Examensarbeten **2010:20**
Institutionen för skogens ekologi och skötsel

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A case study of stem and species distribution in Sabah, Malaysia

Effekter av en tio år gammal hjälpplantering i en sekundär dipterocarp regnskog - En fallstudie av stam och artsammansättning i Sabah, Malaysia

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Sveriges Lantbruksuniversitet Skogligt magisterprogram/Jägmästarprogrammet
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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 examinator. However, the author is the sole responsible for the content.

Preface

The field work was done at the INIKEA project which is a co-operation between the Swedish University of Agricultural Sciences, IKEA and Innoprise which lies under the Sabah government. Innoprise and IKEA have financially sponsored the project. I would especially like to thank my supervisors, Olle Forshed and Jan Falck for invaluable help and support. Thanks' to Sören Holm and Magnus Ekström for statistical advice of how to plan the inventory and calculating the results. I could not have done my thesis without the very helpful staff at the INIKEA project, they assisted me with the; method of inventory, data collection, data treatment and so much more. Terimah kasih (thank you); David Alloysius (Manager of INIKEA),Elisa Linda Laiman (Research Officer), Albert Lojingi (Research Team Leader), Zulkipli Bin Ahmad, Suhari Safari, Dizolkeply Bin Sundolon, Jemmie Bin Japar, Jemmin Bin Japar and Napolean Bin Nasir and Tonglee Bin Kurundi. At last but not least, gratitude's to my friends for comments and revision of the text and calculations, especially Hugo Lövheim, Mirjam Luc, Ewa Weise and Christoph Weise.

Abstract

Large areas of forests in the tropical region have during the last decades been lost and converted to new land uses while other areas have been degraded into secondary forests. These secondary forests need to be restored and rehabilitation through enrichment planting and liberation may help to speed up the recovery process. The objective of this thesis was to evaluate a rehabilitation method that includes enrichment planting, slashing of weeds and girdling of unwanted trees. The site for the project is situated in Sabah, Borneo in a secondary forest which had been logged and burnt by a wildfire. The project's goal is to rehabilitate and increase biodiversity through enrichment planting of seedlings mainly belonging to the family *Dipterocarpeaceae* (dipterocarps). Compositions in terms of families, species, dipterocarps and number of stems were compared between rehabilitated and non-rehabilitated areas using paired plots and ANOVA. On rehabilitated areas enrichment methods of line and gap-cluster planting and maintenance of slashing and girdling of non-dipterocarps were used, whereas the non-rehabilitated areas were not slashed but partly affected by the girdled trees. Ten years after the enrichment planting the double amount of dipterocarp species were found on the rehabilitated area compared to the non-rehabilitated area, which proved to be a significant difference. On the other hand a statistically significant difference with 10 % more families on the non-rehabilitated area was seen. For total number of species, number of stems and dipterocarp stems between the treatments (rehabilitated area and non-rehabilitated area) there were no significant differences. However, in the class sapling a statistically significant difference was found between all families with more stems in the untreated area. In the class saplings of the dipterocarps a tendency was found with more stems in the treated area. This result indicates that planted dipterocarp seedlings have the opportunity, due to the artificial gap, to grow into the next size and become a sapling, whereas in the non-rehabilitated area the forest lacks gaps and seedlings do not have the same prospect to grow. The results suggest that it is possible to increase the number of dipterocarp species using the project's methods of line and gap-cluster planting with accompanying maintenance. Few projects have been conducted to evaluate active human intervention in the rehabilitation of rainforest. The results described in this study demonstrate the usefulness of enrichment planting. More research of the natural recovery processes of secondary rainforests and continued rehabilitation projects are essential to assist in the development of future rehabilitation strategies.

Keywords: artificial gaps, Borneo, *Dipterocarpaceae*, forest degradation, forest fire, forest rehabilitation, liberation.

Sammanfattning

Stora delar av skogar i den tropiska regionen har under de senaste årtiondena försvunnit helt och ändrat markanvändning men en del områden har även degraderats till sekundära skogar. Kvarvarande sekundära skogar är i ett stort behov av återhämtning och via rehabilitering som t.ex. innebär att man hjälpplanterar och röjer konkurrerande vegetation runt de planterade plantorna, kan antagligen processen av skogens återhämtning påskyndas. Syftet med detta examensarbete var att utvärdera en rehabiliteringsmetod som inkluderar; hjälpplantering, röjning av konkurrerande vegetation och uppöppnande av skogen genom att ringbarka oönskade träd. Platsen för projektet är beläget i Sabah, Borneo i en sekundär regnskog som både har påverkats av brand och avverkning. Målet med projektet är att rehabilitera och öka biodiversiteten genom hjälpplantering av arter som främst tillhör familjen *Dipterocarpeaceae* (dipterocarper). Sammansättningen av familjer, arter, dipterocarper och antal stammar jämfördes mellan rehabiliterade och icke- rehabiliterade ytor, då man använder sig av parade ytor och ANOVA. På rehabiliterade ytor användes två hjälpplanterings metoder; linje och ”luck-kluster” plantering som sedan även underhölls genom röjning och ringbarkning av icke- dipterocarper, medan icke- rehabiliterade ytor ej har röjts men delvis har påverkats av de ringbarkade träden. Tio år efter hjälpplanteringen fann man dubbla antalet arter av dipterocarper på de rehabiliterade ytorna i jämförelse med de icke- rehabiliterade ytorna, vilket även visade sig vara en statistisk signifikant skillnad. Å andra sidan fann man en statistisk skillnad med 10 % fler antal familjer på icke- rehabiliterade ytor. För totala antalet arter, antal stammar och antal dipterocarp stammar mellan behandlingarna (rehabiliterade och icke rehabiliterade ytor) fanns inga signifikanta skillnader. Emellertid, av ”saplings” (plantor över 150 cm höjd upp till en diameter i bröst höjd på 4,9 cm) av alla familjer fanns en signifikant skillnad med fler antal stammar på de ytor som ej hade rehabiliterats. Det motsatta kunde ses i ”saplings” av dipterocarperna, där fann man en tendens med fler antal stammar på de rehabiliterade ytorna. Detta resultat antyder att odlade plantor har en fördel genom artificiella luckor som bidrar till att de kan växa in i nästa storleksklass och bli en ”sapling”, medans på icke- rehabiliterade ytor så finns inte så stor andel luckor och plantor där får inte samma möjlighet att växa. Resultaten indikerar att det är möjligt att öka antalet arter av dipterocarper genom att använda sig av projektets metoder av linje- och ”luck- kluster” plantering och underhåll av plantor i tio år. Få rehabiliteringsprojekt har utformats för att utvärdera åtgärder som t.ex. hjälpplantering och röjning. Förhoppningsvis kan dessa resultat och projektets planteringsmetoder vara till nytta för framtida projekt. Mer forskning om den naturliga återhämtningsprocessen av sekundära regnskogar och fortsatta rehabiliteringsprojekt är av betydelse för framtida strategier och metoder.

