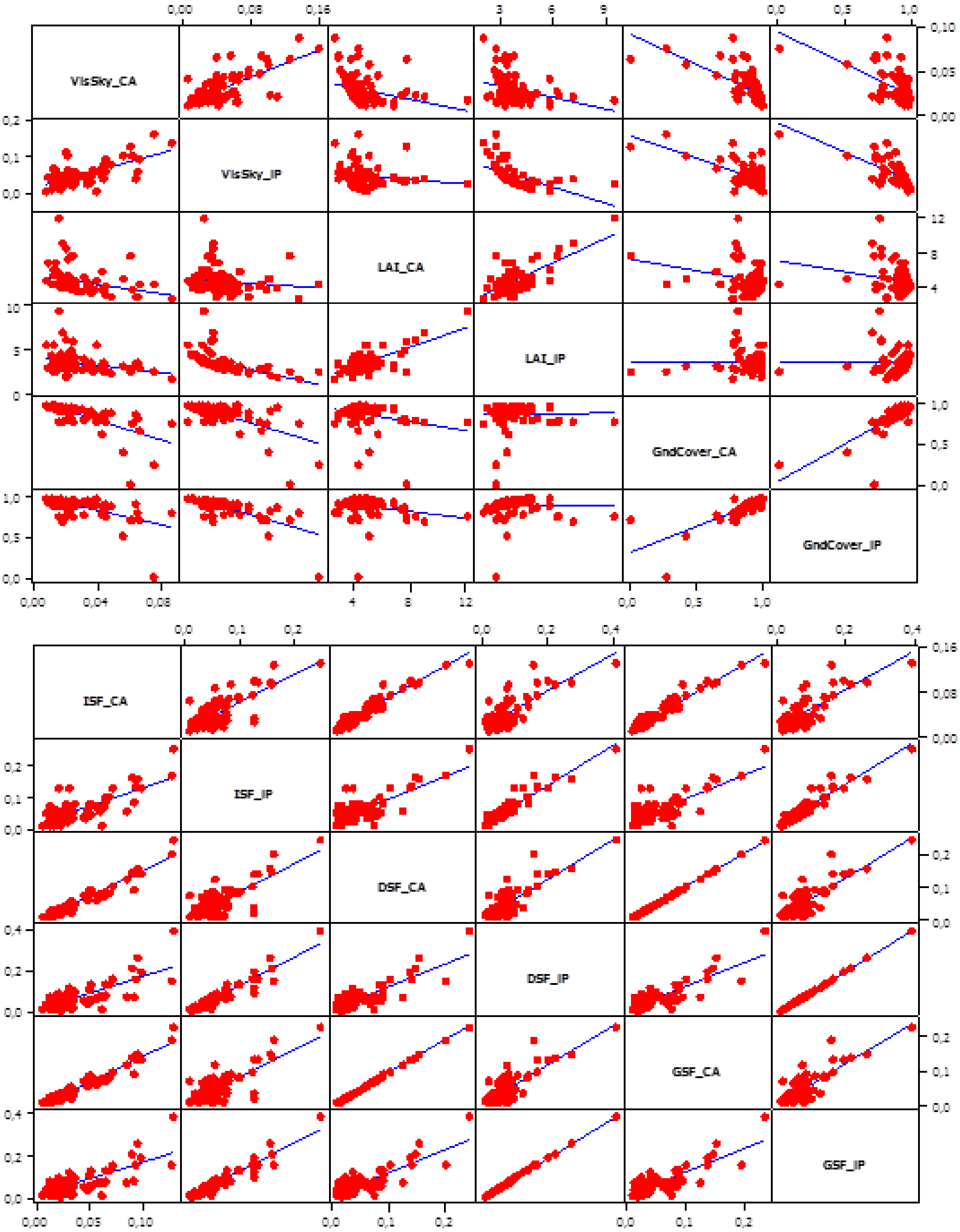

Figure 13. Matrix-plots of measured variables from DSLR-camera and smartphone-camera. VisSky stands for Visible sky, LAI stands for Leaf Area Index, GndCover stands for Ground Cover, ISF stands for Indirect Site Factor, DSF stands for Direct Site Factor, GSF stands for Global Site Factor. Variables with suffix _CA originate from the DSLR-camera. Variables with suffix _IP originate from the smartphone camera.

