Examensarbeten 2015:6

Fakulteten för skogsvetenskap
Institutionen för skogens ekologi och skötsel

Restoring biodiversity in degraded secondary rain forest in Sabah, Malaysia

- natural regeneration of trees after restoration treatments

Återskapande av biodiversitet i degraderad sekundär regnskog i Sabah, Malaysia - naturlig föryngring av träd efter restaureringsåtgärder

Foto: Sara Waern

Sara Waern

Sveriges Lantbruksuniversitet
Examensarbete i biologi, 30 hp, avancerad nivå A2E
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I denna rapport redovisas ett examensarbete utfört vid Institutionen för skogens ekologi och skötsel, Skogsvetenskapliga fakulteten, SLU. Arbetet har handletts och granskats av handledaren, och godkänts av examinator. För rapportens slutliga innehåll är dock författaren ensam ansvarig.

This report presents an MSc/BSc thesis at the Department of Forest Ecology and Management, Faculty of Forest Sciences, SLU. The work has been supervised and reviewed by the supervisor, and been approved by the examiner. However, the author is the sole responsible for the content.

PREFACE

This thesis was done as a Minor Field Study and was financially sponsored by the Swedish International Development Cooperation Agency (SIDA). The field work was conducted in the Sg. Tiagau Forest Reserve in Sabah, Malaysian Borneo. Many people have helped me in different ways with this thesis and for that I am very grateful.

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Terimah kasih!

SUMMARY

Many tropical rain forests has been lost or degraded as a result of human activities and environmental factors. Since the level of biodiversity is high in the tropics, maintaining these areas is of great importance. Forests like these are often assumed to benefit from forest restoration and rehabilitation. The INIKEA project area in Eastern Sabah, Malaysian Borneo, aims to improve biodiversity and/or species richness in the degraded forest through enrichment planting with indigenous species. The objective of this thesis was to evaluate how different treatments (liberation, gap-cluster planting and line planting) affect the biodiversity of natural regeneration in different forest types in the Rain forest Restoration Experiment, located in the INIKEA project area. The forest in this experiment was divided into three types based on the degree of disturbance they had been exposed to. Species richness, species rank abundance (including evenness), biodiversity indices and measurements of ecological distance were compared between treatments and forest types for all size classes of forest vegetation (i.e. trees, saplings, seedlings and seeds). The results showed that there were almost no differences regarding biodiversity in natural regeneration between treatments, but some significant differences between forest types. However, the differences between forest types were not consistent throughout all analyses. The differences between forest types may indicate that they are in need of different treatments when practicing restoration. Also, large differences in species richness and evenness could be observed between the different tree size classes. The greater differences between forest types than between treatments could be explained by the recently performed treatments. The forest types have been constant for a longer time period and the differences should be larger between the forest types than the treatments. The differences between the size classes could mostly be explained by inter- and intraspecific competition and the, at the time of the inventory, ongoing mast fruiting. To be able to observe possible differences between the effects of the treatments in this project, more time is needed.

Keywords: Forest fire, selective logging, *Dipterocarpaceae*, assisted natural regeneration (ANR)

SAMMANFATTNING

De tropiska regnskogarna har som ett resultat av mänsklig påverkan och miljöfaktorer blivit allt färre och av sämre kvalitet. På grund av den höga biodiversiteten som återfinns i regnskogar är bibehållandet av sådana områden av stor betydelse. Tropiska regnskogar tros gynnas av restaurering och rehabilitering. INIKEA-projektet i östra Sabah, Malaysiska Borneo, jobbar med hjälpplantering med inhemska arter för att öka biodiversiteten samt artrikedomen i de degraderade skogarna i området. Målet med den här uppsatsen var att utvärdera hur olika behandlingar (liberation, gap-cluster planting och line planting) påverkar biodiversiteten hos den naturliga föryngringen i olika skogstyper i ett restaureringsprojekt, vilket var lokaliserat i INIKEAS projektområde. Skogsområdet i experimentet var indelat i tre skogstyper baserat på dess störningsgrad. Artrikedom, rangordningsbaserad artabundans (inklusive jämnhet i artsammansättning), biodiversitetsindex och ekologiskt avstånd jämfördes mellan behandlingar och skogstyper för alla storleksklasser av skogsvegetation (dvs. träd, saplings, plantor och frön). Resultaten visade att det knappt fanns några skillnader gällande biodiversitet i naturlig föryngring mellan de olika behandlingarna, men signifikanta skillnader mellan skogstyperna. Skillnaderna mellan skogstyper var dock inte likartade och beständiga i alla analyser. Skillnaderna mellan skogstyperna kan indikera att de olika skogstyperna kräver olika typer av skötsel vid genomförandet av restaurering. Återkommande skillnader i artrikedom och jämnhet i artsammansättningen hos de olika storleksklasserna observerades. Den större skillnaden mellan skogstyper än behandlingar kunde förklaras av att behandlingarna utförts relativt nyligen i området. Skogstyperna har varit konstanta under en längre tidsperiod och en större skillnad mellan dessa var därför väntad. Skillnaderna mellan olika utvecklingsstadier kunde främst förklaras genom inter- och intraspecifik konkurrens samt genom det, under inventeringens gång, pågående fröfallet. För att kunna utläsa eventuella skillnader mellan behandlingarnas effekt i detta projekt krävs att projektet får fortgå ytterligare några år.

Nyckelord: Skogsbrand, selektiv avverkning, *Dipterocarpaceae*, assisterad naturlig föryngring (ANR)

CONTENTS

1. INTRODUCTION

In 1990 there were 1,756 million hectares (ha) of tropical forests in the world (Whitmore 1998), that number has decreased steadily and 55,000 km^2 of primary tropical forests are estimated to be lost each year (Ghazoul & Sheil 2010). Since the level of biodiversity is high in the tropics and since many species only exist in the tropics, maintaining these areas is of great importance (Ghazoul & Sheil 2010, Corlett & Primack 2011). The selective logging methods commonly used in the tropical rain forests in Southeast Asia (Corlett & Primack 2011) affects forest structure, regeneration dynamics and species composition to a high degree and can lead to future species extinction (Yamada et al. 2013). A lot of species are already today threatened with extinction and in 2050 24 % of all tropical rain forest species are projected to be extinct due to habitat loss and projected climate change scenarios (Ghazoul & Sheil 2010). Asides from logging, Borneo has been largely affected by drought periods, mostly associated with the El-Niño-Southern Oscillation cycle (ENSO) (Ghazoul & Sheil 2010). In 1982-83 and in 1997-98 the strongest El-Niño events of the last century took place (Corlett & Primack 2011) and this resulted in pronounced dry periods and insect outbreaks (Ghazoul & Sheil 2010). Selective logging together with dry periods increases the vulnerability to fire (Ghazoul & Sheil 2010) and the El-Niño events resulted in heavy forest fires that burned almost a million ha in Sabah (Alloysius et al. 2010). Drought, fire and selective logging result in forest loss as well as in degraded forests. It is believed that characteristics and functions in degraded forests can be restored by forest restoration and rehabilitation. Restoration is primarily applied to degraded primary forests and aims to accelerate and enhance natural processes of forest regeneration (ITTO 2002). The intent is to create an ecosystem as close as possible to the original ecosystem (Lamb & Gilmour 2003). Rehabilitation aims to re-establish forest or woodland ecosystems to improve some ecosystem services, but not necessarily the original system, and is most commonly used when forest ecosystems have been severely degraded and replaced by e.g. grassland (ITTO 2002). What advantages these actions may have and if they actually do accelerate recovery are not fully evaluated and to gather more knowledge in this area further research is needed.

In 1998 Yayasan Sabah, a state-owned organization in Sabah, Malaysian Borneo, together with IKEA founded a forest rehabilitation project. The project is located in a degraded forest within the Yayasan Sabah Concession Area in Eastern Sabah and is known as the INIKEA Sow-a-seed Project. The objective of the project is to improve biodiversity and species richness in the degraded forests through enrichment planting with indigenous species (Alloysius et al. 2010). The project area consists of 18,500 ha and the aim was to rehabilitate, restore and manage 12,500 ha in three phases extending from 1998-2023 (Alloysius et al. 2010). At the end of 2014: 12,396 ha had already been rehabilitated (Alloysius 2014) and a new phase (Phase 4) and new goals will most likely be initiated in 2015 (Ilstedt 2015). The project employs people from local villages to perform the rehabilitation work and does not use contractors. This creates good employment terms for the workers as well as better job quality (Alloysius et al. 2010). The INIKEA project area was degraded by the drought induced forest fires in 1982 and 1983 (Alloysius et al. 2010, Garcia & Falck 2002), as well as by selective logging from the 1970's to the 1990's (Reynolds et al. 2011). The area is now mainly covered by the pioneer species *Macaranga spp*. together with lianas, climbers and vines (Alloysius et al. 2010). Some smaller, less fire-ravaged, areas with higher abundance of dipterocarps can also be found (Ilstedt 2015).

In one part of the INIKEA project area an experiment called the Rain forest Restoration Experiment (RRE) was established. The forest in the RRE-area has been divided into three forest types based on the extent of disturbance that they have been exposed to, their successional stages and their vegetation. The forest types range from a more open forest dominated by ginger, vine, fern and climber and with features of some primary species as e.g. *Macaranga spp*. to *Macaranga spp*. dominated with a few dipterocarp trees and onwards to a more mixed forest with higher extent of dipterocarp species and denser canopy cover (more details about RRE in section 3.2). The need for assisted planting depends on the amount of disturbance and the forest types are, based on their state, assumed to benefit from different treatments (Ilstedt 2014). Three different treatments, as well as control areas, have therefore been applied in the experiment to test whether the assumptions are correct or not. The treatments applied are liberation, gap-cluster planting and line planting. The liberation method, also known as assisted natural regeneration (ANR) (e.g. Shono, Cadaweng & Durst 2007), aims to favor already established trees by removing competing vegetation while gap-cluster planting and line planting create open gaps and lines where plants of selected species are planted. Line planting affects the area to a higher extent than gap-cluster planting (more details about the treatments can be found in Section 3.2). Forest type 1 is assumed to benefit from liberation treatments, forest type 2 from gap-cluster planting and forest type 3 from line planting. All treatments have been performed in all forest types. By conducting inventories of the natural regeneration in this experiment an estimation of what effect the treatments have on the natural regrowth can be made. The effect of different treatments on natural regeneration has not been previously explored in the Sg. Tiagau Forest Reserve due to the fairly recent establishment of the project, and no other similar studies regarding biodiversity and natural regeneration with these treatment methods have been found. Knowledge about this can be very helpful when choosing regeneration methods for future restoration areas. Natural regeneration can be of great importance for biodiversity in the area. If support of natural regeneration provides good results regarding biodiversity and regrowth it can lower the restorations costs, since no or less plants and plant-related work are needed (Shono, Cadaweng & Durst 2007). Since the project is young the result can be of great importance for future inventories. If no differences between treatments exist, the inventory data can function as baseline values for the experiment area.

1.1. Objectives

The main objective of this study was to evaluate whether any differences in biodiversity of natural regeneration could be distinguished between the three forest types and/or between the four treatments (liberation, gap-cluster, line planting and control) and if there were any interactions between forest type and treatment in the RRE.

My hypothesis was that the overall differences should not be that large since the experiment was established only one year before this inventory. A larger difference between the forest types than between the treatments was to be expected, since the treatments should not have affected the area as much as the forest types at that time, due to the recent performance of the treatments. If differences between the treatments existed, the difference should have been the greatest between liberation and line planting since the degree of disturbance was greatest between these treatments.

2. THEORETICAL BACKGROUND

2.1. Tropical rain forests

Definitions of tropical rain forests can be based on climate and/or the actual vegetation present. Features defining a tropical rain forest are wet, warm and frost-free climatic conditions with no pronounced dry periods (Ghazoul & Sheil 2010). Tropical rain forests exist around the equator and are among the most diverse and complex ecosystems on Earth. More than 50 % of all terrestrial species can be found here (Sands 2005). Java, Sumatra and the Malay Peninsula together with Borneo is the third largest rain forest area and this region is called "Sundaland". This area has no regular dry periods but is affected by dry periods connected to the ENSO, which occurs at intervals of 2-8 years (Corlett & Primack 2011). The tropical forests in Southeast Asia are important contributors to wood production, biodiversity conservation, land and water protection as well as climate change reduction. Therefore forest loss in this area is of great concern (FAO 2011). If forested areas are lost or heavily affected by forestry activities ecological functions such as the water cycle, ground temperature and regional transpiration can be largely affected (FAO 2005). The health of the forests in Southeast Asia is threatened by logging, forest degradation, land conversion, fires, pests and diseases. Out of these threats logging seems to have the highest impacts on forest health, due to generally low quality harvesting operations (FAO 2011). To be able to maintain these forested areas, national parks and other protected areas could be established. Restorations and rehabilitations of forest areas can be an alternative way to maintain biodiversity (Corlett & Primack 2011). The loss of tropical forests has raised concerns for especially three topics: (i) the loss of biodiversity, (ii) disruption of human societies and (iii) the possible contribution to the climate change (Whitmore 1998). When it comes to carbon, mature climax rain forest are close to carbon neutral (Sands 2005). Rain forests are not the lungs of the world, but the fixed carbon in tropical forests do play an important role in the global carbon cycle. However, rain forests function as sources and sinks for numerous trace gases, e.g. tropical rain forest soils absorb 10-20 % of the global methane budget. Replacement of tropical rain forests with other land cover is likely to increase the level of greenhouse gases (Ghazoul & Sheil 2010).

2.2. Biodiversity

Biodiversity includes all existing life forms, their variety, their genetic diversity and their ecological roles (FAO 1989). Biodiversity assessments can be made at different scales including landscapes, ecosystems, populations, species, individuals and genetic makeup. Among these a variety of complex interactions exist. Only if there are clearly defined goals or aspects monitoring and assessments are possible (FAO 2010, ch.3). Biodiversity can be estimated at three different scales: Alpha (α)-diversity, beta (β)-diversity and gamma (γ)-diversity. Alpha diversity describes the species richness within a specific area, β-diversity describes the accumulation rate of species richness over larger landscapes and γ-diversity describes the total regional species richness (Ghazoul & Sheil 2010). Forests, especially tropical forests, have greater biodiversity than other terrestrial ecosystems (Sands 2005).

Species richness can be one parameter when estimating biodiversity (Sands 2005). Species richness is defined as the number of recorded species for a group of organisms in a specific area during a fixed time period. To get a good overview and to simplify comparison between different groups it can be presented as a species accumulation curve (Kindt & Coe 2005). Diversity is a combination of species richness and the evenness of species in an area. That means the number of species that can be distinguished and the relative abundance of those species. Diversity is independent of density and total abundance (Kindt & Coe 2005). To simplify diversity analysis, rank-abundance curves can be a good tool. This curve is based on number of individuals (abundance) of each species and a ranking of their abundance. The slope of the curve indicates evenness of species and the width of the curves indicate species richness; a horizontal curve indicates complete evenness and a wider curve indicates higher species richness. Evenness and richness can be combined to a single statistical number in numerous ways, which have resulted in different diversity indices. Simpson and Shannon diversity indices are two of the most commonly used (Kindt & Coe 2005). Differences in species composition can be observed by calculating the ecological distance between two or more sites; the ecological distance will describe the amount of shared species. A larger ecological distance indicates few common species between the investigated sites. A good way to present the results is e.g. through an ordination plot. Ecological distance can be measured in many ways; Euclidean distance and Bray-Curtis distance are two examples (Kindt & Coe 2005).