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Introduction

There are approximately 4 billion hectares (ha) of forest in the world, which equals 30 % of the total land area on earth (Anon 2007). The tropical rainforest covers 6-7 % of the entire land area and stretches approximately 10° north and south around the equator (Gay 2001). Tropical rainforests covers mainly three regions; Southeast Asia, tropical South and Central America and West and Central Africa (Smith 2010). Tropical rainforest are characterized by high rainfall (1800- 2500 mm yr^{-1}) that is evenly spread most days of the year, and high temperature that is relatively constant all year around, mean temperature does not go below 18 °C. Tropical rainforest is the oldest existing biome and today more than 50 % of all the species on earth inhabit the rainforest (Gentry 1992; Hardaway 1994; Richards 1996; Gay 2001), which makes it the most species-rich ecosystem on the globe (Smith 2010). An example of this is the island of Borneo inhabited by over 3000 tree species (MacKinnon *et al.* 1996) which can be compared with Europe with about 50 indigenous tree species (Whitmore 1997).

Significant areas of forest are still being lost every year. The Food and Agricultural Organization of the United Nations (FAO) estimates that forests are decreasing with 13 million ha yr^{-1} (Anon 2007). Between the years of 1999-2005 the world lost three percent of its total forests, and in average 20 000 ha of forest is lost every day. Of all regions in the world, deforestation occurs fastest in Southeast Asia (Anon 2007). In Indonesia 13 % of the forest land have been lost in just five years. From 1999-2000 Southeast Asia lost 1.2 % forest land and from 2000-2005 deforestation had increased to 1.3 % (Anon 2007).

At a global level 36 % of the forest land is defined as primary forest (Anon 2007). Primary forests are characterised by not having been significantly affected by humans or exotic species. Globally, six million ha of primary forests is lost every year. Degradation of primary forests usually happens in several phases (Kammescheidt 2002). Two of the phases are logged-over forest and secondary forest (Bruenig 1996). Secondary forests have been more degraded, are less diverse and have a more homogenous structure than logged-over forests (Bruenig 1996). Human impact or natural disturbances causes the creation of secondary forests. After the disturbances the forest continues to grow, however, it does not have the original structure and/or species composition (Brown & Lugo 1990). In 1990 around 40 % of the forest land area in the tropics had been converted to secondary forests and the degradation of these forests was at a rate of 9 million ha $year^{-1}$ (Brown & Lugo 1990).

The causes of degradation and deforestation are many and complex and act both on a local, regional and global scale (Eliasch 2008). In general, degradation and deforestation happen as a consequence of demand for timber and/or agricultural products. Direct causes of tropical degradation and deforestation are primary logging, disturbances such as fire and changes of land use to agricultural, crops, pasture land or infrastructure (Bruenig 1996; Curran *et al.* 2004; Anon 2007). Fires have been the greatest cause of degradation and deforestation during the last two to three decades in both the Amazon and Southeast Asia (Cochrane 2003; Anon 2007). Increasing numbers of fires are due to poor methods of logging and agriculture and climatic factors associated with El Niño (Walsh & Newbery 1999; Anon 2007). In Southeast Asia a great part of the forest is converted into oil palm and pulp wood plantations (Curran *et al.* 2004). However, land conversion often happens in a second phase mainly after timber extraction (Kammescheidt 2002). Selective logging is the dominant form of harvesting forest in the humid tropics (Asner *et al.* 2005). Unfortunately illegal and unsustainable methods of logging are still widely spread (Anon 2007). Tropical forests are being degraded as a result of excessively intense logging activities and too short intervals between logging which does not allow for adequate regeneration (Appanah & Weinland 1993). Poor logging methods are to a larger extent used due to the opinion that it is more expensive to use sustainable methods such as Reduced Impact Logging (RIL) and because of a lack of knowledge on how to use these methods (Putz *et al.* 2000). A majority of the countries in the tropics have regulations and laws for a more sustainable forest management but they are seldom implemented (Hardaway 1994). It is also hard to control logging activities because deforestation is often vastly spread and occurs in very inaccessible areas (Langner *et al.* 2007).

Consequences of the degradation and reduction of tropical rainforest include a loss of watersheds, biodiversity, timber, non timber products such as rattan. The degradation also has a large impact on people in poor rural communities close to or in tropical forests (Lamb *et al.* 2005; Freer-Smith *et al.* 2009 One way to counter forest degradation is to implement and use Sustainable Forest Management plans (SFM). These plans need to be adjusted to natural dynamics in the forest, for example natural gaps created by fallen trees, so that biodiversity can be maintained (Whitmore 1997). Other advantages that can be obtained by SFM are less fragmentation and more viable populations of plants and animals. It is not easy to predict the loss of biodiversity in the tropical forests but it is likely that fragmentation will lead to a great decline in biodiversity (Whitmore 1997).

Dipterocarpaceae is a so-called pan tropical family with a dominating distribution in Southeast Asia (Maury-Lechon & Curtet 1998). The common name for tree species belonging to the *Dipterocarpaceae* family are dipterocarps and this term will be used in the following text. The family includes around 17 genera and 500 species with a majority in Borneo with 267 species (Ng 1991; Maury-Lechon & Curtet 1998). The greater part of the upper layer in lowland primary forest in Borneo belongs to the dipterocarp family (Appanah & Weinland 1993; Slik *et al.* 2003). Dipterocarps are one of the most famous tree families in the tropics and have during the last centuries been one of the dominant timber recourses and therefore endangered the future of dipterocarp forests (Appanah & Weinland 1993; Maury-Lechon & Curtet 1998). Dipterocarps are generally classified as shade tolerant, slow growing climax species, however some are relatively fast growing and light demanding (Appanah & Weinland 1993). A majority of the dipterocarps reproduce through mass fruitings that occur irregularly (Appanah 1985; Ashton *et al.* 1988; Sakai 2002). Dipterocarps often flower simultaneously within a population (Maury-Lechon & Curtet 1998). Mass fruiting is thought to be connected with the El Niño phenomena; the theory is that a variation in temperature and/or rainfall triggers the flowering (Maury-Lecon & Curtet 1998). Many dipterocarp's seeds do not have a dormant stage but germinate within a few days after falling to the forest floor (Ng 1991). Most species from the *Dipterocarpaceae* family needs more light than received under the canopy of a closed dipterocarp forest, but less than received in an open area exposed to full sunlight to survive in an early stage (Ashton 1998). As mentioned some species of dipterocarps are very shade tolerant and seedlings can survive for more than ten years under an existing canopy and not emerge greatly in height until a gap is created (Tuomela *et al.* 1996; Kuusipalo *et. al.* 1997; Ashton 1998). However, mast fruiting replaces most of the seedlings regularly (Ashton 1998).