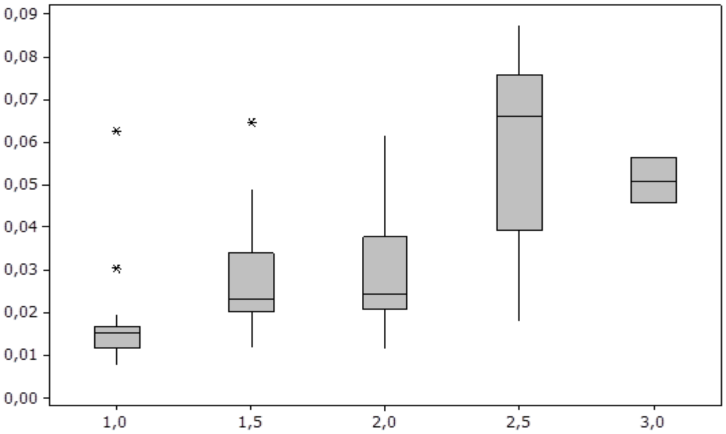

Figure 18. Box-plots of the distribution of Visible Sky sorted in Crown Illumination Index classes. Y-axis shows amount of Visible sky on a scale on 0.00 to 1.00. X-axis shows CII classes.

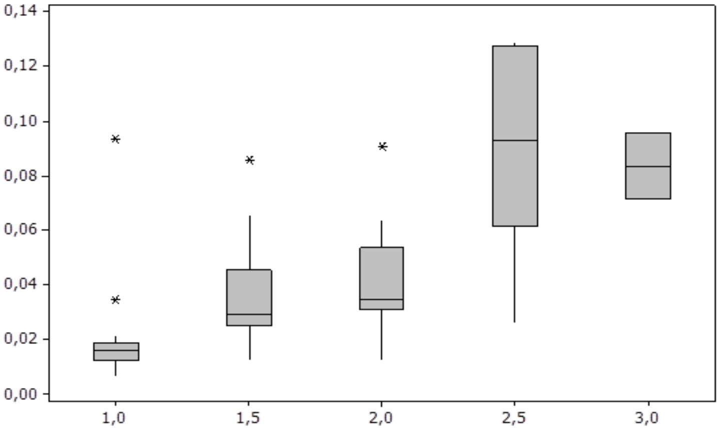

Figure 318. Box-plots of the distribution of ISF sorted in Crown Illumination Index classes. Y-axis shows amount of ISF on a scale on 0.00 to 1.00. X-axis shows CII classes.

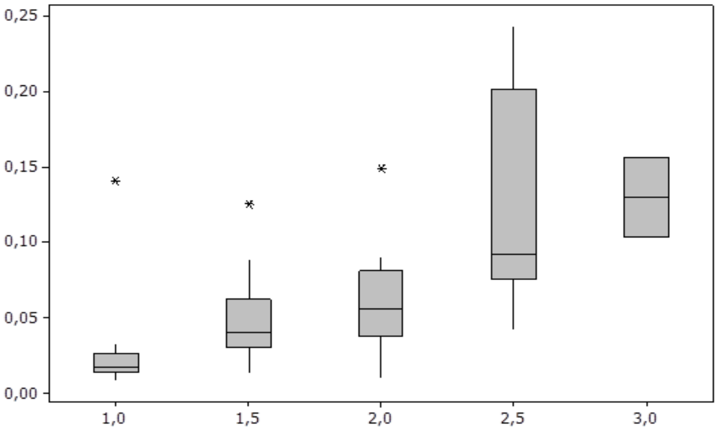

Figure 418 Box-plots of the distribution of DSF sorted in Crown Illumination Index classes. Y-axis shows amount of DSF on a scale on 0.00 to 1.00. X-axis shows CII classes.