2.3. Deforestation and forest degradation

Forest degradation can be defined in many ways. The Food and Agriculture Organization of the United Nations (FAO) (2003) has gathered different definitions set by FAO, The International Tropical Timber Organization (ITTO), United Nations Environment Programme (UNEP), Convention on Biological Diversity (CBD) and Intergovernmental Panel on Climate Change (IPCC). They all agree that a degraded forest is a forest in which a reduction of biomass and functions has taken place. Many definitions include reduction that is human-induced. Forest degradation should not be mixed up with deforestation. A forest is considered to be deforested if the canopy cover is less than 10 % or if the land is converted to other land use such as agriculture or urban development (FAO 2000, Sands 2005). If a forest is reduced, but still has a canopy cover higher than 10 %, it is considered degraded (FAO 2000). A degraded forest has lost structure, species composition, function and/or the productivity that would have existed if natural conditions would occur. Also, the level of biodiversity is affected by degradation (ITTO 2002).

South and Southeast Asia are the tropical regions with the highest rate of forest degradation and deforestation. The main reasons are the conversion of forest into cash crops, e.g. palm oil, and the large logging industry (Corlett & Primack 2011). A total of 850 million ha in the world were estimated to be degraded or secondary forests in 2000 (ITTO 2002). Out of these 4.6 million ha of degraded or secondary forest was found in Malaysia and 1.1 million ha in Sabah **(**Ahmad Zainal bin Mat Isa 1992, see Krishnapillay, Razak & Appanah 2007, p.87). Secondary forest is particularly defined by ITTO (2002) as woody vegetation that grows back on land that has been partly or completely cleared from its original forest cover. These forests usually develop naturally on land that has been abandoned after completed land use activities. After disturbances an area gradually recovers, which is known as secondary succession (Townsend, Begon & Harper 2008, Ghazoul & Sheil 2010). How fast an area recovers depends on many factors, including the extent of disturbance and distance to seed trees. Different parts of a disturbed area can therefore have reached different successional stages at the same time (Ghazoul & Sheil 2010).

The majority of the forests in Malaysia consist of secondary, naturally regenerated forest (FAO 2010, table 7). The areas covered by forests have declined over the last decade, from 22.4 million ha in 1990 to 20.5 million ha in 2010 (FAO 2010, table 3). Dipterocarp forests, mostly consisting of trees of the family D*ipterocarpaceae*, dominate the Malay forests (Blaser et al. 2011, Corlett & Primack 2011). The canopy height often reaches 50 m or more and the tree base is often supported. These characteristics make the trees more stable and keep them standing for a longer time period, which makes the forests darker. The dipterocarps contains a resin in all plant parts which protects them from fungi, animals and bacteria. The stability combined with the protective resin are probably the two main factors behind the dipterocarp success in Southeast Asia. In the almost constantly wet regions of Southeast Asia most dipterocarp species only flower and fruit every 2-7 years, so called mast fruiting. This event depends on drought periods (Corlett & Primack 2011). Drought combined with fire causes great damage since both smaller and larger stems are killed (Ghazoul & Sheil 2010). The specific logging method used in Malaysia during the 1950's, 60's and 70's was called the ''Malaysian Uniform System'' (MUS) and this method generally selected and removed dipterocarp trees over 45 cm diameter at breast height (dbh). This method resulted in naturally regenerated trees of varied age, most of them light-demanding species (Yamada et al. 2013).

3. MATERIAL AND METHODS

3.1. Site and location

The inventories have been made in the RRE, which is a part of the INIKEA Forest Rehabilitation Project in the Sg. Tiagau Forest Reserve in Southeast Sabah, Malaysian Borneo (approximately lat 4°36'N, long 117°14'E (Romell 2007) (Fig. 1). The inventory took place from the 28th of August 2014 – 12th of September 2014, one year after the treatments were performed. The mean annual precipitation in the area was around 2389.2 mm (Luasong Forestry Centre 2014, unpublished data for year 2002-2013) and the temperature had not shifted much throughout the year, the average daily temperature being 29°C (Sabah Forestry Department 2007).

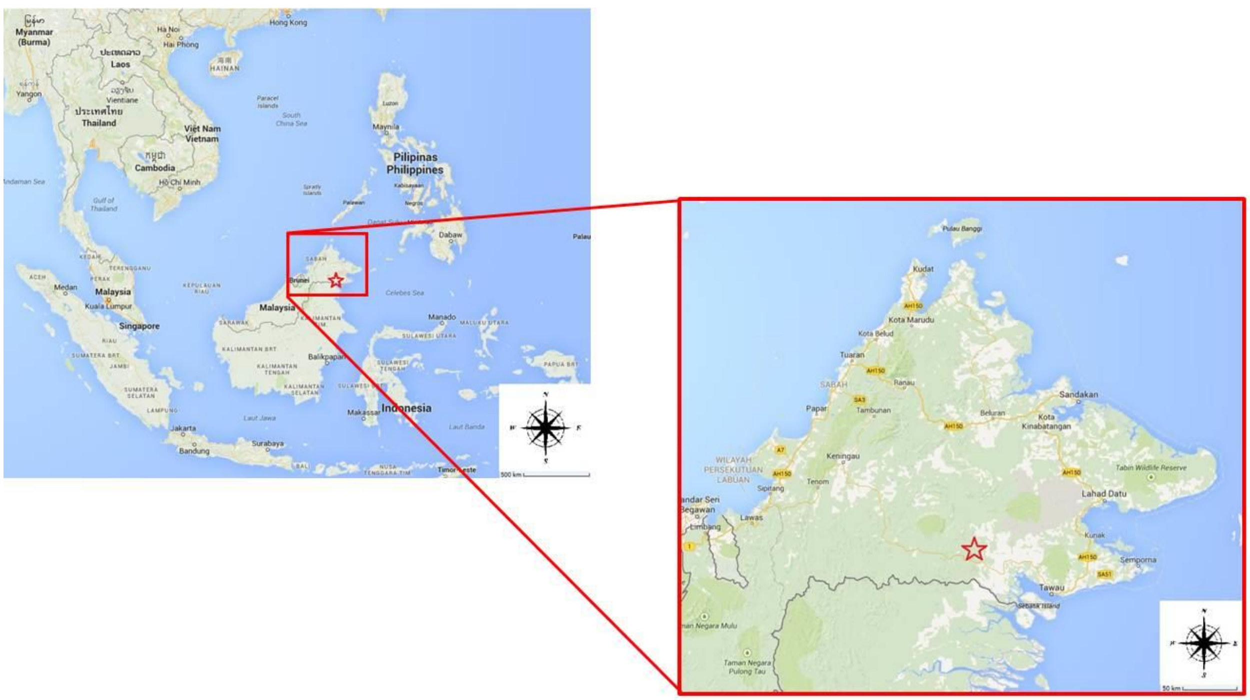

Fig. 1. *Map of Southeast Asia and Sabah (Google Maps 2014) with the location of the INIKEA Forest Rehabilitation Project marked as a red star.*

3.2. Design of the Rain forest Restoration Experiment, RRE

In 2013 the RRE was established in the Sg. Tiagau Forest Reserve and since then different research projects have been conducted in the experiment area. The RRE-area was originally created to test how different treatments affect the three forest types in the area. The forest types were numbered from 1-3 where forest type 1 corresponds to mixed forest, forest type 2 to Macaranga forest and forest type 3 to open forest. The forest types are thus numbered from low to high extent of disturbance. The RRE-area consists of 72.9 ha and holds 21 blocks, seven in each of the three forest types. In these blocks there are four 40x40 m plots, each with a different treatment. One plot is managed with liberation, one with gap-cluster planting and one with line planting. The fourth is non-treated and has the function of a control plot. How the blocks and their plots are located can be seen in Fig. 2.

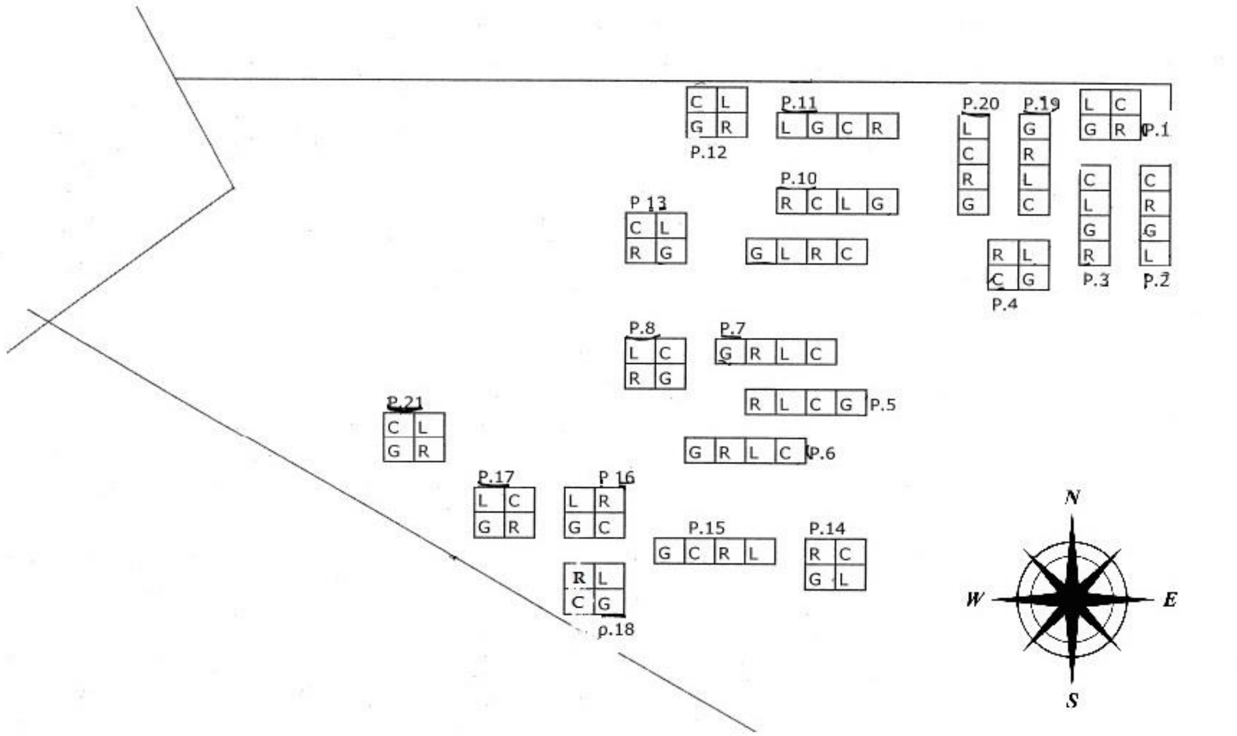

__Fig. 2.__ Map over the 21 blocks in the Rain forest Restoration Experiment located in Sabah, Malaysian Borneo. The experiment aims to investigate the possible effects that different treatments have in different forest types. In each block there are four 40x40 m plots each with a different treatment: R= Liberation, G= Gap-cluster, L= Line planting and C= Control. The liberation method aims to favor established trees while gap-cluster planting and line planting involves planting new seedlings. Line planting affects the area to a higher extent than gap-cluster planting.

3.2.1. Liberation

The liberation management method aims to favor already established naturally regenerated tree plants. This is made by ring barking of *Macaranga spp*. to create better light conditions for natural regeneration and by selective climber cutting (Alloysius et al. 2010).

3.2.2. Gap-cluster planting

Gap-cluster is a planting technique where four gaps within a 20x20 m quadrant are created or if possible, chosen. Four imaginary 10x10 m sub-quadrants can be located in the quadrant and every sub-quadrant holds a gap. The gap/opening is created or chosen subjectively based on terrain, standing trees, etc. (Alloysius et al. 2010, Ilstedt 2014). Within each gap a cluster of four seedlings of different species is planted. If a sub-quadrant holds more than five natural dipterocarp species, no planting will be made in that sub-quadrant (Alloysius et al. 2010). For a schematic picture see Fig. 3.

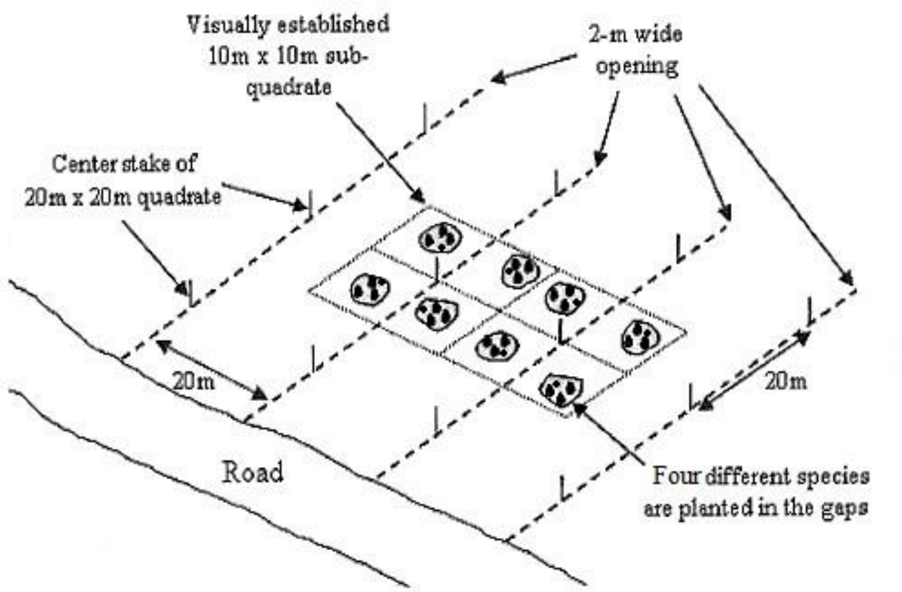

Fig. 3. *Schematic picture of the design of gap-cluster planting (remade from Alloysius et al. 2010). Four gaps are created or chosen within a 20x20 m quadrant and four seedlings are planted in each gap.*

3.2.3. Line planting

Line planting is a planting technique with 2 m wide planting strips and seedlings planted every 3 m. The strips are made with a 10 m interval (Alloysius et al. 2010). For a schematic picture see Fig. 4.

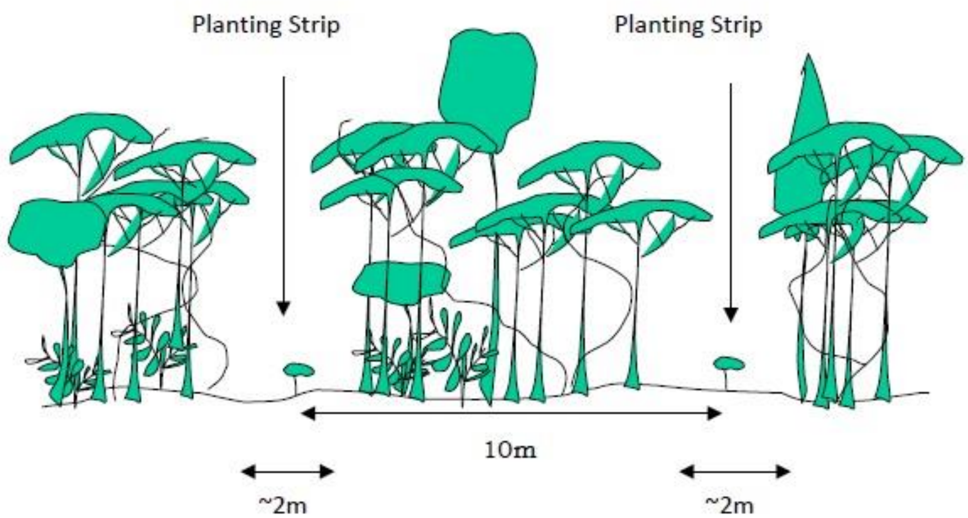

Fig. 4. *Schematic picture of the design for line planting (Garcia & Falck 2002). Lines with the width of approximately 2 m are created every 10 m. In these open lines seedlings are planted every 3 m.*

3.3. Method of inventory

The center of each 40x40 m plot was located, which at times involved using measure-tape and compass, and marked with a permanent red stick. Around the center of each plot a 10x10 m subplot was established by using measure tape and a compass and the border of the subplot was marked with eight permanent red sticks. The sticks were located with a compass and their location can be seen in Fig. 5. One 5x5 m plot was selected inside the 10x10 m plot. The placement of the 5x5 m sub-plots was set by a compass. Sub-plot number 1 was always in northwest, number 2 in northeast, number 3 in southwest and number 4 in southeast from the center of the 10x10 m plot (Fig. 5). The 5x5 m plot was selected randomly out of a randomization scheme created in Excel using the formula *random between*. The randomization list can be seen in Appendix 1. The center of the 5x5 m plot was permanently marked with a red stick. The center of the 5x5 m plot was also set to be the center of two circular plots with radii 1 m and 1.8 m. For a schematic picture of the sample plot design see Fig. 5.