The term restoration refers to an attempt to reverse not too damaged ecosystems as closely as possible to its original state (Aronson *et al.* 1993). The term rehabilitation refers to an effort to restore an ecosystem that has been irreversibly changed and where the aim is to repair the damaged function of ecosystems as quickly as possible (Aronson *et al.* 1993). Both restoration and rehabilitation intend to restructure self sustained ecosystems (Aronson *et al*. 1993). Forests can recover on their own, but to succeed there has to be a successful regeneration of climax species (Romell 2007). How fast a forest can recover after a disturbance depends, for example, on the intensity or timing of a disturbance or the frequency of disturbances. Other factors are soil conditions, surrounding areas which will influence the seed source and therefore the future regeneration (Whitmore 1984). If natural regeneration is inadequate, artificial regeneration as enrichment planting can be used to rehabilitate the area (Appanah &Weinland 1993; Bruenig 1996). Trials of enrichment plantings on the Malaysian peninsula already started in 1949 and were done using methods of line planting (Appanah & Weinland 1993). Enrichment planting using gaps is an alternative and more recent method compared to line planting (Tuomela *et al.* 1996; Otsamo 2000).

Gap dynamics in primary forests plays a vital role for the regeneration of dipterocarps (Appanah & Weinland 1993). Natural gaps in a primary forest are created by fallen trees or branches and in these gaps regeneration has an advantage to grow compared to surrounding regeneration (Kuusipalo *et al.* 1997). Tree species differ in their requirement of amount of solar radiation for their regeneration (Whitmore 1998). They also differ in their ability to take advantage of different sizes of gaps (Shugart 1984). The spatial light transmittance that reaches the forest floor depends on the different layers and composition of canopy and the vegetation floor (Montgomery & Chazdon 2001). Heavily disturbed primary forests by for example logging or fire, creates too wide gaps and openings that most certainly will be re-established by pioneer trees which will outcompete climax species as the dipterocarps (Whitmore 1984; Nykvist 1996). In Borneo the majority of pioneer trees that occupies the forest after a disturbance belong to the *Macaranga* genus (Slik *et al.* 2002, Slik & Eichhorn 2003). Canopy treatments such as slashing and girdling improve the light conditions at the forest floor and can have a positive effect of establishment of seedlings, their growth and survival (Romell 2007). In this context the definition of girdling is removing the bark and cambium so that the trees are cut off from water and nutrient supply. The consequence is that the canopy gets reduced and in some cases the tree dies. The definition of slashing is when weeds such as ferns, gingers and climbers are removed around planted seedlings.

Due to degradation and reduction of tropical primary forests, the pressures on secondary forests are increasing and the necessity to rehabilitate these forests is immense. Several rehabilitation and restoration projects are in progress all around the tropics (Moura- Costa *et al.* 1994; Kuusipalo *et al.* 1996; Aerts *et. al.* 2008) and additional projects are in the process to start. An example is Ulu segama forest reserve in Sabah, Borneo where the goal is to restore 240 000 ha of lowland tropical rainforest (Udarbe pers.comm). Evaluations of small scale rehabilitation projects are needed before starting large scale ones. Few trials of different rehabilitation techniques exist and when large areas are to be rehabilitated, established methods that have a scientific base are required. Few known studies exist of rehabilitation of forest and information of enrichment planting in tropical secondary forest on growth and survival is still incomplete.

The study site for this thesis was situated at the INIKEA project, Sabah, Borneo (Figs. 1 & 2). The project started 1998 using both line and gap cluster planting as enrichment methods, with gap cluster planting used on the larger part. The planted area was then maintained for ten years. The objective of the project is to rehabilitate and speed up recovery of a secondary tropical rainforest that has been severely degraded by both wildfire and logging (Falck pers.comm.). The main goal is to improve biodiversity through enrichment plantings with a majority of dipterocarps but also with a certain percentage of fruit trees. These trees will hopefully attract birdlife and mammals that will act as seed vectors and bring more species into the area.

The rehabilitation method used by INIKEA is unique, as is the long period of time since the enrichment planting was done. No studies have so far been made to evaluate the method which is the reason why this thesis was done and hopefully the result will give a more scientific base for future rehabilitation projects.

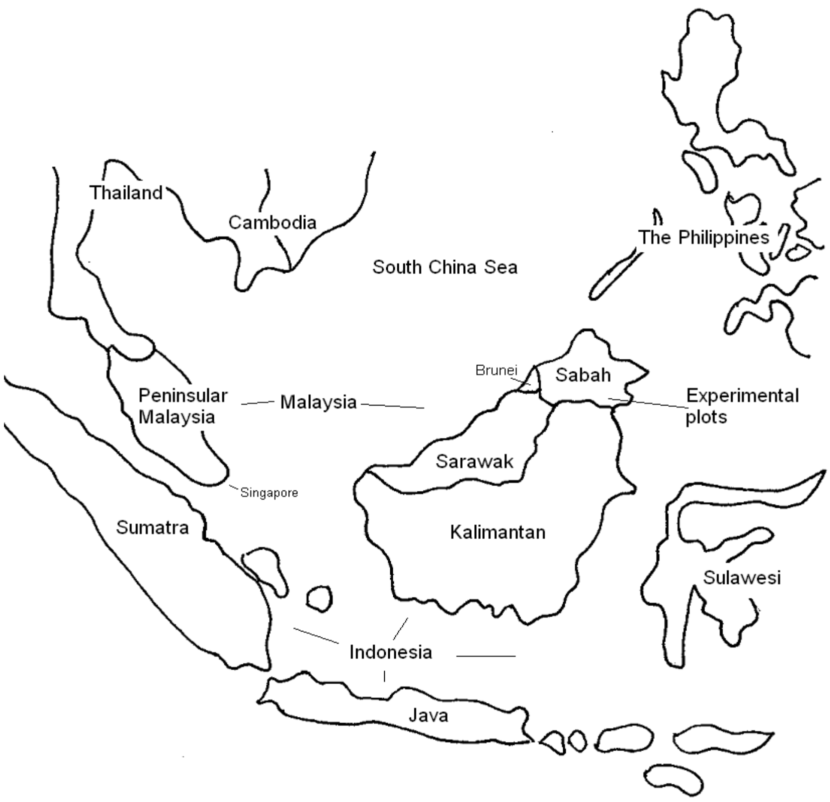

Fig. 1 Map over Southeast Asia, the state boundaries of Borneo and where the experimental plots lies and where the inventory of this study was done (from Forshed 2006).

Objectives

The main objective with this study was to evaluate the methods of line and gap cluster planting used at the INIKEA project and how these methods have contributed to the rehabilitated area in terms of:

1. Differences in number of families and species and solitaire dipterocarps between the rehabilitated area and the non rehabilitated area.
2. Differences in number of total stems of species, solitaire dipterocarps and all species divided into four size classes on the rehabilitated area and the non rehabilitated area.