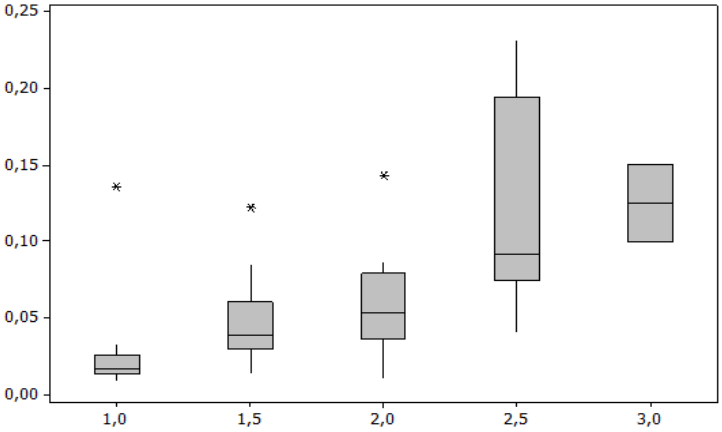

Figure 518 Box-plots of the distribution of GSF sorted in Crown Illumination Index classes. Y-axis shows amount of GSF on a scale on 0.00 to 1.00. X-axis shows CII classes.

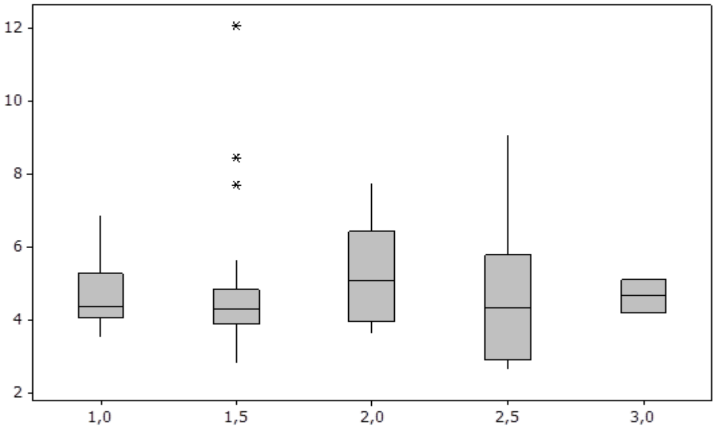

Figure 618 Box-plots of the distribution of Leaf Area Index sorted in Crown Illumination Index classes. Y-axis shows amount of LAI. X-axis shows CII classes.