In this inventory the definitions of vegetative development stages were as follows: All plants with a dbh>10 cm were defined as trees, all plants with a dbh between 2.5-10 cm were defined as saplings and all plants higher than 30 cm and with a dbh smaller than 2.5 cm were defined as seedlings (Table 1). In the 10x10 m plot all trees were identified and recorded and their dbh was measured with a diameter measure tape. In the 5x5 m plots all saplings were identified and counted and their height and dbh were measured, using a measuring stick and a caliper. In the circular 1.8 m plots all seedlings were counted and divided into species. In the circular 1 m plots all seeds divided by species were counted. All species identification were based on Lee (2003) and the expertise of the INIKEA staff.

Table 1. *Definitions of trees, saplings and seedlings used in the inventories*

Plant type	Height	dbh
Tree	> 30 cm	> 10 cm
Sapling	> 30 cm	2.5 cm < dbh < 10 cm
Seedling	> 30 cm	< 2 .5 cm

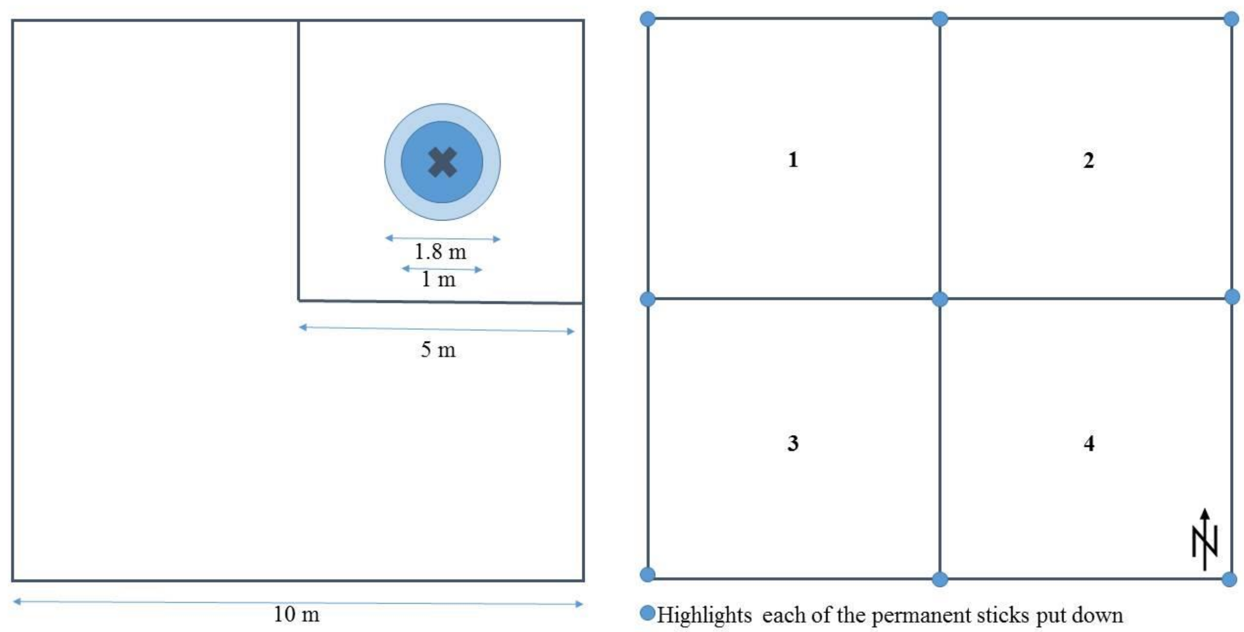

Fig. 5. *Schematic picture of the sample plot design used in the inventories. Around the center of the 40x40 m plots a 10x10 m subplot was established and 4 possible subplots of 5x5 m located, all according to a compass. The center as well as the corners of all possible subplots was marked with permanent marking sticks. What subplot area to use for the inventory was decided from a randomization list (Appendix 1). In the chosen 5x5 m plot one circular plot with radii 1.8 m and one circular plot with radii 1 m were established.*

3.4. Data-analysis and calculations

The number of trees, saplings, seedlings and seeds from the inventory data were converted to number/ha. The basal area of *Macaranga spp*., trees and saplings were converted to basal area/ha.

Species accumulation curves were performed for trees, saplings, seedlings and seeds respectively. For each of the development stages, species accumulation curves for the tree forest types were performed separately. They also contained a division of treatments. The species accumulation curves were conducted by using the specaccum-function in the Biodiversity Analysis Package (Kindt & Coe 2005). 100 permutations and the species accumulation method "exact" were used in order to find the expected species richness (Kindt & Coe 2005). Rank abundance curves were performed for trees, saplings, seedlings and seeds respectively. For each of the development stages, rank abundance curves for the tree forest types were performed separately. They also contained a division of treatments. The rank abundance curves were conducted by using the rank abundance-function in the Biodiversity Analysis Package (Kindt & Coe 2005). Shannon and Simpson diversity indices (equation 1 & 2, see e.g. Peet 1974) was performed by using the diversity function in the Biodiversity Analysis Package (Kindt & Coe 2005). The Biodiversity Analysis Package was a package in the statistical program Rstudio (2014).

Shannon diversity index: $H' = -\sum_{i=1}^{S} p_{i \log p_i}$ [1]

Simpson diversity index: $\lambda = \sum_{i=1}^{S} p_i^2$ [2]

A two-way ANOVA was used to assess whether species richness, Shannon diversity index and Simpson diversity index differed between forest types and treatments. Log transformations were applied to the Shannon diversity index for the basal area of trees as well as to the Simpson diversity index for number of trees. This was done before the analyses were conducted, to establish a normal distribution of the values (Zar 1999). The ANOVA analyses were conducted in Minitab (2010).

Measurements of ecological distance were conducted in the statistical program Rstudio (2014).
Species composition of trees, saplings, seedlings and seeds was analyzed separately in the forest plots, with respect to abundance, using a non-metric multidimensional scaling ordination (NMDS). This due to the ordination method being less susceptible for abnormal scales (McCune & Grace 2002, Oksanen 2013). The metaMDS function in the Vegan-package version 2.2-0 was used in order to search for a solution where the stress was minimized (Oksanen 2013, Oksanen et al. 2015). The Euclidean distance measurement was used to calculate dissimilarity index, as some plots had zero trees, saplings and seedlings.
The turnover of trees, saplings and seedlings between sites were separately analyzed using the betadiver function in the Vegan-package version 2.2-0 (Oksanen et al. 2015). Sørensen index of dissimilarity was used (Oksanen 2015). The function adonis was further used, which is a

permutational multivariate analysis of variance in the Vegan-package version 2.2-0 (Oksanen et al. 2015) in order to analyze whether species sharing was greater within treatment, forest type and abundance of *Macaranga spp.* The Bray–Curtis dissimilarity was used and statistical significance was tested against 200 null permutations. For the analysis of trees, site 17.2C, 1.1C, 2.3R were excluded from the adonis analyses, since they lacked tree species. For the analysis of saplings, site 10.3L and 13.3G were excluded from the adonis analyses, since they lacked sapling species. For the analysis of seedlings, site 2.3C was excluded from the Adonis analyses, since they lacked seedling species. The axes derived from the ordination analyses correspond to gradients of change in species composition and they were interpreted by correlating stand positions (Spearman's rank correlation coefficient) with the abundance of *Macaranga spp.* in the same sites.

The results of the statistical analysis were considered to be significant if $p \leq 0.050$ and to show a tendency if $0.050 < p \leq 0.100$.

4. RESULTS

The inventory resulted in a total of 116 species divided into 41 families. The largest family was D*ipterocarpaceae* followed by the family E*uphorbiaceae*. A total of 169 individuals were classified as other timber, and 2 seeds were not able to be identified and went under the category of unknown. Out of all 116 species, 29 could only be identified to family or species group. All development stages had numerous individuals from the unidentified species as can be seen in Table 2. The distribution over forest types and treatments were more even than between the development stages (Table 2). Out of these results it appeared that 7 unidentified species in fact could belong to already identified species and thus were not isolated species. For more details about species and families found in the inventory see Appendix 2 and 3.

Table 2. *Distributions of the number of individuals in the Rain forest Restoration Experiment that only could be identified to family or species group and the number of unidentified species they represented. The results are presented for development stages, forest types and treatments separately. The forest types were numbered from 1-3 where forest type 1 corresponds to mixed forest, forest type 2 to Macaranga forest and forest type 3 to open forest. The liberation method aimed to favor established trees while gap-cluster planting and line planting involved planting of new seedlings. Line planting affected the area to a higher extent than gap-cluster planting*

		Number of individuals	**Number of unidentified species**
Development stage	**Trees**	212	24
	Saplings	178	22
	Seedlings	231	20
	Seeds	95	9
Forest type	**1**	212	116
	2	316	111
	3	188	124
Treatment	**Liberation**	136	86
	Gap-cluster	211	99
	Line planting	201	77
	Control	168	89

The species accumulation curves varied between the development stages as well as between the forest types. However, the overall species accumulation curves for the different development stages looked rather similar to each other and had the shape of a negative exponential curve. The rank abundance curves showed varying results between the development stages and some differences between the forest types (more details can be found in Appendix 4). Overall the results from the two-way ANOVA showed very little differences between treatments and varying results regarding forest types. No significant results regarding saplings and seedlings could be seen. An overview of the results from the two-way ANOVA can be found in Tables 5 and 6. The analyses of ecological distance overall showed few significant results.

4.1. Trees

70 tree species were recorded from a sample size of 84 plots. The total species accumulation curve for trees (Fig. 6a) showed that the species richness was rapidly increasing in the beginning but started to flatten out after approximately 75 plots. The highest species richness was estimated in the gap-cluster plots for all forest types independently. In forest type 1 (n=28) the species richness was highest in gap-cluster plots followed by line planting, liberation and control plots (Fig. 6b). In forest type 2 (n=28) the species richness was highest in gap-cluster plots followed by liberation, line planting and control plots (Fig. 6c). In forest type 3 (n=28) the species richness as highest in gap-cluster plots followed by control, line planting and liberation plots (Fig. 6d).

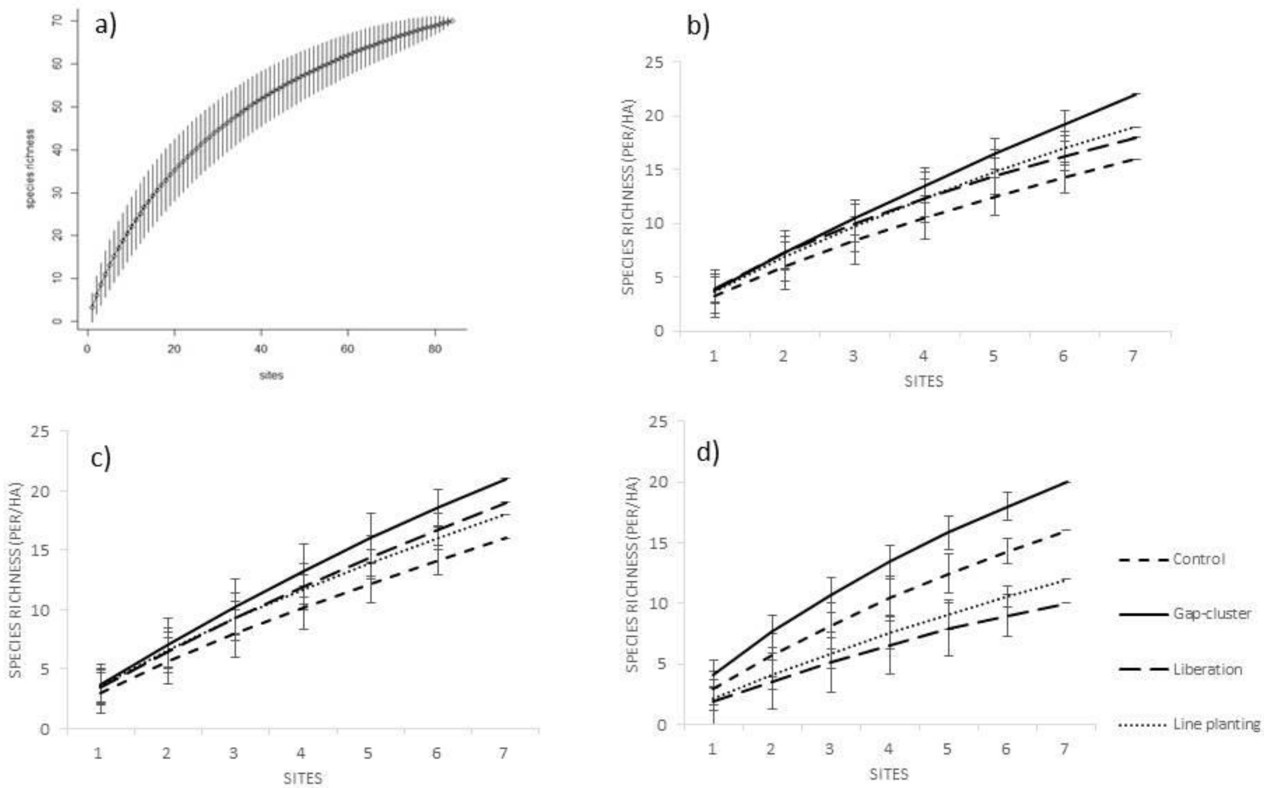

Fig. 6. *Species accumulation curves for all inventoried trees in the Rain forest Restoration Experiment located in Sabah, Malaysian Borneo. The curves showed a) All forest types and treatments (control, gap-cluster, liberation and line planting) b) Forest type 1 divided into treatments c) Forest type 2 divided into treatments d) Forest type 3 divided into treatments. The forest types were numbered from 1-3 where forest type 1 corresponds to mixed forest, forest type 2 to Macaranga forest and forest type 3 to open forest. The liberation method aimed to favor established trees while gap-cluster planting and line planting involved planting of new seedlings. Line planting affected the area to a higher extent than gap-cluster planting. The error bars indicated +2 and -2 standard deviation.*

Species richness for *Number of trees* showed no significant results, but tendencies of forest type 1 being different from forest type 3 (p=0.099). The Shannon diversity index showed that the relations between forest types in the analysis were significant (p=0.039). The relations showed that forest type 1 was significantly different from forest type 3 (p=0.039), but not from forest type 2. Forest type 2 could be grouped with both forest type 1 and forest type 3 (Fig. 7). The Simpson diversity index on the other hand showed tendencies of significant relations between treatments (p=0.066), but not between forest types. Line planting showed tendencies of being significantly different from control (p=0.092) as well as from gap-cluster (p=0.083) (Fig. 8).