Materials and methods

1. Site and location

The site for this project is situated in Malaysian Borneo in the southeast province of Sabah, west of Luasong Forest Centre in the Kalabakan Forest reserve (approximately lat. 4°36´N, long. 117°14´E) (Fig. 2). The landscape is dominated by hills and valleys at a range from 300-700 m a.s.l. The soil reference groups are a mixture of acrisols and cambisols (Anon 1999, unpublished). The climate is equatorial, with high precipitation, temperature and humidity. Mean annual precipitation is 2890 mm, temperatures are diurnal rather than seasonal and vary from 22.0-32.7 °C (Romell 2007). Pre-logging, the area consisted of lowland Dipterocarp forest. Large areas of tropical rainforest were burnt in Borneo by a wildfire 1983, the fire was caused by a drought that occurred the years of 1982-1983 due to the El Niño phenomena (Woods 1989; Walsh 1996; Mackinnon *et al.* 1996). The majority of the project area was selectively logged between the years of 1975-1985 and partially disturbed by the wildfire that occurred 1983. Today the area consists of a secondary forest degraded to varying extents. The vegetation that covers the forest floor today is dominated by a mixture of ferns, gingers (*Zingerberaceae* family), climbers and seedlings from both pioneer and secondary species similar to a nearby areas investigated in 2002 (Romell 2007). The project area is connected with Maliau Basin (Fig. 2) which is a protected primary forest. The areas are linked through a river which on each side has a protected area of 1 km creating a wildlife corridor.

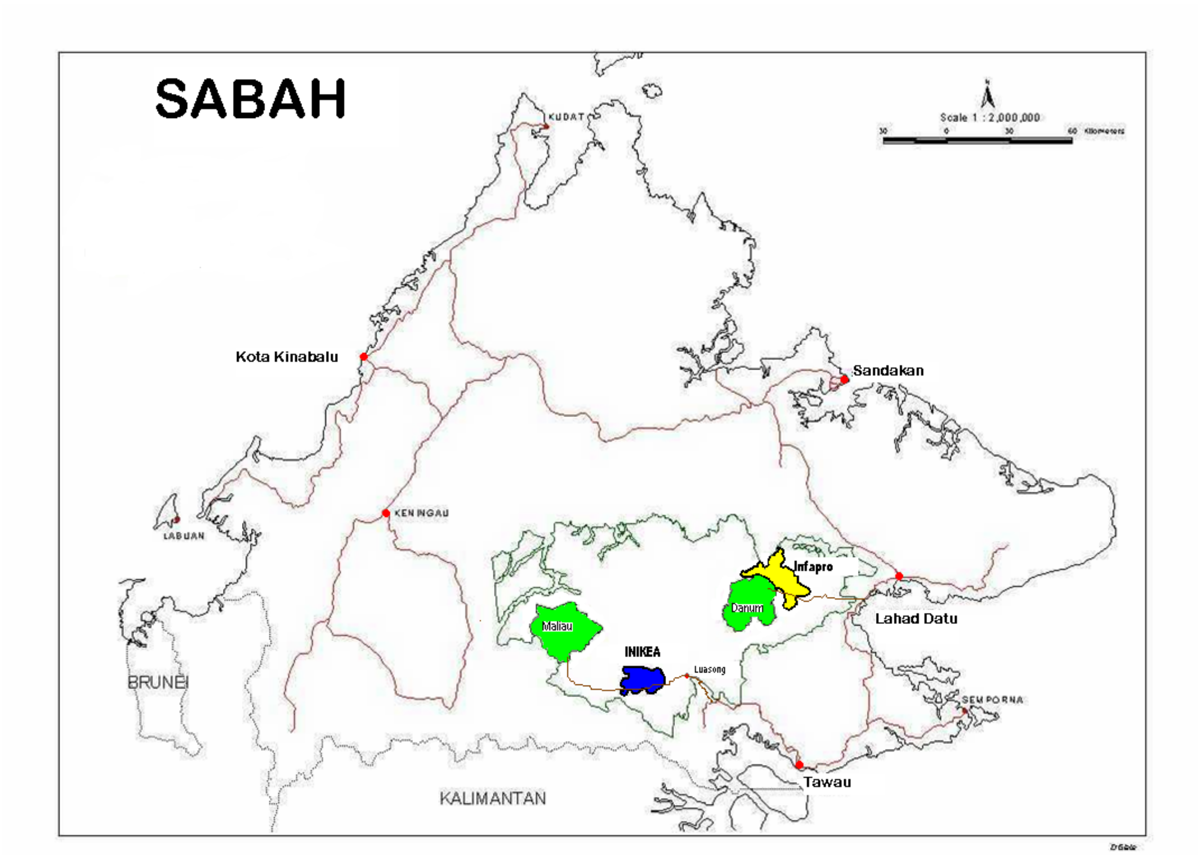

Fig. 2 Map over Sabah with: the INIKEA rehabilitation area (blue area), Luasong village and Forest Centre (red dot east of INIKEA area), Maliau Basin conservation area (green area west of INIKEA), Infapro rehabilitation area (yellow area) and Danum Valley conservation area (green area east of INIKEA) (from Innoprise Corporation Geographic Information System).

2. Design of the rehabilitation project

The project area consists of approximately 18 500 ha and was divided into subareas from 20 up to a 100 ha (Fig. 3) (Alloysius *et. al.* 2005, unpublished). Features such as streams and roads were used as borders for the subareas. Basic information were gathered such as the status of canopy opening, terrain and regeneration of each subarea. Based on this information it was decided whether to perform liberation or enrichment planting. In this context liberation means to remove or girdle unwanted trees and slash weeds around natural regeneration of desired species, such as dipterocarps. Three to six months prior planting, liberation of climbers and some pioneer species was done with a parang (a long sharp knife) to clear lines and gaps. Lines were directed so they were as easily accessible as possible for example from roads. Sticks made of rot-resistant wood (*Eusideroxylon zwageri* Teijsm. & Binn.) (belian) were placed in the beginning and at the end of each line and were also used to mark gaps and placed at each planted seedling. Information such as the length of the line, line number, number of gaps and number of seedlings planted were carved into metallic tags that were placed on the sticks in the beginning of the line. Planting was possible most of the year, though a general rule was followed; if there were more than three consecutive days without rain, planting stopped but after three successive days of heavy rain planting continued (Alloysius pers. comm.). Other guidelines when not to plant were: the presence of a tree of climax species assumed to produce seeds, steep terrain (exceeding 45°), wetlands or rocky areas, if there were wetlands or if the area was too rocky. Species used in the project were assumed to have existed in the area prior logging. 95 % of seedlings planted in 1999, were from the *Dipterocarpaceae* family, the remaining 5 % seedlings were of non-dipterocarps and fruit trees (Anon 1999, unpublished).