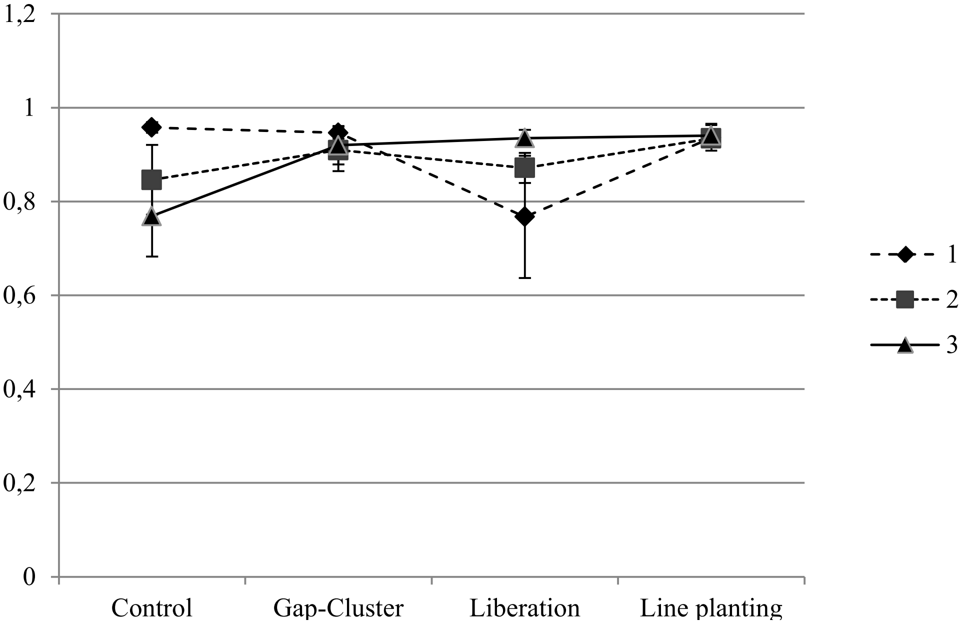

Figure 719 Interaction plot for Ground Cover between means of forest types 1, 2 and 3. Y-axis shows amount of Ground cover. X-axis shows the 3 rehabilitation methods, plus control.