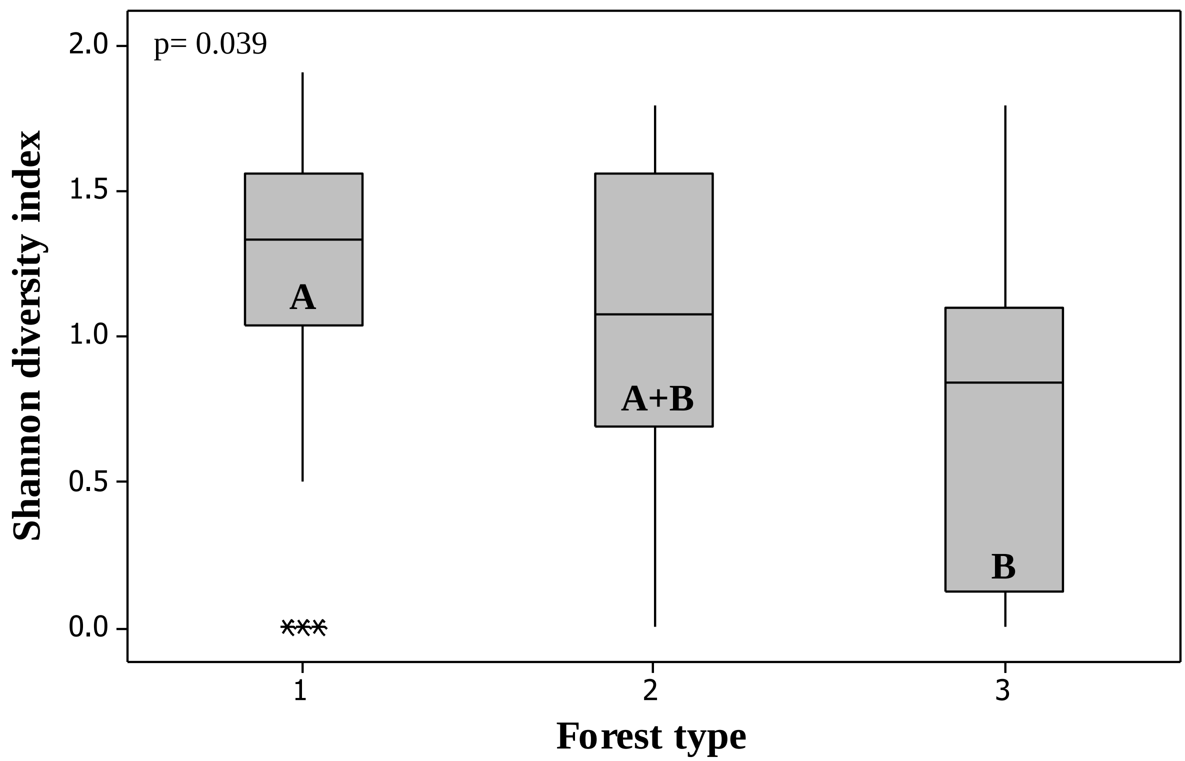

Fig. 7. *Boxplot of Shannon diversity index for number of trees in the Rain forest Restoration Experiment located in Sabah, Malaysian Borneo. The Shannon diversity index showed significant results (p=0.039) and forest type 1 was significantly different from forest type 3 (p=0.039). Boxes that did not share a letter were significantly different. Forest type 2 could be grouped with both Forest type 1 and forest type 3. Grouping information used Tukey method and 95.0 % confidence. The forest types were numbered from 1-3 where forest type 1 corresponds to mixed forest, forest type 2 to Macaranga forest and forest type 3 to open forest. Asterisks indicated outliers.*

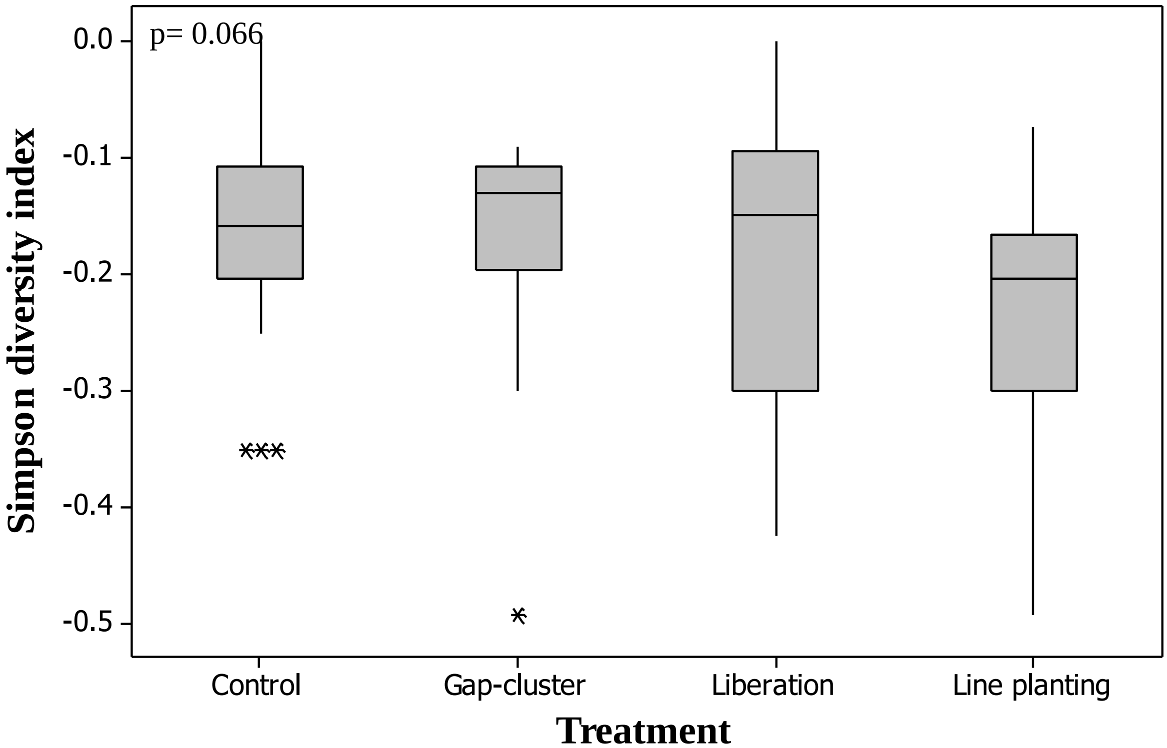

Fig. 8. *Boxplot of Simpson diversity index for number of trees in the Rain forest Restoration Experiment located in Sabah, Malaysian Borneo. The Simpson diversity index showed a tendency of significant results (p=0.066). Line planting showed tendencies to be different from control (p=0.092) and from gap-cluster (p=0.083). The liberation method aimed to favor established trees while gap-cluster planting and line planting involved planting of new seedlings. Line planting affected the area to a higher extent than gap-cluster planting. Asterisks indicated outliers.*

Species richness for *Basal area of trees* showed tendencies of significant results regarding forest types (p=0.087) as well as tendencies of forest type 1 being different from forest type 3 (p=0.087). The Shannon diversity index showed that the relations between forest types in the analysis were significant (p=0.022). The relations showed that forest type 1 was significantly different from forest type 3 (p=0.028) but not from forest type 2. However, forest type 2 showed tendencies of being significantly different from forest type 3 (p=0.071) and could be grouped with both forest type 1 and forest type 3 (Fig. 9). The Simpson diversity index only showed tendencies of significant relations regarding forest type (p=0.073).

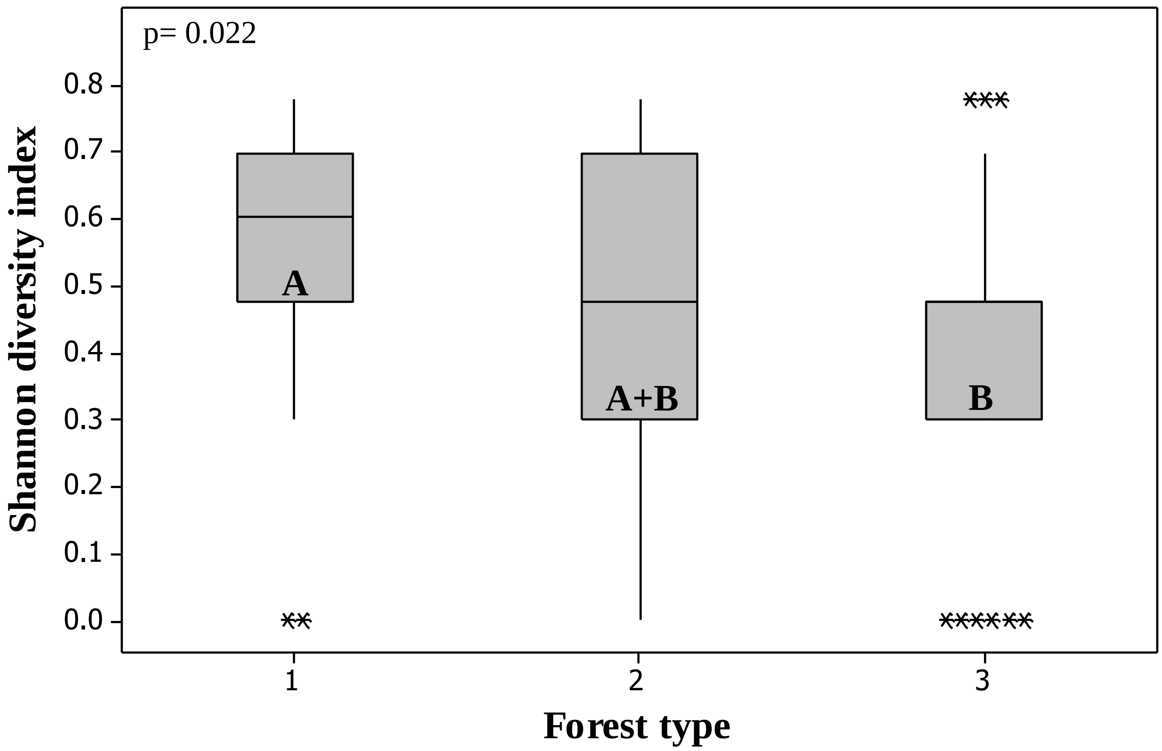

Fig. 9. *Boxplot of Shannon diversity index for basal area of trees in the Rain forest Restoration Experiment located in Sabah, Malaysian Borneo. The Shannon diversity index showed significant results (p=0.022) and forest type 1 was significantly different from forest type 3 (p=0.028). Boxes that did not share a letter were significantly different. Forest type 2 could be grouped with both forest type 1 and forest type 3. Grouping information used Tukey method and 95.0 % confidence. The forest types were numbered from 1-3 where forest type 1 corresponds to mixed forest, forest type 2 to Macaranga forest and forest type 3 to open forest. Asterisks indicated outliers.*

The NMDS ordination based on the composition of trees resulted in a 2-dimensional solution with stress of 0.22. The first axis was significantly correlated with the abundance of *Macaranga spp.* (r= -0.683, p<0.001). The second axis was not significantly correlated with *Macaranga spp*. (r=0.190, p=0.084) (Fig. 10 & Fig. 11). There was no relationship between the composition of tree species and treatment, forest type or abundance of *Macaranga spp*. based on the adonis-analysis.

4.2. Saplings

70 sapling species were recorded from a sample size of 82 plots. The total species accumulation curve for saplings (Fig. 10a) showed that the species richness was rapidly increasing in the beginning and was still increasing after 82 plots. The treatments with highest species richness varied between the forest types. In forest type 1 (n=27) the species richness was highest in control plots followed by liberation, line planting and gap-cluster plots (Fig. 10b). In forest type 2 (n=28) the species richness was highest in line planting plots followed by control, liberation and gap-cluster plots (Fig. 10c). In forest type 3 (n=27) the species richness was highest in gap-cluster plots followed by control, liberation and line planting plots (Fig. 10d). No significant results could be seen in the sapling data based on the two-way ANOVA.

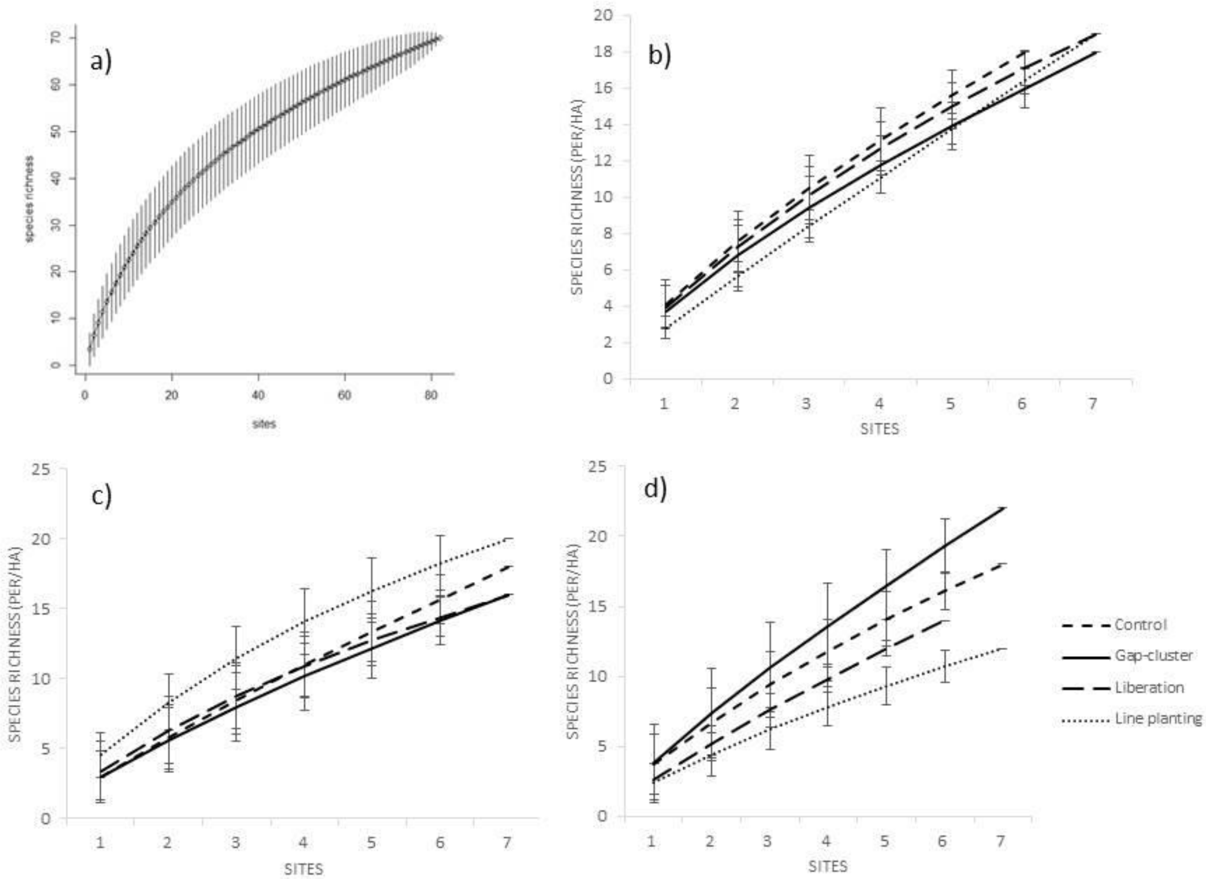

Fig. 10. *Species accumulation curves for all inventoried saplings in the Rain forest Restoration Experiment located in Sabah, Malaysian Borneo. The curves showed a) All forest types and treatments b) Forest type 1 divided into treatments c) Forest type 2 divided into treatments d) Forest type 3 divided into treatments. The forest types were numbered from 1-3 where forest type 1 corresponds to mixed forest, forest type 2 to Macaranga forest and forest type 3 to open forest. The liberation method aimed to favor established trees while gap-cluster planting and line planting involved planting of new seedlings. Line planting affected the area to a higher extent than gap-cluster planting. The error bars indicated +2 and -2 standard deviation.*

The NMDS ordination based on the composition of saplings resulted in a 2-dimensional solution with stress of 0.23. The first axis was not significantly correlated with the abundance of *Macaranga spp.* (r=-0.004, p=0.971) neither was the second axis (r=0.060, p=0.591). There was no relationship between the composition of sapling species and treatment, forest type or abundance of *Macaranga spp*. based on the adonis-analysis.