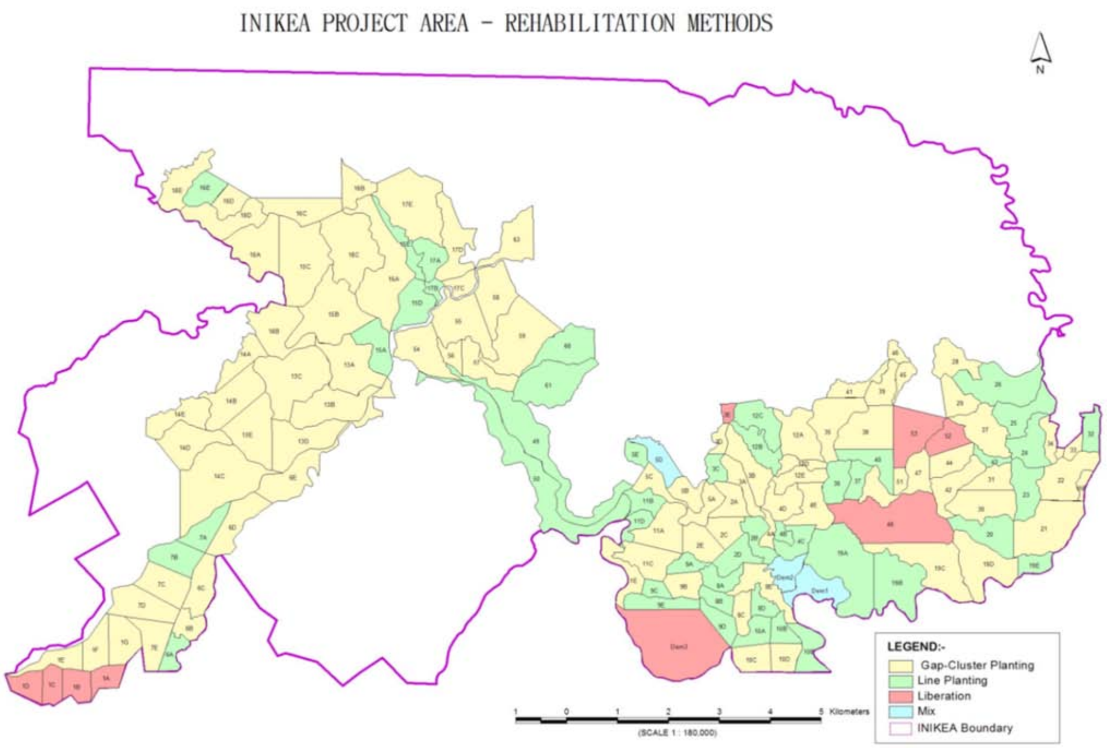

Fig. 3 Map over INIKEA rehabilitation area which consists of 18 500 ha and correspond to the blue area in Fig. 2. The area is divided in subareas and the different colours represent if a subarea has been liberated or if one of the enrichment methods, line or gap cluster planting, have been used (from Innoprise Corporation Geographic Information System)

2.1 Planting methods and materials

The majority of planting materials 1999 was brought from a neighbouring project, Infapro (yellow area in Fig. 2) (Alloysius pers. comm.). Seedlings were also produced at INIKEAs own nursery, which at that time were in an establishing phase. Both seeds and wildlings (natural regenerated seedlings in the forest) were collected in the forest and raised in polythene bags at the nursery. Seeds were more economical to raise and therefore they were preferred, though fruiting occurs irregular and to upgrade stock it was necessary to collect wildlings (Alloysius pers. comm.). After about 6-8 months the seedlings or wildlings were ready for planting and used in the two different planting methods depending on the environment.

2.1.1 Line planting

Line planting is a method using systematically aligned strips or lines which are cleared from vegetation and then used as a planting base (Fig. 4). Seedlings were planted at a distance of three meters between each other in the lines. In general, trees closest to the cleared line were selected for girdling which allowed more light to penetrate down to the planted seedlings. If a subarea had a more open canopy, line planting was used as enrichment method (Alloysius pers. comm.).

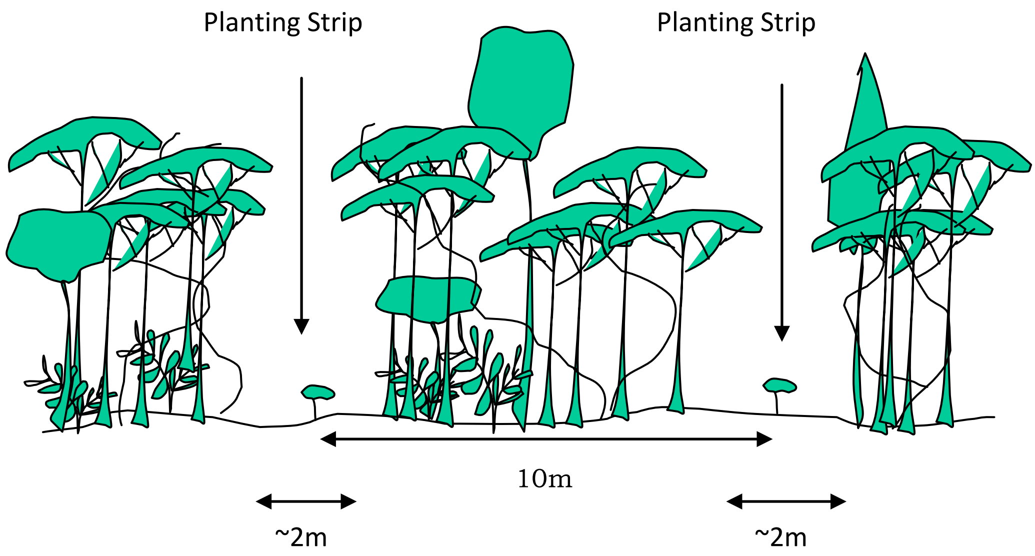

Fig. 4 Design of line planting, each line was cleared at a width of around two meters in systematic aligned strips at a distance of 10 meter. Seedlings mainly from the dipterocarps were planted with a distance of three meters in the cleared lines (from Garcia & Falck 2002).

2.1.2 Gap cluster planting

The design of gap cluster planting was to plant seedlings in either natural or artificially created gaps of around two meters radius in square plots of 100 m^2 (10 x 10 m) grid system (Fig. 5) (Anon 1999, unpublished). To access the plots as easily as possible, lines were cleared at a distance of 20 meters, at a width of approximately one meter. A belian stick was placed every 20 meters in the centre of four sub- squares. The gap allowed more light to penetrate down to the seedlings that were planted in a cluster of three. The goal was to have three different species in each gap, though, at some occasions only one species were planted in the same gap due to lack of planting material the first year. If there were more than five climax species in a sub- square no planting was made (Anon 2005, unpublished). If the forest in a subarea were dense the gap cluster method was used (Alloysius pers. comm.).