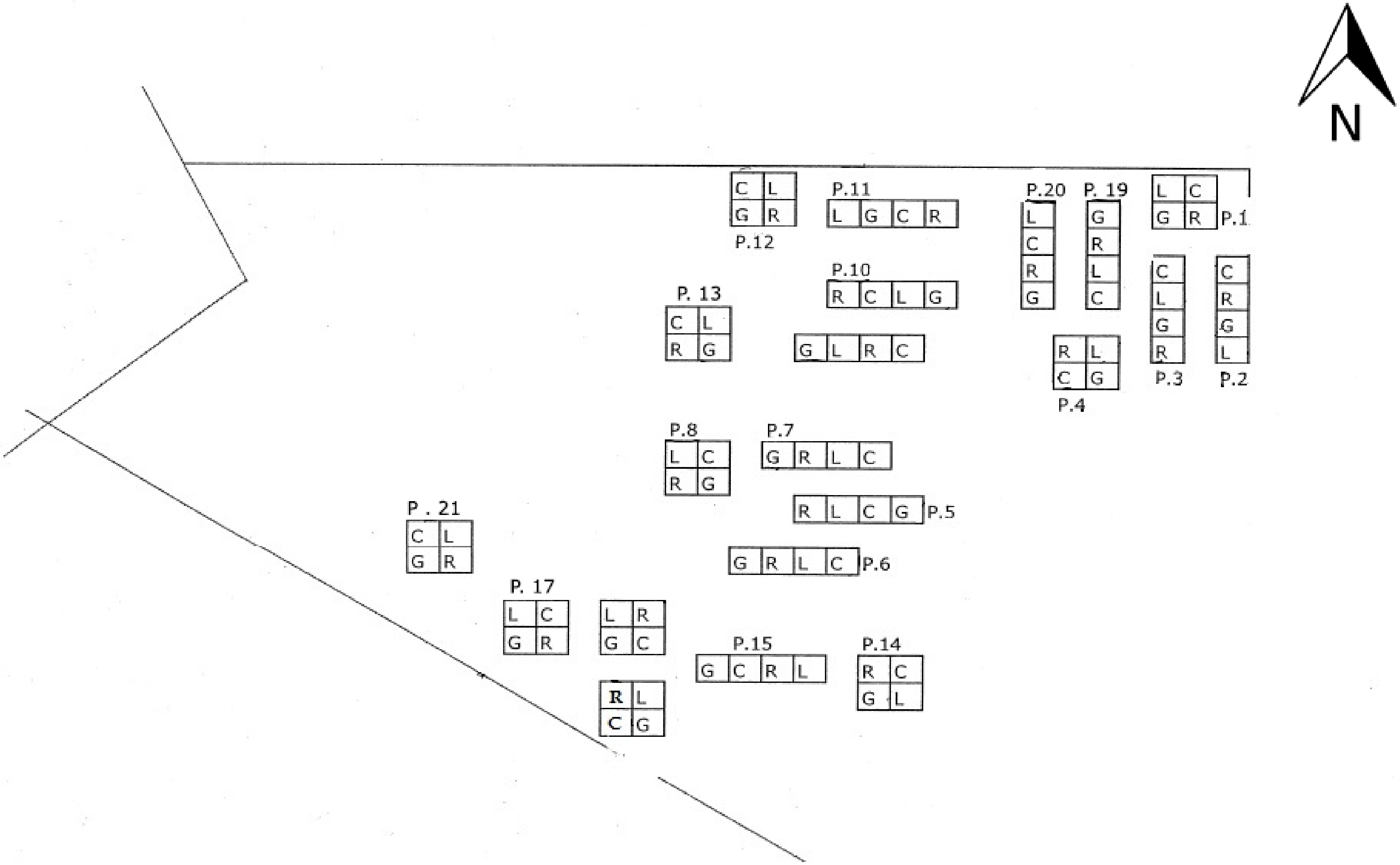

Figure 820. Idealized Map of study plots located 25 km west of Luasong Forestry Centre (latitude 4.6N, longitude 117.2E),where field study took place.

Table 6 Description of RRE-plots

Forest type 1 : Line planting

	Block						
Treatment	1	2	3	4	5	6	7
A	Control	Control	Liberation	Gap	Gap	Liberation	Control
B	Liberation	Line	Line	Liberation	Line	Control	Line
C	Gap	Gap	Control	Line	Liberation	Line	Liberation
D	Line	Liberation	Gap	Control	Control	Gap	Gap
	Plot 2	**Plot 3**	**Plot 4**	**Plot 6**	**Plot 9**	**Plot 10**	**Plot 13**

Forest type 2 : Gap-cluster planting

	Block						
Treatment	1	2	3	4	5	6	7
A	Line	Liberation	Line	Liberation	Liberation	Liberation	Gap
B	Control	Line	Control	Gap	Line	Control	Liberation
C	Gap	Control	Liberation	Line	Control	Gap	Line
D	Liberation	Gap	Gap	Control	Gap	Line	Control
	Plot 1	**Plot 5**	**Plot 8**	**Plot 7**	**Plot 18**	**Plot 14**	**Plot 19**

Forest type 3 : Liberation

	Block						
Treatment	1	2	3	4	5	6	7
A	Line	Control	Gap	Line	Line	Line	Control
B	Gap	Line	Control	Liberation	Control	Control	Line
C	Control	Gap	Liberation	Gap	Gap	Liberation	Gap
D	Liberation	Liberation	Line	Control	Liberation	Gap	Liberation
	Plot 11	**Plot 12**	**Plot 15**	**Plot 16**	**Plot 17**	**Plot 20**	**Plot 21**

SENASTE UTGIVNA NUMMER

2014:21	Författare: Jennifer McGuinness Effect of planting density and abiotic conditions on yield of *Betula pendula* and *Pinus sylvestris* seedlings in monoculture and mixture
2014:22	Författare: Emil Mattsson Zonerat skogsbruk – en möjlighet för Sverige
2014:23	Författare: Emma Borgstrand Plantors och träds tillväxt efter schackrutehuggning och i konventionellt trakthyggesbruk
2014:24	Författare: Fredrik Eliasson Förutsättningar för virkesinriktad skogsodling med inhemska trädslag i Peru
2014:25	Författare: Torun Bergman Markanvändning och ekosystemtjänster i en gradient från borealt till alpint landskap – Vilhelmina Model Forest
2014:26	Författare: Molly Nord Gårdman Enskilda privata skogsägares inställning till skogsgödsling i Västerbottens län
	________
2015:1	Författare: Anders Henriksson Kan markfuktighetskartor användas för att hitta skogsmark med hög bonitet? – Ett GIS-baserat försök med DTW-index och laserskannad övre höjd
2015:2	Författare: Louise Magnusson Markberedning i blockrik terräng – En jämförelse mellan grävmaskin och harv
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