4.3. Seedlings

76 seedlings species were recorded from a sample size of 82 plots. The total species accumulation curve for seedlings (Fig. 11a) showed that the species richness was rapidly increasing in the beginning but started to flatten out after approximately 75 plots. Species richness was highest for gap-cluster plots in forest type 1 and forest type 3, while in forest type 2 the species richness was highest in the control plots. In forest type 1 (n=27) the species richness was highest in the gap-cluster plots followed by liberation, control and line planting plots (Fig. 11b). In forest type 2 (n=28) the species richness was highest in the control plots followed by liberation, line planting and gap-cluster plots (Fig. 11c). In forest type 3 (n=27) the species richness was highest in gap-cluster plots followed by line planting, control and liberation plots (Fig. 11d). No significant results could be seen in the seedling data based on the two-way ANOVA.

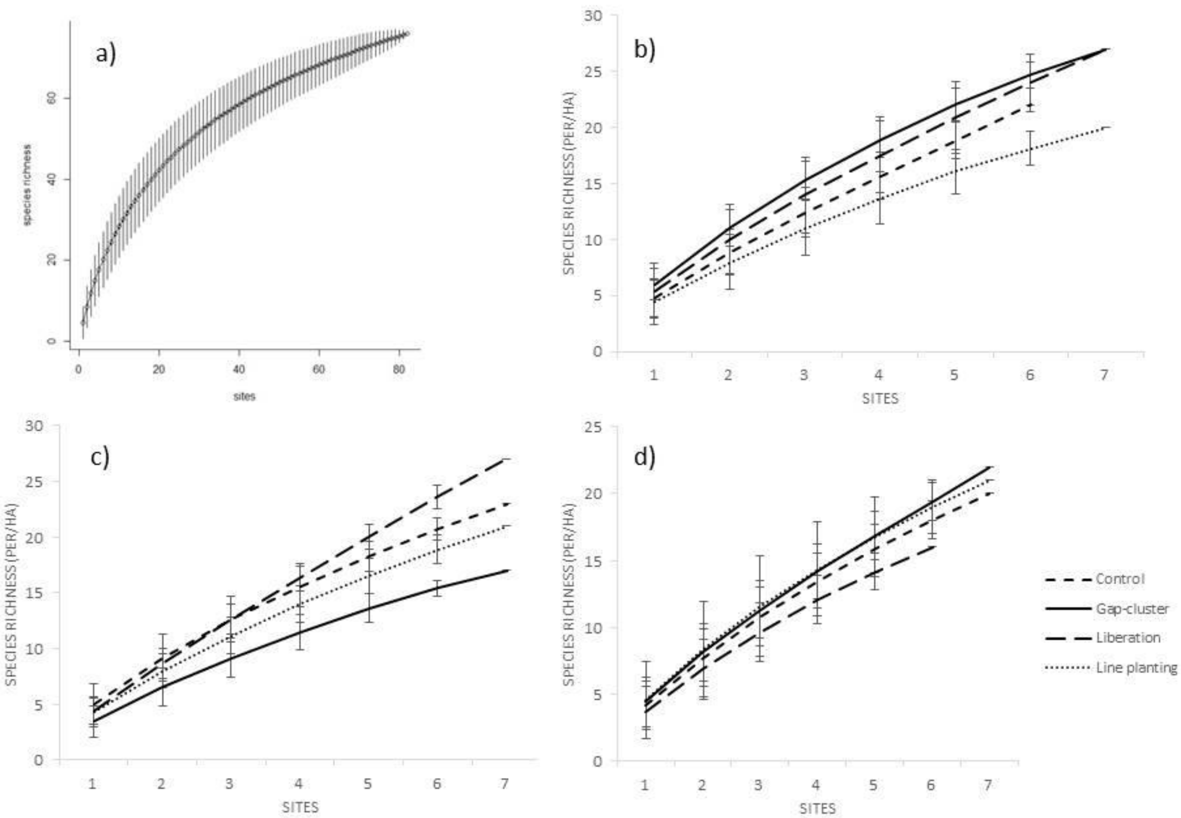

Fig. 11. *Species accumulation curves for all inventoried seedlings in the Rain forest Restoration Experiment located in Sabah, Malaysian Borneo. The curves showed a) All forest types and treatments b) Forest type 1 divided into treatments c) Forest type 2 divided into treatments d) Forest type 3 divided into treatments. The forest types were numbered from 1-3 where forest type 1 corresponds to mixed forest, forest type 2 to Macaranga forest and forest type 3 to open forest. The liberation method aimed to favor established trees while gap-cluster planting and line planting involved planting of new seedlings. Line planting affected the area to a higher extent than gap-cluster planting. The error bars indicated +2 and -2 standard deviation.*

The NMDS ordination based on the composition of seedlings resulted in a 2-dimensional solution with stress of 0.227. The first axis was not significantly correlated with the abundance of *Macaranga spp.* (r=-0.007, p=0.952) neither was the second axis (r=0.039, p=0.731). The adonis-analysis showed that the composition of seedling species was significantly different between forest types and there was also a significant difference between sites in relation to an interaction between treatment and *Macaranga spp.* (Table 3).

Table 3. *Results from the adonis-analysis of seedlings in the Rain forest Restoration Experiment located in Sabah, Malaysian Borneo. Plot 2.3C was excluded since it lacked seedling species. Bold figures denote significant differences*

	Df	SS	MS	F-value	R^2	p-value
Treatment	3	0.713	0.238	0.636	0.023	0.960
Forest type	2	1.453	0.726	1.944	0.047	**0.005**
Macaranga	1	0.208	0.208	0.557	0.007	0.891
Treatment:Forest type	6	2.681	0.447	1.195	0.087	0.114
Treatment:Macaranga	3	1.644	0.548	1.466	0.053	**0.025**
Forest type:Macaranga	2	0.752	0.376	1.006	0.024	0.448
Treatment:Forest type:Macaranga	6	2.120	0.353	0.946	0.069	0.632
Residuals	57	21.303	0.374		0.690	
Total	80	30.874			1.000	

4.4. Seeds

29 seed species were recorded from a sample size of 70 plots. The total species accumulation curve for seeds (Fig. 12a) showed that the species richness was rapidly increasing in the beginning but started to flatten out after approximately 65 plots. The treatments with highest species richness varied between the forest types. In forest type 1 (n=27) the species richness was highest in the gap-cluster and line planting plots followed by liberation and control plots (Fig. 12b). In forest type 2 (n=24) the species richness was highest in the liberation plots followed by line planting and gap-cluster plots and control (Fig. 12c). In forest type 3 (n=19) the species richness was highest in the control plots followed by line planting, gap-cluster and liberation plots (Fig. 12d).

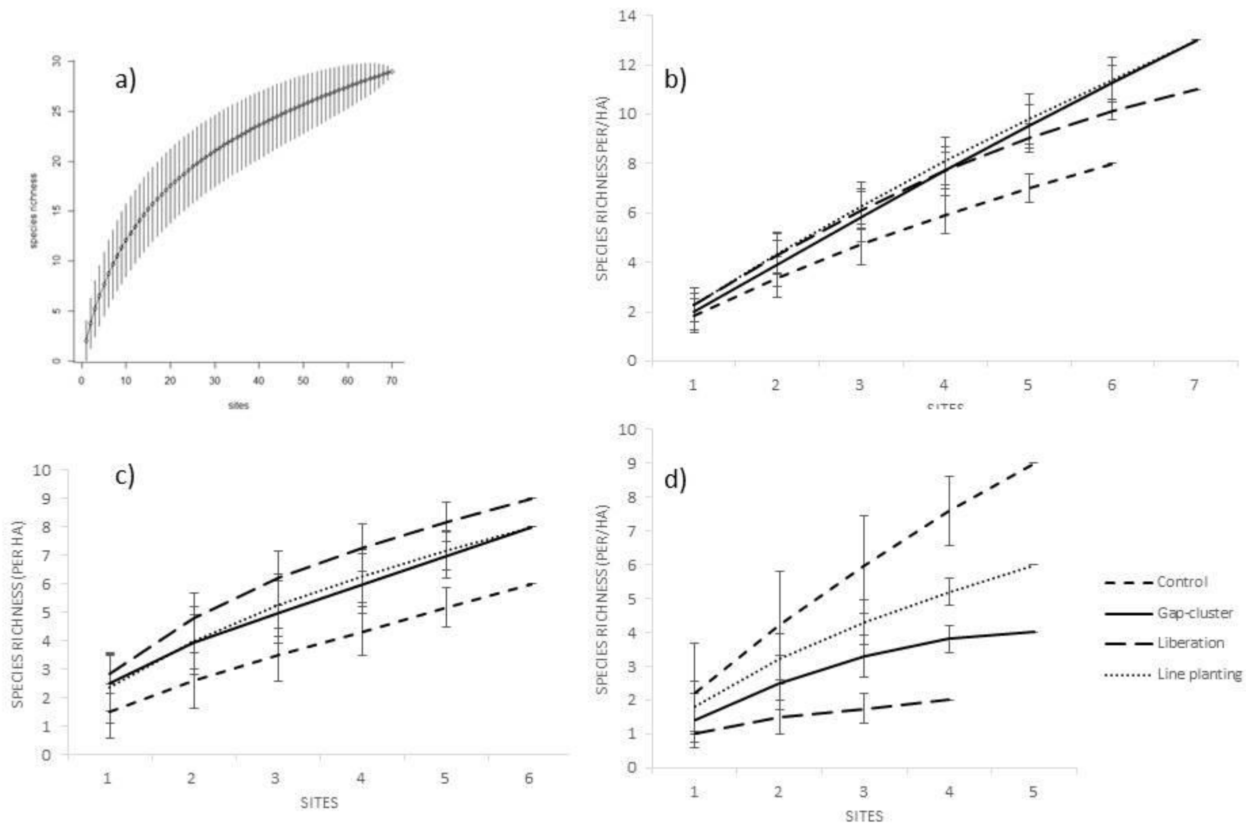

Fig. 12. *Species accumulation curves for all inventoried seeds in the Rain forest Restoration Experiment located in Sabah, Malaysian Borneo. The curves showed a) All forest types and treatments b) Forest type 1 divided into treatments c) Forest type 2 divided into treatments d) Forest type 3 divided into treatments. The forest types were numbered from 1-3 where forest type 1 corresponds to mixed forest, forest type 2 to Macaranga forest and forest type 3 to open forest. The liberation method aimed to favor established trees while gap-cluster planting and line planting involved planting of new seedlings. Line planting affected the area to a higher extent than gap-cluster planting. The error bars indicated +2 and -2 standard deviation.*

Species richness for *Number of seeds* with *Macaranga spp*. as a covariate (p=0.081) showed significant results regarding relations between forest type (p=0.037). The relations showed that forest type 2 was significantly different from forest type 3 (p=0.034) but not from forest type 1. Forest type 1 could be grouped with both forest type 2 and forest type 3 (Fig. 13). The Shannon diversity index with *Macaranga spp.* as a covariate (p=0.121) also showed that the relations between forest types in the analysis were significant (p=0.038) and that forest type 2 was significantly different from forest type 3 (p=0.047) but not from forest type 1. Forest type 1 could be grouped with both forest type 2 and forest type 3 (Fig. 14). The Simpson diversity index only showed tendencies of significant relations regarding forest type (p=0.053), but significant differences between forest type 1 and forest type 3 (p=0.046). Forest type 2 could be grouped with both forest type 1 and forest type 3 (Fig. 15).

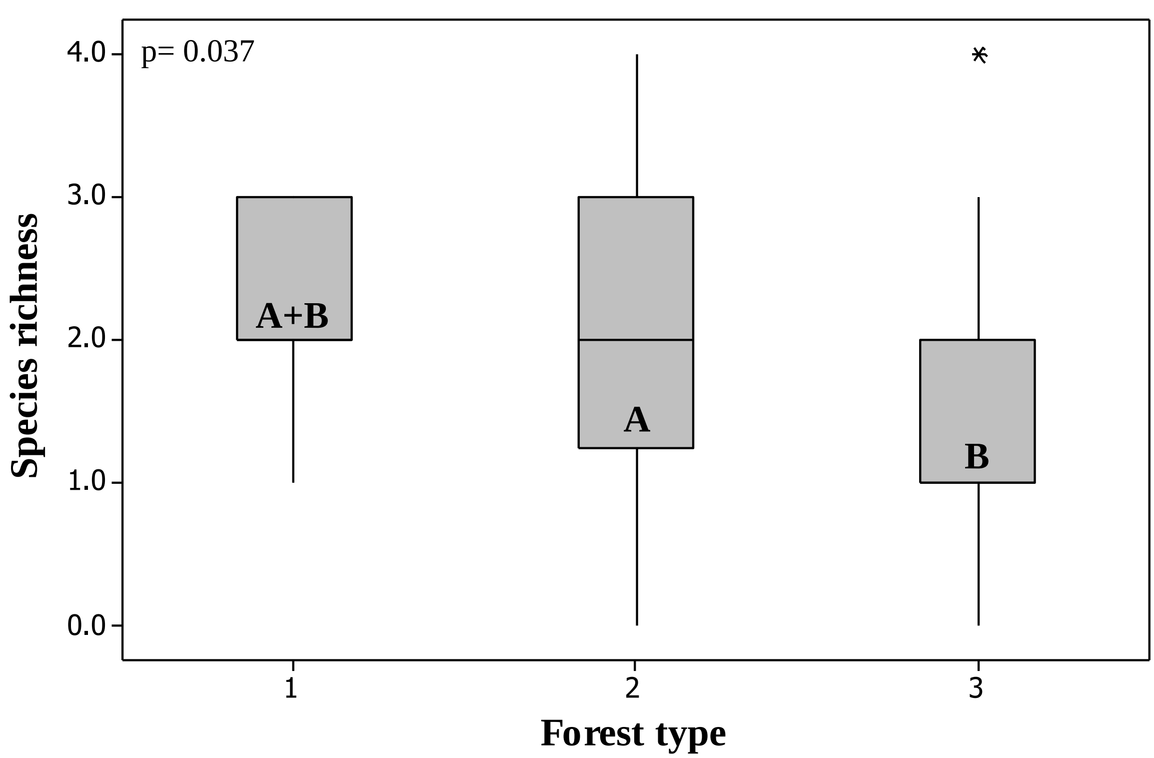

Fig. 13. *Boxplot of species richness for number of seeds in the Rain forest Restoration Experiment located in Sabah, Malaysian Borneo. Species richness showed significant results (p=0.037) and forest type 2 was significantly different from forest type 3 (p=0.0343). Boxes that did not share a letter were significantly different. Forest type 1 could be grouped with both forest type 2 and forest type 3. Grouping information used Tukey method and 95.0 % confidence. The forest types were numbered from 1-3 where forest type 1 corresponds to mixed forest, forest type 2 to Macaranga forest and forest type 3 to open forest. Asterisks indicated outliers.*