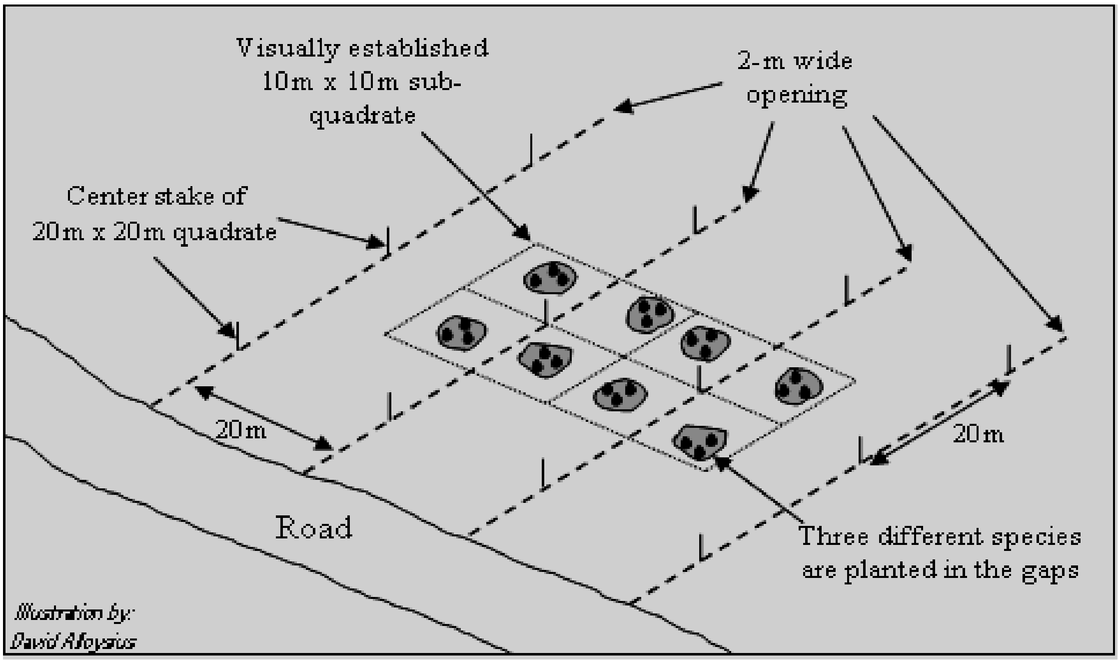

Fig. 5 Design of gap cluster planting, where gaps were natural or artificially created in square plots of 100 m^2 (10*10 m) and lines cleared in fixed intervals every 20 meters to make the gaps more accessible. Three seedlings were planted in each gap (from Alloysius *et. al*. 2005, unpublished).

2.2 Maintenance

Maintenance included girdling and slashing of weeds in both lines and in gaps, it also included removing of wines and climbers from the planted seedlings, however no slashing was to be done on natural regeneration of dipterocarps. The regularity of maintenance depended on the state of the forest (Anon 1999, unpublished). A canopy that is too open can lead to excessive growth of weeds such as ferns and gingers, so in these areas a higher frequency of slashing needed to take place. Number of times slashing in each subarea can be seen in appendix 1. About two to three months after planting a 100 % census was conducted. If mortality was higher than 5 % a refilling of seedlings up to a 100 % was made (Anon 1999, unpublished). After maintaining the subareas for a ten year period they are left for nature and are protected from logging for an additional 50 years.

3. Method of inventory

The inventory was carried out in November 2009 on subareas that were rehabilitated in 1999. The area consisted of approximately 540 ha divided in to 17 subareas of different sizes. About 5 % of the numbers of lines were randomly selected in each subarea. Out of 46 lines, 34 were subjected to gap cluster planting and the rest were subjected to line planting. An inventory of species composition in the 17 subareas on the rehabilitated area (in the sampled lines and gaps) and the non-rehabilitated area (in between the lines and gaps) was conducted. Species composition was measured in paired plots with a radius of 1.13 meters giving an area of 4 m^2. The paired plots were called plot A and B. Plot A was placed on rehabilitated areas where it had been planted and therefore maintained with slashing and girdling. These areas will be referred to as treatment A when the results are presented. Plot B was placed on non- rehabilitated areas between lines or gaps where no plantation or maintenance had been carried out. These areas will be referred to as treatment B when the results are presented. A metal pole with a sharp end was used and put in the centre of each plot. A line of 1.13 meter was attached with an adjustable knot so each plot could be measured at a horizontal level. Plants were divided into four size classes defined as follows ; seedling; 20.0-149.9 cm high, sapling; 150.0 cm high up to a diameter at breast height (DBH) of 4.9 cm, pole; DBH ranging from 5 cm – 9.9 cm and tree; 10 cm and above in DBH. The DBH was measured at 1.3 meter on larger trees with a diameter measuring tape and a vernier calliper on smaller trees. The height was determined with a measuring tape. If the base of seedlings and saplings were inside the circle they were included in the inventory. If the DBH centre of saplings, poles and trees were inside the circle they were inventoried. In plot A the following variables were noted of each stem in the plot: species, which of the four size classes it belonged to and if the stem was of natural regeneration or had been planted. In line planting a maximum of one planted seedling could be found in plot A, whereas in gap cluster planting a maximum of three planted seedlings could be found in plot A. In plot B the following variables were noted of each stem in the plot; species and which of the four size classes the stem belonged to.

3.1 Method in line planting

A random distance (23) was selected, and at this distance the first plot was inventoried in line planting (Fig 6). In the beginning and end of a majority of lines, no rehabilitations were made due to too open areas, therefore the draw was done between the numbers of 15-25. The remaining plots were measured at a fixed distance of 20 meters with a measuring tape. In the centre of the cleared line, plot A was laid out. Plot B was placed at a distance of five meters perpendicular to the centre of the line.

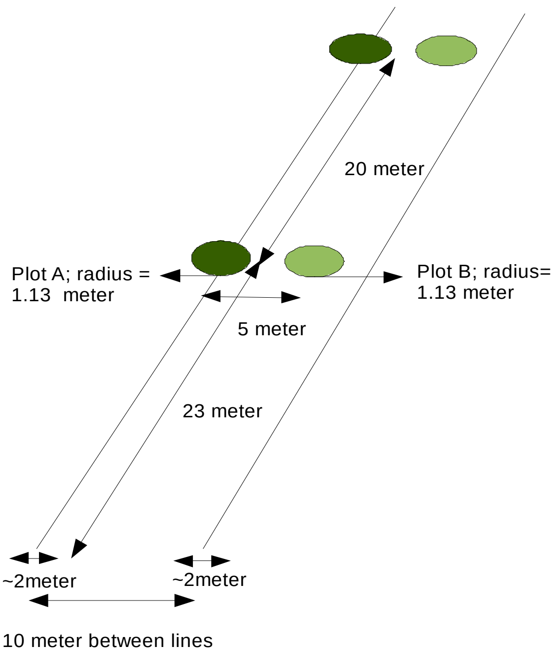

Fig. 6. Layout of method for evaluation of species composition in line planting. Paired plots were used, one in the cleared and planted rehabilitated area= plot A and one in the non rehabilitated area= plot B. Plot B was placed perpendicular to the direction of the line and five meters from the centre of plot A. The random number of 23 was drawn and at this distance the first plot was laid out. After the first plots the remaining plots were laid out at a fixed distance of 20 meters.

3.2 Method of gap cluster planting

In gap cluster planting sub-quadrate two and three were randomly selected. Sub-square number three were to be measured in first place and sub- square number two in second place. The centre of the gap in the sub-square was located and plot A was inventoried (Fig 7). Plot B was placed in the bottom of sub-square three, perpendicular of the direction to the lines, which are cleared at a 20 meters distance to make the gaps more accessible. Depending on the gap (plot A) plot B was placed either five or ten meters from the line. The plots were not allowed to overlap. If there was no gap in sub-square three or if the gap touch plot B (the gap had a radius of two meters) the inventory was done in sub- square two. If there were no gaps in either sub- square three or two no measurements could be done.

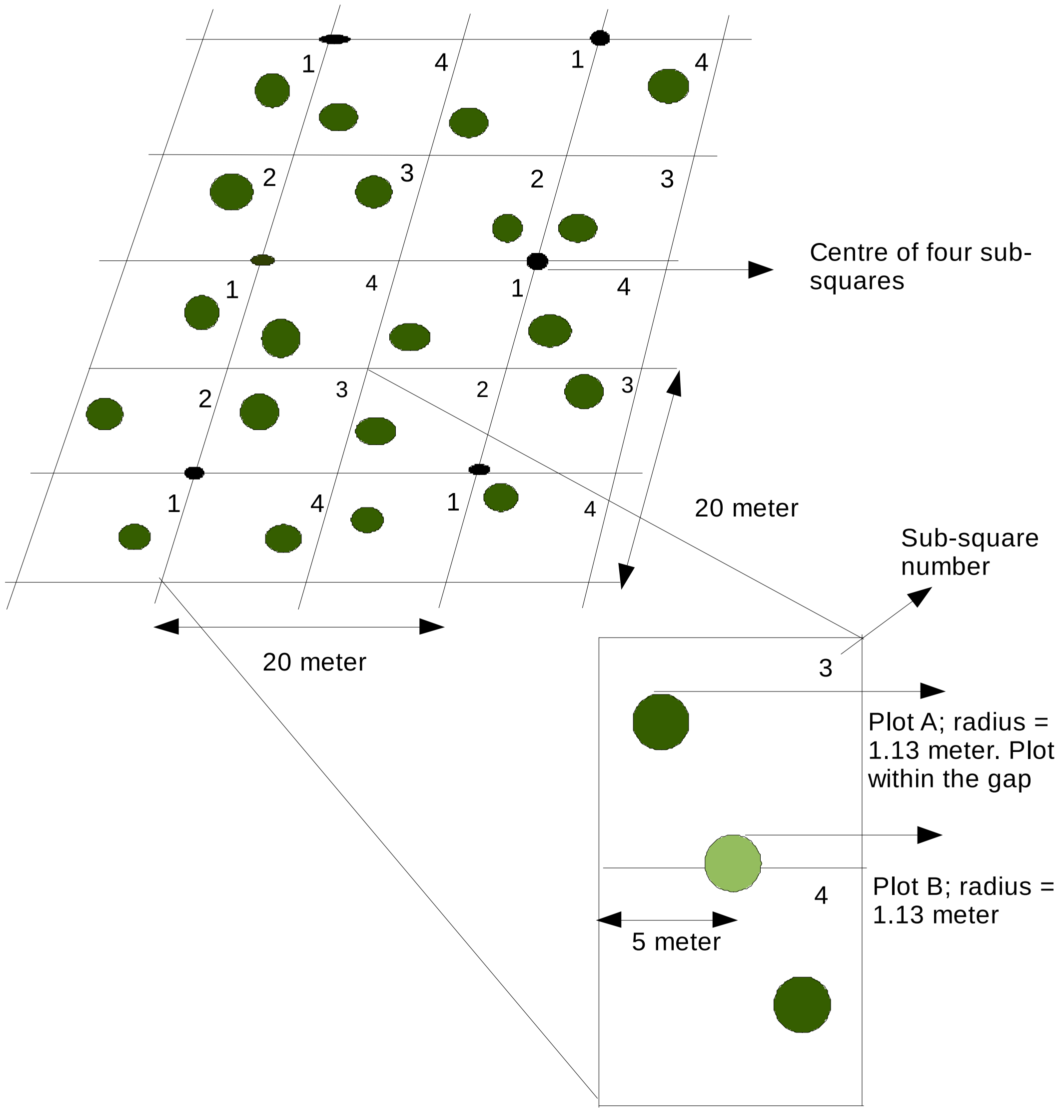

Fig. 7 Layout of method for evaluation of species composition in gap cluster planting. Paired plots were used, one in the planted and cleared gap= plot A, and the other one in the non rehabilitated area= plot B. Sub square three was randomly selected and the gap and bottom line in the square were used for the paired plots. Plot B was placed either five meters or ten meters perpendicular to the direction of the access line depending where the gap (plot A) was placed, the paired plots were not allowed to touch.

4. Data analysis

The following variables were calculated for each plot:

- Number of families
- Number of species
- Number of dipterocarp species
- Number of stems
- Number of stems of dipterocarps
- Number of stems of all families in every size class
- Number of stems of dipterocarps in every size class

Mean number of families and dipterocarp species on each plot and Standard Error of the mean (*SE mean*), respectively, was also calculated. To test if the distribution of the four classes were equal in all families and of dipterocarps in the two treatments (A and B), Chi^2 tests were performed. Minitab 15 was used both for the general linear model (GLM) and the Chi^2 test. Analyses of each variance (ANOVA) using GLM were used in the model that follows.

The comparisons of the variables between the treatments were based on the model;

$$y_{ijkl} = \mu + T_i + S_j + (TS)_{ij} + L_{k(j)} + (TL)_{ik(j)} + P_{l(jk)} + e_{ijkl} \qquad (1)$$

where;

y_{ijkl} is the value (e.g., number of species in plot A) for treatment *i*, subarea *j*, line *k* within subarea *j* and pair *l* within subarea *j* and line *k*,

T_i is treatment *i* main effect (fixed),

S_j is subarea *j* main effect (random),

$(TS)_{ij}$ is treatment by subarea interaction effect (random),

$L_{k(j)}$ is the line effect within subarea (random),

$(TL)_{ik(j)}$ is the treatment by line within subarea interaction effect (random),

$P_{l(jk)}$ is effect of pair (block) within line and subarea (random) and

e_{ijkl} is a random deviation, assumed $NID(0, \sigma^2)$

The deviation e_{ijkl} has been tested for normality and showed a high degree of normality (Anderson-Darlings test).