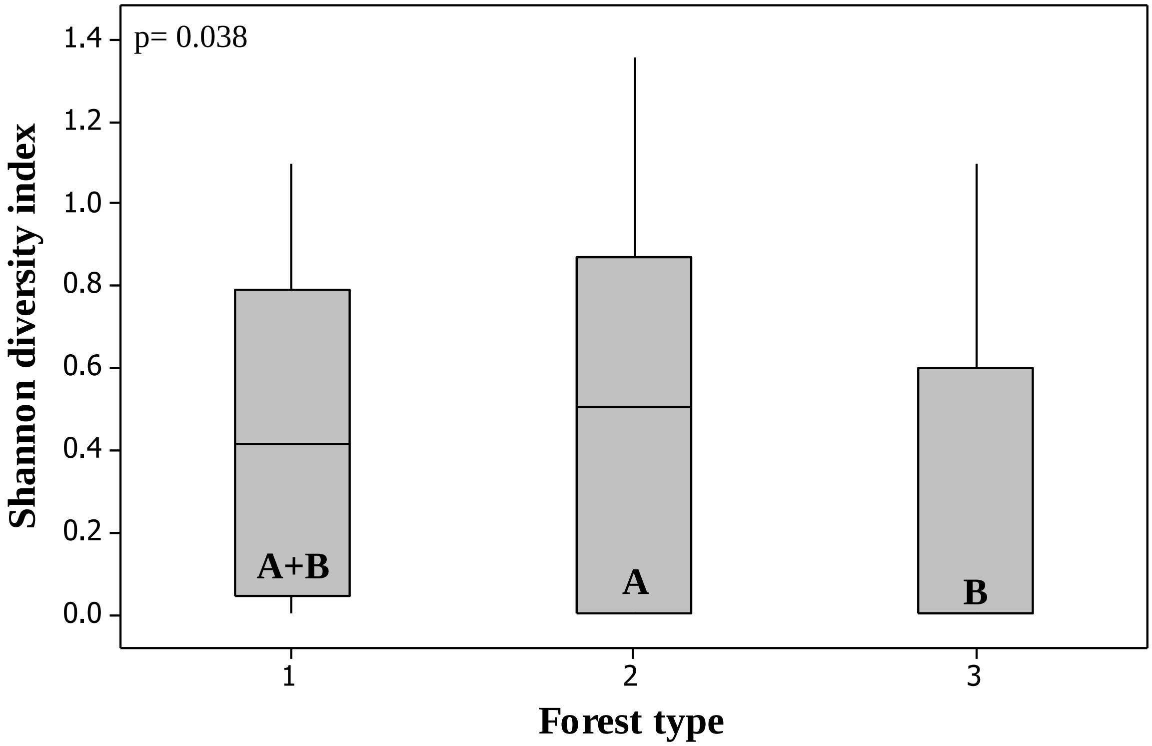

Fig. 14. *Boxplot of Shannon diversity index for number of seeds in the Rain forest Restoration Experiment located in Sabah, Malaysian Borneo. The Shannon diversity index showed significant results (p=0.038) and forest type 2 was significantly different from forest type 3 (p=0.047). Boxes that did not share a letter were significantly different. Forest type 1 could be grouped with both forest type 2 and forest type 3. Grouping information used Tukey method and 95.0 % confidence. The forest types were numbered from 1-3 where forest type 1 corresponds to mixed forest, forest type 2 to Macaranga forest and forest type 3 to open forest.*

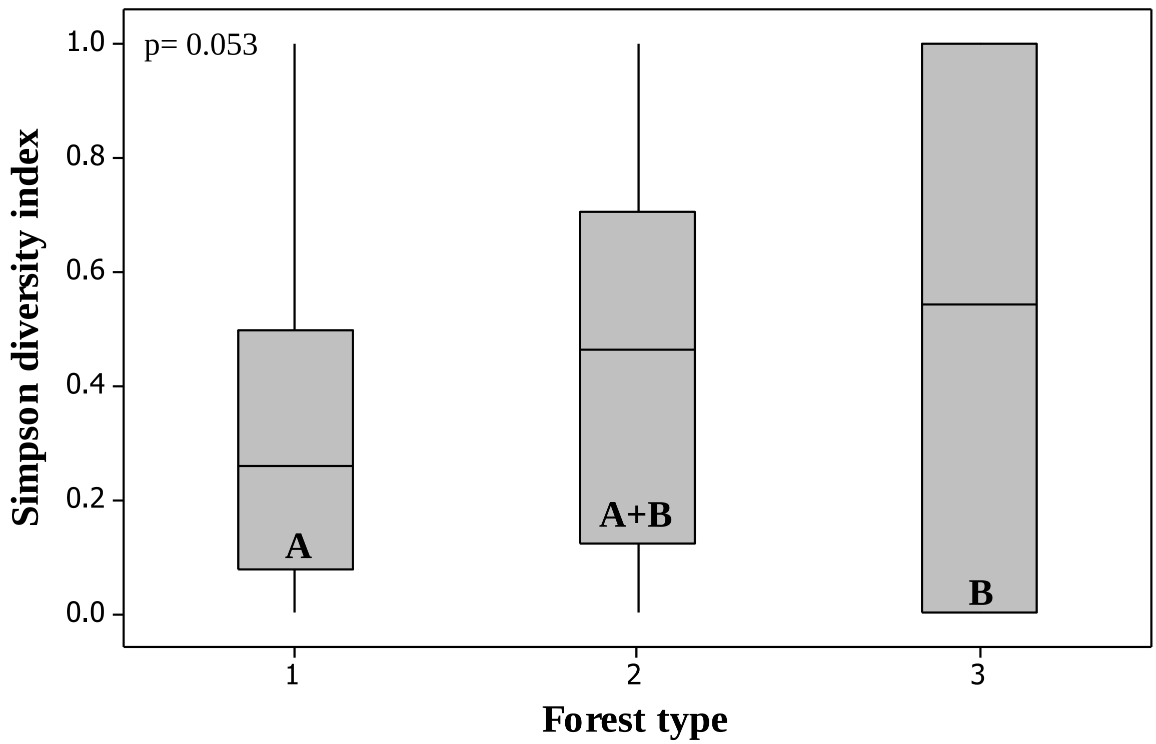

Fig. 15. *Boxplot of Simpson diversity index for number of seeds in the Rain forest Restoration Experiment located in Sabah, Malaysian Borneo. The Simpson diversity index showed a tendency of significant results (p=0.053) and forest type 1 was significantly different from forest type 3 (p=0.046). Boxes that did not share a letter were significantly different. Forest type 2 could be grouped with both forest type 1 and forest type 3. Grouping information used Tukey method and 95.0 % confidence. The forest types were numbered from 1-3 where forest type 1 corresponds to mixed forest, forest type 2 to Macaranga forest and forest type 3 to open forest.*

The NMDS ordination based on the composition of seeds resulted in a 2-dimensional solution with stress of 0.216. The first axis was not significantly correlated with the abundance of *Macaranga spp*. (r= -0.160, p=0.187) neither was the second axis (r=0.007, p=0.852). The adonis-analysis showed that the composition of seed species was significantly different between forest types (Table 4).

Table 4. *Results from the adonis-analysis of seeds in the Rain forest Restoration Experiment located in Sabah, Malaysian Borneo. Bold figures denote significant differences*

	Df	SS	MS	F-value	R^2	p-value
Treatment	3	0.506	0.169	0.484	0.020	0.980
Forest type	2	3.293	1.646	4.723	0.129	**0.005**
Macaranga	1	0.346	0.346	0.994	0.014	0.428
Treatment:Forest type	6	2.158	0.360	1.032	0.084	0.433
Treatment:Macaranga	3	1.448	0.483	1.385	0.057	0.080
Forest type:Macaranga	2	0.936	0.468	1.343	0.037	0.134
Treatment:Forest type:Macaranga	5	1.522	0.304	0.874	0.060	0.756
Residuals	44	15.338	0.349		0.600	
Total	66	25.547			1	

Table 5. *Overview of the results from the two-way ANOVA regarding differences between treatments in the Rain forest Restoration Experiment located in Sabah, Malaysian Borneo. The liberation method aimed to favor established trees while gap-cluster planting and line planting involved planting of new seedlings. Line planting affected the area to a higher extent than gap-cluster planting. The values denote the significance level (p-values) of the difference between the treatments combined from the two axes. Bold values are significant (p ≤ 0.050) and other values tend to be significant (0.050 < p ≤ 0.100). Missing values mean there were no tendencies of or no significant differences*

		Treatment	*Liberation*	*Gap-cluster*	*Line planting*	*Control*
Number of trees	**Species richness**	*Liberation*				
		Gap-cluster				
		Line planting				
		Control				
	Shannon diversity index	*Liberation*				
		Gap-cluster				
		Line planting				
		Control				
	Simpson diversity index	*Liberation*				
		Gap-cluster			0.083	
		Line planting		0.083		0.092
		Control			0.092	

Table 6. *Overview of the results from the two-way ANOVA regarding differences between forest types in the Rain forest Restoration Experiment located in Sabah, Malaysian Borneo. The forest types were numbered from 1-3 where forest type 1 corresponds to mixed forest, forest type 2 to Macaranga forest and forest type 3 to open forest. The values denote the significance level (p-values) of the difference between the forest types combined from the two axes. Bold values are significant ($p \leq 0.050$) and other values tend to be significant ($0.050 < p \leq 0.100$). Missing values mean there were no tendencies of or no significant differences*

		Forest type	*1*	*2*	*3*
Number of trees	**Species richness**	*1*			0.099
		2			
		3	0.099		
	Shannon diversity index	*1*			**0.039**
		2			
		3	**0.039**		
	Simpson diversity index	*1*			
		2			
		3			
Basal area of trees	**Species richness**	*1*			0.087
		2			
		3	0.087		
	Shannon diversity index	*1*			**0.028**
		2			0.071
		3	**0.028**	0.071	
	Simpson diversity index	*1*			
		2			
		3			
Number of seeds	**Species richness**	*1*			
		2			**0.034**
		3		**0.034**	
	Shannon diversity index	*1*			
		2			**0.038**
		3		**0.038**	
	Simpson diversity index	*1*			**0.046**
		2			
		3	**0.046**		

5. DISCUSSION

5.1. Results

The results from this study were not fully conclusive since they pointed in somewhat different directions. The overall tendency observed was a greater difference between forest types than between treatments; almost no differences could be seen between treatments. These results strongly supported my hypothesis.

Many studies have been conducted that deal with regeneration in tropical areas, both artificial regeneration (mostly enrichment planting) and natural regeneration. The focus on the artificial regeneration has mostly been on investigating how different treatments and methods affect planted species (e.g. Romell et al. 2008, Kuusipalo et al. 1996, Kuusipalo et al. 1997) as well as on how these treatments can be improved (e.g. Ådjers et al. 1995). Studies regarding natural regeneration have e.g. focused on mother trees and site factors (e.g. Backlund 2013) as well as on finding what kind of forests that are in greater need of artificial regeneration (e.g. Romell 2011). Luc (2010) did evaluate how different treatments have contributed to the overall rehabilitation in the studied area, but no specific results for natural regeneration can be interpreted from those results. I did not find any studies discussing the effect that treatments made to improve the growth of planted seedlings had on the natural regeneration in the treated area. Therefore the following discussion will mostly focus on my own thoughts of why the results appeared as they did.

In the inventory the family *Dipterocarpaceae* dominated followed by *Euphorbiaceae*. This result was consistent with the one from Luc (2010) as well as with the general pattern in Southeast Asia (Whitmore 1984, MacKinnon et al. 1996, Slik et al. 2003 in Luc 2010). The fact that the general presence of species was consistent with other similar forests in the area created a good chance for using this thesis as a comparison to future studies in the area. When analysing the species accumulation curves and the rank abundance curves no evident differences in species richness between forest types or treatments could be seen. However, some interactions between treatment and forest type could be interpreted; both the species accumulation curves and the rank abundance curves showed a higher species richness when gap-cluster planting was made in forest type 1 and forest type 3. The rest of the results for species richness based on forest type and treatment were randomly distributed. These results are rather consistent with the results from Luc (2010) who compared areas where rehabilitation methods (line planting, gap-cluster planting and maintenance of these treatments) had been conducted and areas where no rehabilitation actions had been conducted. These results showed no significant differences regarding number of species between rehabilitated and non-rehabilitated areas, which are fairly consistent with the results found in my inventory.

No differences in evenness between forest types or treatments could be seen but rather large differences between the development stages regarding species richness as well as evenness. The overall species accumulation curves showed similar shapes of a negative exponential curve where the species richness was rapidly increasing in the beginning but started to flatten out after a while.

At what level of species richness and after what number of inventoried plots the curve started to flatten out varied between the development stages. Since the sampling size did not vary much it was not to be considered affecting the results. The results indicated that the species richness for saplings most probably should have kept increasing if additional plots would have been inventoried and that the species richness in fact could have been higher for the saplings than the trees, based on the traditional extrapolation discussed in Ugland, Gray & Ellingsen (2003). The combined results from all species accumulation curves indicated that the species richness of seedlings was highest followed by saplings, trees and seeds. This is logical since plants get fewer as they grow larger due to inter- and intraspecific competition and selective logging activities. Some species survive better than others going through the vegetation phases and finally grow to become trees. Then, due to factors as e.g. nutrient availability and differences between species, not all trees set seeds which clearly affect the species richness of seeds.

The results from the rank abundance curves showed a more even distribution of species the more developed the plant was, i.e. the tree species were more evenly distributed than the seed species (Appendix 4). The explanation for this could be the mast fruiting that took place before and to some extent during the inventory. Huge amounts of heavy seeds were released from the trees and due to their weight and size most seeds were distributed close to the seeding tree. The dipterocarp seeds are poorly protected chemically and their features make them attractive to both wild pigs and insects (Ashton, Givnish and Appanah 1988). Since the mast fruiting was occurring just before and during the inventory most seeds were still unaffected by predation of pigs and insects. This resulted in lots of seeds from one species gathered in rather small areas and therefore an uneven distribution. The fact that the sapling species was more evenly distributed than the seedling and seed species could also be explained by the mast fruiting dynamic combined with competition. When a lot of seeds accumulate in a small area the chance of these germinating there is larger. This creates greater opportunities for more seedlings, saplings and finally trees in the area. However, competition (as mentioned above) between the plant individuals becomes more intense the larger the plants get and some individuals will not withstand the competition and eventually die.

The results based on the two-way ANOVA were rather consistent and all significant or close to significant results showed differences between forest types, except from one. The divergent result showed tendencies of differences between treatments. The result for treatments that showed tendencies to be significant might give an indication of what to expect in the future, but the importance of these results was the fact that the majority indicated differences between forest types and not between treatments. The analyses of ecological distance showed some variations between forest types, one significant interaction of treatment and *Macaranga spp.* as well as one correlation with *Macaranga spp.* and species composition. The ordination plot for the *Macaranga spp*. correlation (Fig 10 & Fig. 11) was difficult to interpret since it was cluttered and showed no clear patterns of interactions when observing the scatterplot. However, the line of the *Macaranga spp.* correlation gave some help for understanding the relation. The correlation showed that the difference in species composition of trees between forest types to some degree depends on the abundance of *Macaranga spp.* The stress for these tests were quite high, mostly as an effect of using the Euclidean distance measure instead of e.g. the Bray-Curtis distance measure. The choice of the Euclidean distance measure was a result of the use of base data that contained empty plots. Different species can be positively or negatively affected of the abundance of *Macaranga spp*. and since the different forest types contained different amount of *Macaranga spp*. this could have been one possible explanatory factor for the differences between forest types. However, the results showed no relationship between species composition and *Macaranga spp*. The combination of abundance of *Macaranga spp*. and treatment was shown to affect the species composition of seedlings, i.e. at a specific level of abundance of *Macaranga spp*. and for a specific treatment a certain species composition was expected. Leaving a lot of *Macaranga spp*. when e.g. performing liberation actions could therefore result in an establishment of a specific species composition. What abundance of *Macaranga spp*. and what treatment that interacted have not been further investigated, but if and when this specific interaction is found there is a possibility that the establishment of some specific species can be somewhat controlled. The fact that both the two-way ANOVA and the ecological distance showed larger differences between forest types than between treatments was not surprising. The treatments have been conducted fairly recently in the area and their effects might not be seen for a few more years. The forest types had been constant for a longer time period and the difference should be larger between those than the treatments. These results were in accordance with my hypothesis.

5.2. Methods

While identifying species in the plots inventoried for this thesis some were not possible to classify as specific species, but only to a species group or family. They were however counted as their own species in the analyses. The number of individuals not determined to specific species seemed to be randomly distributed over the development stages, forest types and treatments. The seed group was the only group that showed deviations from this randomness. The unidentified number of seeds was distinctly lower and a smaller amount of unidentified species was found. The more individuals not identified as specific species increases the risk for over- and underestimations of number of species per site. Some of the unidentified individuals seen as their own species in the analyses could probably belong to an already identified species and the total amount of species could therefore be overestimated. Based on the species group and family of the unidentified species I estimated that 7 of the 29 unidentified species could in fact belong to an already identified species of the study. However, if more than one individual has been classified as a probable species the chance of these individuals representing more than one actual species does exist, and the number of actual species could therefore be underestimated. This estimation was more difficult to assess than the chance of overestimations. Since the distribution of these unidentified species was rather evenly distributed over the development stages, forest types and treatments, the final results should only have been affected to a smaller degree.

Some plots have shown abnormal values during the analyses, probably more fitting values for another forest type than the one it was classified as. This could be due to some incorrect classifications when setting up the RRE. Since the experiment was young when the inventory took place, misclassified blocks could have been undiscovered until the abnormal results were found in this study. I believe an overlook of the classification of the blocks in the experiment could be of great use for future projects in the area. The plots that showed abnormal values can be found in Appendix 5.

5.3. Conclusions and Recommendations

The significant results and the ones who tended to be significant in the study confirmed my hypothesis of a somewhat larger difference between forest types than between treatments. Even though no remarkable results was expected, I did expect more distinct differences regarding forest types as well as results that comprised all development stages. Since the results did show very small differences between treatments, the data collected for this thesis could now function as baseline values for future projects and research in the area.

Since this study did not show just about any differences between treatments I suggest that a follow-up in the form of a similar inventory is made in a few years from now, when the effects should be more distinct. The knowledge of how different treatments not only affect the planted species, but also the natural regeneration, is important since the natural regeneration is an important contributor to biodiversity. Before that inventory is made a follow up on the classification of forest types should be performed. This might make the results more reliable. Later when the actual inventory is carried out a complement of e.g. the parameters of soil profile and access to mobile groundwater could be of great use. Knowledge about these and maybe other parameters in the area can be a great help when estimating how other factors could impact the main factors of the study. The more parameters estimated; the greater is the possibility to make sure that the differences found in a study are not influenced by any other factors. An estimation of the distance to the closest dipterocarp forest, which could function as a seed source, could also be of great use combined with measurements on how far the dipterocarp seeds can disperse. In the future, when the planted species have grown bigger, it could be of interest to investigate how the planted species affect the natural regeneration. What combined biodiversity the composition of planted species together with natural regeneration generates could also be interesting to look into.

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APPENDICES

Appendix 1 – Randomization list for sub-plots (5x5 m)

This randomization scheme was created in Excel using the formula *random between*. The numbers put in the formula was bottom=1, top=4. (=*RANDBETWEEN(1;4)*).

Plot ID	Block	Plot	Sub plot (5x5m)
1.2G	1	Gap	3
1.2L	1	Line	4
1.2R	1	Liberation	1
1.2C	1	Control	3
2.3G	2	Gap	2
2.3L	2	Line	1
2.3R	2	Liberation	2
2.3C	2	Control	2
3.3G	3	Gap	4
3.3L	3	Line	1
3.3R	3	Liberation	2
3.3C	3	Control	3
4.3G	4	Gap	3
4.3L	4	Line	2
4.3R	4	Liberation	1
4.3C	4	Control	3
5.2G	5	Gap	4
5.2L	5	Line	2
5.2R	5	Liberation	1
5.2C	5	Control	1
6.3G	6	Gap	1
6.3L	6	Line	1
6.3R	6	Liberation	2
6.3C	6	Control	1
7.2G	7	Gap	3
7.2L	7	Line	1
7.2R	7	Liberation	3
7.2C	7	Control	3
8.2G	8	Gap	4
8.2L	8	Line	1
8.2R	8	Liberation	3
8.2C	8	Control	2

Plot ID	Block	Plot	Sub plot (5x5m)
9.3G	9	Gap	1
9.3L	9	Line	2
9.3R	9	Liberation	2
9.3C	9	Control	2
10.3G	10	Gap	4
10.3L	10	Line	2
10.3R	10	Liberation	4
10.3C	10	Control	1
11.1G	11	Gap	2
11.1L	11	Line	1
11.1R	11	Liberation	3
11.1C	11	Control	4
12.1G	12	Gap	2
12.1L	12	Line	1
12.1R	12	Liberation	4
12.1C	12	Control	1
13.3G	13	Gap	4
13.3L	13	Line	4
13.3R	13	Liberation	1
13.3C	13	Control	3
14.2G	14	Gap	1
14.2L	14	Line	1
14.2R	14	Liberation	2
14.2C	14	Control	2
15.1G	15	Gap	3
15.1L	15	Line	4
15.1R	15	Liberation	3
15.1C	15	Control	3
16.1G	16	Gap	3
16.1L	16	Line	2
16.1R	16	Liberation	1
16.1C	16	Control	1

Plot ID	**Block**	**Plot**	**Sub plot (5x5m)**
17.1G	17	Gap	1
17.1L	17	Line	1
17.1R	17	Liberation	4
17.1C	17	Control	1
18.2G	18	Gap	3
18.2L	18	Line	1
18.2R	18	Liberation	3
18.2C	18	Control	1
19.2G	19	Gap	1
19.2L	19	Line	2

Plot ID	**Block**	**Plot**	**Sub plot (5x5m)**
19.2R	19	Liberation	1
19.2C	19	Control	3
20.1G	20	Gap	2
20.1L	20	Line	1
20.1R	20	Liberation	4
20.1C	20	Control	4
21.1G	21	Gap	3
21.1L	21	Line	2
21.1R	21	Liberation	4
21.1C	21	Control	2

Appendix 2 – Species list

Species identification based on Lee (2003).

Family	Vernacular name (local name)	Species name (botanical name)
Alangiaceae	Kondolon	*Alangium javanicum (BI) Wangerin*
Anacardiaceae	Bambangan	*Mangifera pajang Kost*
	Layang-layang	*Parishia insignis Hook f*
	Rengas	*Gluta, Semecarpus, Melanochyla & Swintonia*
Annonaceae	Karai*	*Annonaceae**
	Karai hitam	*Orophea myriantha Merr*
	Karai putih	*Polyalthia sumatrana (Miq) Kurz*
Apocynaceae	Pulai sp.*	*Alstonia sp.**
Bombacaceae	Durian sp.*	*Durio sp.**
Burseraceae	Kedondong*	*Canarium sp.**
Chrysobalanaceae	Merbatu	*Parinari oblongifolia Hook f*
Dilleniaceae	Simpoh laki	*Dillenia excelsa (Jack) Gilg*
	Simpoh sp.*	*Dillenia sp.**
Dipterocarpaceae	Kapur gumpait	*Dryobalanops keithii Sym*
	Kapur paji	*Dryobalanops lanceolata Burck*
	Kawang jantung	*Shorea macrophylla (de Vriese) Ashton*
	Keruing daun besar	*Dipterocarpus applanatus van Slooten*
	Keruing kasugoi	*Dipterocarpus validus BI*
	Keruing kesat	*Dipterocarpus gracilis BI*
	Keruing putih	*Dipterocarpus caudeferus Merr*
	Keruing sp.*	*Dipterocarpus**
	Melapi agama	*Shorea agamii Ashton*
	Melapi kuning	*Shorea symingtonii Wood*
	Oba suluk	*Shorea pauciflora King*
	Resak sp. *	*Vatica sp.**
	Selangan*	*Hopea spp.**
	Selangan batu biabas	*Shorea leptoderma Meijer*
	Selangan batu laut	*Shorea falciferoides Foxw*

	Selangan batu terendak	*Shorea seminis (de Vriese) van Slooten*
	Selangan mata kucing	*Hopea ferruginea Parijs*
	Seraya	*Shorea curtisii Dyer*
	Seraya daun kasar	*Shorea fallax meijer*
	Seraya daun mas	*Shorea argentifolia Sym*
	Seraya kepong	*Shorea ovalis (Korth) BI*
	Seraya kuning	*Shorea faguetoides Ashton*
	Seraya kuning bukit	*Shorea angustifolia Ashton*
	Seraya kuning runcing	*Shorea accuminatassima Sym*
	Seraya kuning siput	*Shorea faguetiana Heim*
	Seraya kuning sp.*	*Shorea sp.**
	Seraya lupa	*Shorea parvistipulata Heim*
	Seraya majau	*Shorea johorensis Foxw*
	Seraya melantai	*Shorea macroptera Dyer*
	Seraya punai	*Shorea parvifolia Dyer*
	Seraya sp.*	*Shorea sp.**
	Seraya tembaga	*Shorea leprosula Miq*
	Seraya timbau	*Shorea smithiana Sym*
	Shorea sp.*	*Shorea sp.**
	Sukung-sukung	*Saurauia ferox Korth*
	Urat mata batu	*Parashorea smythiesii Wyatt Smith ex Ashton*
	Urat mata beludu	*Parashorea tomentella (Sym) Meijer*
	Urat mata daun licin	*Parashorea malaanonan (Blanco) Merr*
Ebenaceae	Kayu malam*	*Diospyros spp.**
Euphorbiaceae	Galang-galang	*Aporusa grandistipula Merr.*
	Gambir hutan	*Trigonopleura malayana Hook.f*
	Kapas-kapas	*Croton argyratus BI*
	Kilas	*Koilodepas longifolium Hook. F*
	Kunau-kunau	*Baccaurea parviflora*
	Ludai susu	*Homalnthus populneus (Geisel) Pax*
	Mallotus kering	*Mallotus miquelianus (Scheff) Boerl*
	Mallotus marambokan	*Mallotus floribundus (BI) Muell. Arg*
	Mallotus sagar-sagar	*Mallotus wrayi King ex Hook f*
	Mallotus*	*Mallotus spp.**
	Penatan	*Aporusa elmeri Merr*
	Rambai	*Baccaurea motleyana (Muell. Arg) Muell. Arg*
Fagaceae	Mempening*	*Lithocarpus & Quercus**
Flacourtiaceae	Giewei	*Ryparosa acuminata Merr*

	Karpus sp.*	*Hydnocarpus sp.**
	Takaliu	*Homalium foetidum (Roxb) Benth or Homalium grandiflorum Benth*
Guttiferae	Bintangor	*Calophyllum obliquinervium Merr*
	Manggis	*Garcinia mangostana L*
Hyperiacacae	Geronggang sp.*	*Cratoxylum sp.**
Icacinaceae	Katok	*Stemonurus scorpioides Becc*
Juglandanceae	Pusing-pusing	*Engelhardia serrata BI*
Lauraceae	Belian	*Eusideroxylon zwageri Teijsm. & Binn*
	Kayu manis	*Cinnamomum burmannii (C.G & T. Nees) BI and other Cinnamomu*
	Medang*	*Lauraceace**
Leeaceae	Mali-mali	*Leea indica (Burm f) Merr*
Leguminosae	Mengaris	*Koompassia excelsa (Becc) Taub*
	Sepetir	*Sindora beccariana baker or Sindora iripicina de Wit*
Loganiaceae	Todopon puok	*Fagraea volubilis Wall & several other Fagraea spp*
Magnoliaceae	Cempaka hutan	*Michelia montana BI*
Melastomataceae	Sirih-sirih	*Pternandra coerulescens Jack*
Meliaceae	Koping-koping	*Aglaia argentea BI*
	Langsat	*Lansium domesticum correa*
	Lentupak sp.*	*x*
Moraceae	Kayu ara	*Ficus*
	Terap	*Parartocarpus or artocarpus*
	Terap ikal	*Artocarpus anisophyllus Miq*
Myristicaceae	Darah-darah*	*Myristicaceae**
Myrsinaceae	Surusop	*Ardisia elliptica Thunb*
Myrtaceae	Obah*	*Eugenia spp.**
Rhamnaceae	Monsit	*Zizyphus angustifolius (Miq) Hatusima ex van Steenis*

Rubiaceae	Bangkal sp.*	*x*
	Buluh-buluh	*Pleiocarpidia sandakanica Brem*
	Laran	*Neolamarckia cadamba (Roxb) Bosser*
	Malitap bukit	*Wendlandia dasythyrsa Miq*
Sapindaceae	Mata kucing	*Dimocarpus longan Lour*
	Rambutan	*Nephelium lappaceum L*
Sapotaceae	Nyatoh sp.*	*x*
Simaroubaceae	Pauh kijang	*Irvingia malayana Oliv. Ex Benn*
Sonneratiaceae	Magas	*Duabanga moluccana BI*
Sterculiaceae	Bayor*	*Pterospermum spp.**
	Kembang sp.*	*Heritiera sp.**
Symplocaceae	Jiak	*Symplocos fasciculata Zoll.*
Theaceae	Bawing*	*Adinandra spp.**
	Gatal-gatal	*Schima walichii (DC) korth*
Thymelaeaceae	Gaharu	*Aquilaria malaccensis Lamk*
Tiliaceae	Takalis daun bulat	*Pentace adenophora Kost*
	Takalis daun halus	*Pentace laxiflora Merr*
	Takalis sp.*	*Pentace sp.**
Urticaceae	Anjarapai	*Dendrocnide elliptica (Merr). Chew*
Verbenaceae	Buak-buak batu	*Teijsmanniodendron holophyllum (Baker) Kost*
	Tambong	*Geunsia pentandra (Roxb) Merr*
X	Macaranga spp.*	*x*
X	Other timber*	*x*
X	Unknown*	*x*

* Species only identified to family or species group.

Appendix 3 – Unidentified species

	Bangkal sp.	Bawing	Bayor	Darah-darah	Durian sp.	Geronggang sp.
Trees	7	2	5	3	2	0
Saplings	9	0	1	12	0	1
Seedlings	5	0	4	14	3	0
Seeds	0	0	10	0	2	0
Total	*21*	*2*	*20*	*29*	*7*	*1*

	Karai	Karpus sp.	Kayu malam	Kedondong	Kembang sp.	Keruing sp.
Trees	8	1	2	2	0	6
Saplings	5	4	5	7	1	1
Seedlings	10	1	8	16	9	2
Seeds	0	0	0	10	0	36
Total	*23*	*6*	*15*	*35*	*10*	*45*

	Lentupak sp.	Macaranga spp.	Mallotus	Medang	Mempening	Nyatoh sp.
Trees	10	64	2	5	6	2
Saplings	10	2	5	14	2	3
Seedlings	9	0	15	2	8	3
Seeds	0	0	0	0	3	0
Total	*29*	*66*	*22*	*21*	*19*	*8*

	Obah	Other timber	Pulai sp.	Resak sp.	Selangan	Seraya kuning sp
Trees	25	52	1	0	1	1
Saplings	45	36	0	5	1	3
Seedlings	32	81	0	0	0	4
Seeds	7	0	0	0	4	21
Total	*109*	*169*	*1*	*5*	*6*	*29*

	Seraya sp.	Shorea sp.	Simpoh sp.	Takalis sp.	Unknown
Trees	1	0	1	3	0
Saplings	0	0	6	0	0
Seedlings	0	1	4	0	0
Seeds	0	0	0	0	2
Total	*1*	*1*	*11*	*3*	*2*

	Total number of individuals	Total number of species
Trees	212	24
Saplings	178	22
Seedlings	231	20
Seeds	95	9
Total	*716*	*29*

Appendix 4 – Rank abundance curves

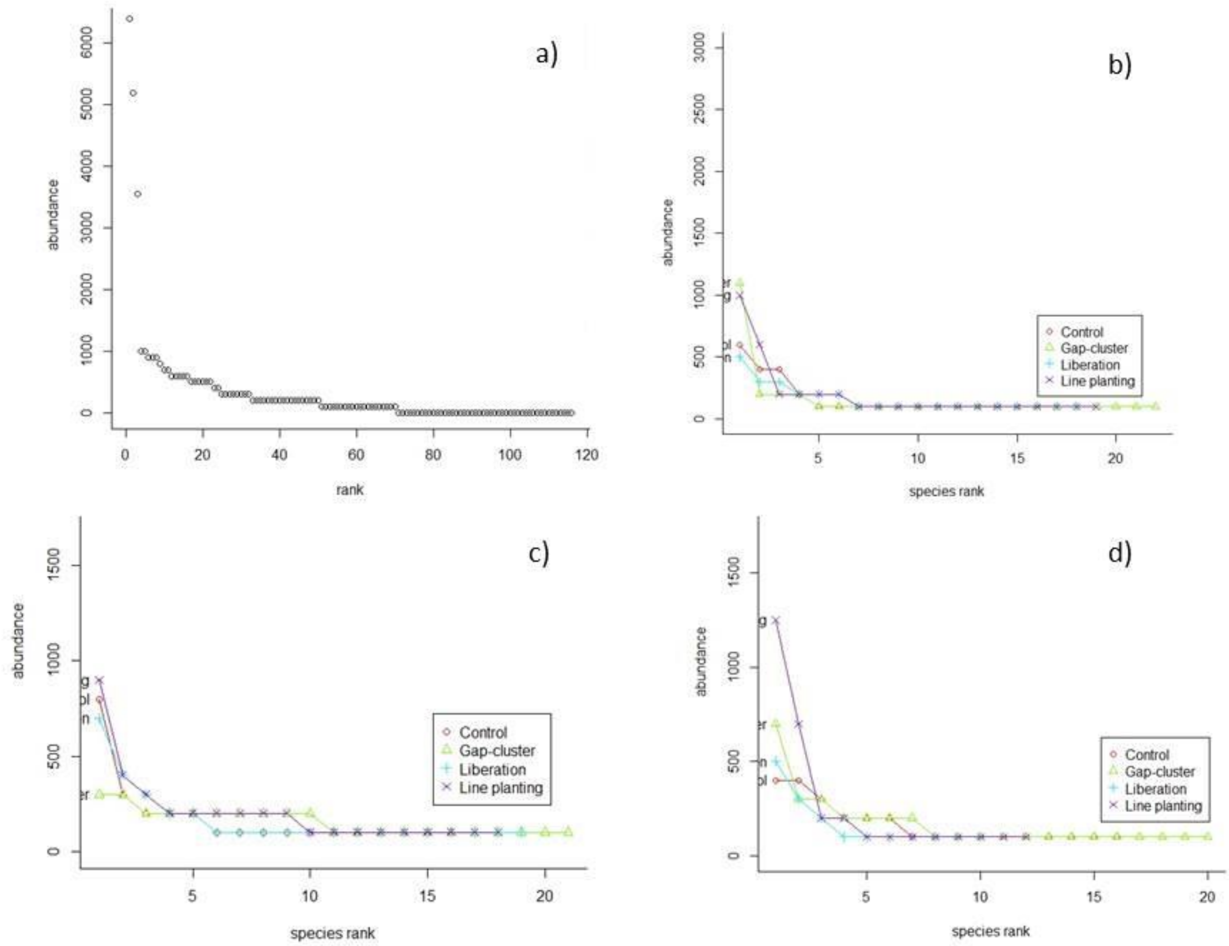

Fig 4:1. *Tree rank abundance curves for a) All forest types and treatments b) Forest type 1 divided into treatments c) Forest type 2 divided into treatments d) Forest type 3 divided into treatments.*

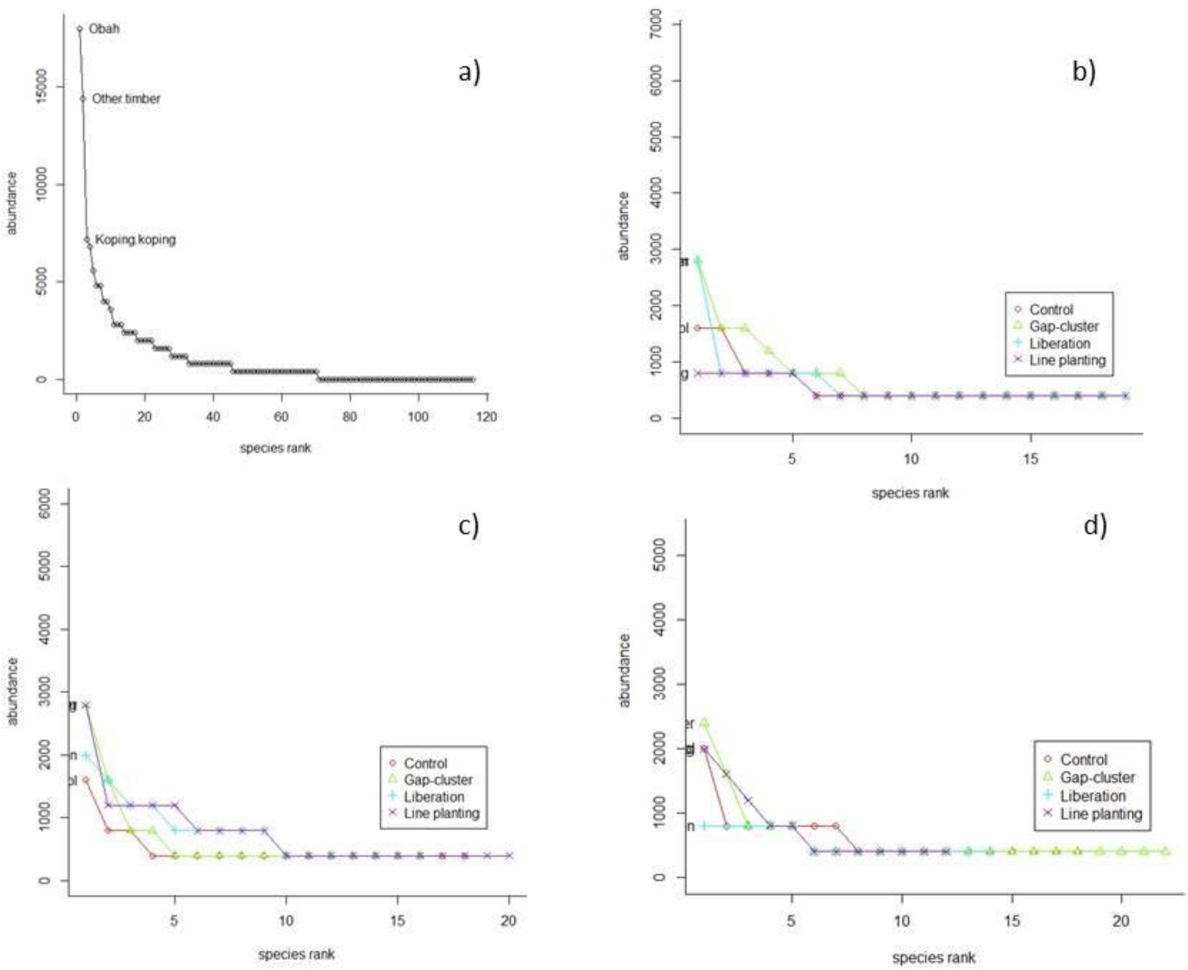

Fig 4:2. *Sapling rank abundance curves for a) All forest types and treatments b) Forest type 1 divided into treatments c) Forest type 2 divided into treatments d) Forest type 3 divided into treatments.*

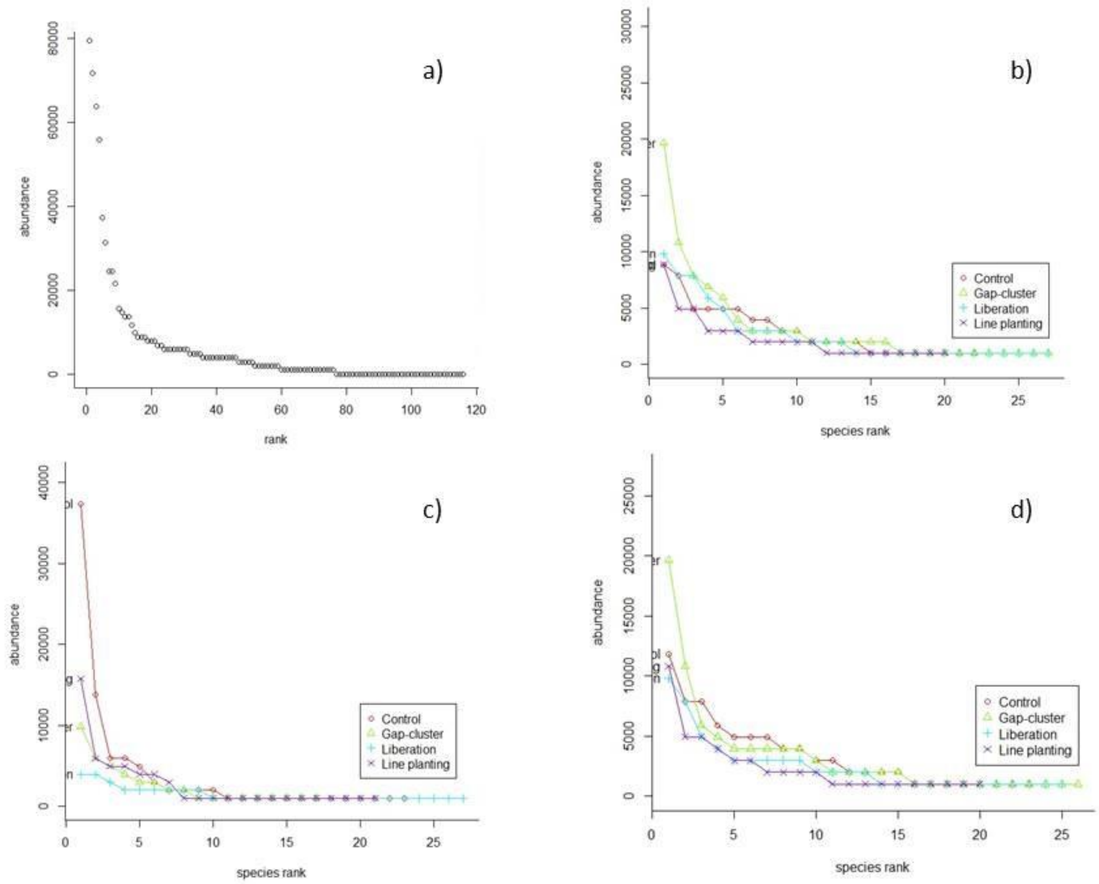

Fig 4:3. *Seedling rank abundance curves for a) All forest types and treatments b) Forest type 1 divided into treatments c) Forest type 2 divided into treatments d) Forest type 3 divided into treatments.*

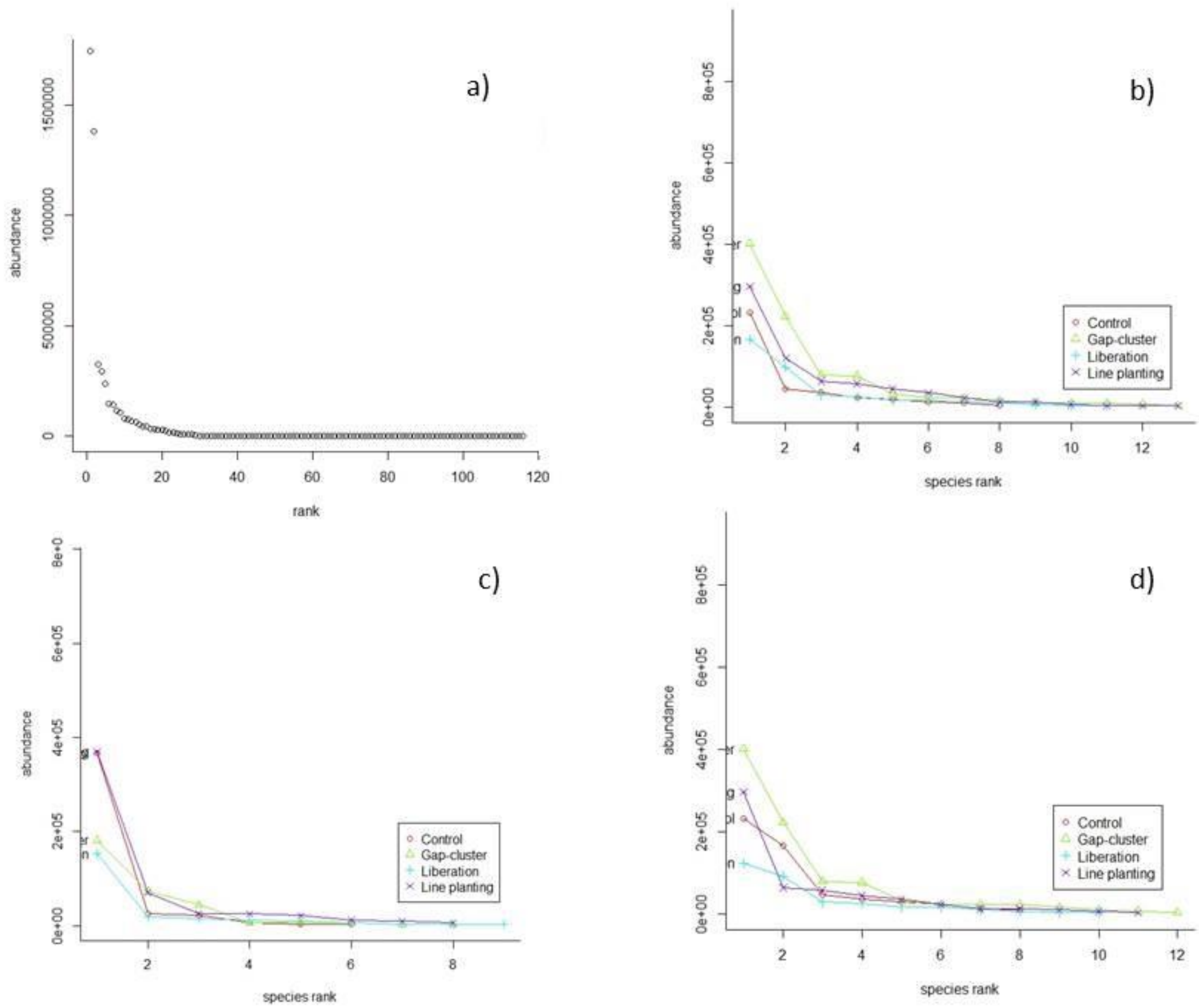

Fig 4:4. *Seed rank abundance curves for a) All forest types and treatments b) Forest type 1 divided into treatments c) Forest type 2 divided into treatments d) Forest type 3 divided into treatments.*

Appendix 5 – Abnormal values

The following plots showed abnormal values based on recurring outliers in the residual plots. The first group was most recurring followed by group 2 and 3.

Group 1 (most recurrent)	2.3R
	8.2R
	9.3L
	10.3L
	13.3C
	17.1G
Group 2	3.3C
	9.3G
	16.1R
	17.1R
Group 3	2.3L
	10.3G
	11.1L
	15.1C
	19.2L

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