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

Results

On the 540 ha area 924 plots where inventoried and a total of 3710 stems were found. When number stems are mentioned it includes stems of all four size classes; seedlings, saplings, poles and trees. In 122 plots, 62 in treatment A (rehabilitated area) and 60 in treatment B (non- rehabilitated area), there was no planted material or natural regeneration at all. The highest numbers of stems in one plot was 38, of which 33 were seedlings. On average there were 4.0 stems in each plot. In all plots, 90 species within 33 families were registered. However, some individuals could only be identified as belonging to a certain family or genus, these will be called species groups when further results are presented. *Praravinia* sp. had the highest number of stems (226). In six species only one stem of each was found. Of all stems, 5.5 % could not be identified at all and have been put in a separate group of species and family which have been called "unidentified".

1. Families

The two predominant families in the area and in the two treatments were *Dipterocarpaceae* and *Euphorbiaceae*, which composed of 33 % respectively 17 % of all stems inventoried. *Dipterocarpaceae* represented 40 % of the stems in treatment A and 28 % in treatment B (Fig. 8). *Euphorbiaceae* represented 13 % in treatment A and 20 % in treatment B.

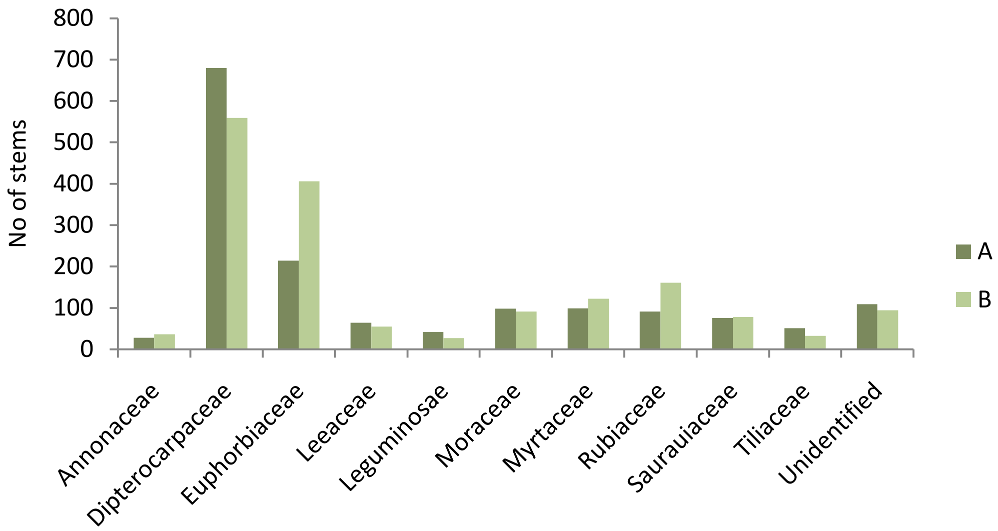

Fig. 8 Number of stems in each treatment of the ten most common families, including unidentified species. The dark green bars, A represent the rehabilitated area and the light green bars, B represent the non-rehabilitated area.

In treatment A, 30 families were found in total and in treatment B, 33 families (excluding "unidentified"). Out of the 33 families, 22 families only had one species to represent the family. There was a significant difference of number of families between the two treatments (*P*=0.012) (Fig. 9), with 10 % more families in treatment B. For complete result of the ANOVA, see appendix 2. In appendix 3, the number of families divided between subareas can be found.

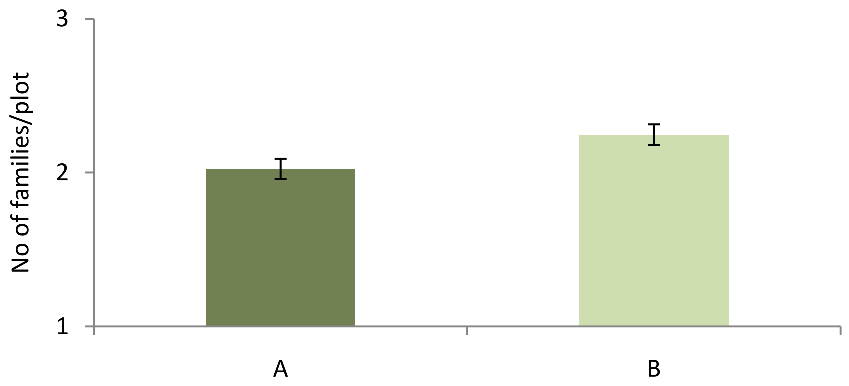

Fig. 9 Mean number (± *SE Mean*) of families in each plot in treatment A (rehabilitated area) and B (non-rehabilitated area). A significant difference was found with 10 % more families in treatment B (*P*=0.012).

2. Species

In treatment A, 82 species were found and in treatment B, 77 species were found. No significant difference (*P*= 0.98) of the number of species between the two treatments was found, for complete result of the ANOVA see appendix 4. A significant difference (*P*< 0.001) for number of dipterocarp species was found between the two treatments (Fig. 10), complete result of the ANOVA can be seen in appendix 5. Of the dipterocarps, 35 species were found in total whereof 32 species were found in treatment A and 24 species in treatment B (including individuals that could only be identified to a certain genus, as *Hopea* sp. and *Shorea* sp.). In average, the double number of dipterocarp species was found in treatment A compared to treatment B. For more information on how stems were divided between all species, families and the two treatments, see appendix 6.

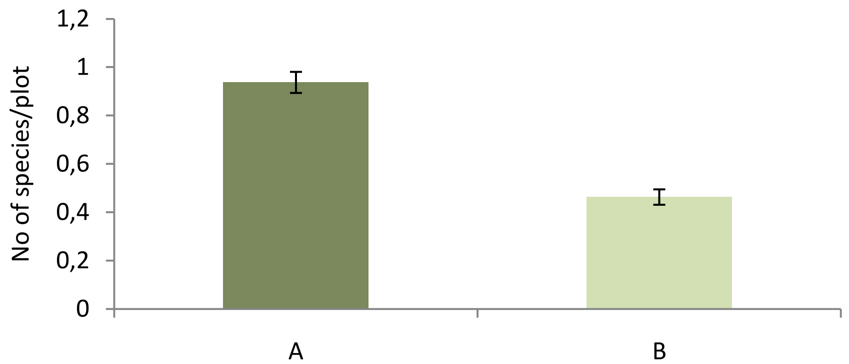

Fig. 10 Mean number (± *SE Mean*) of species of dipterocarps in each plot in treatment A (rehabilitated area) and treatment B (non- rehabilitated area). The double number of species was found in treatment A which proved to be a significant difference (*P*< 0.001).

3. Unique families and species

There were three families exclusively found in treatment B, (number of stems of each family in parenthesis); *Apocynaceae* (1), *Chrysobalanaceae* (5), *Sapindaceae* (3). A few species were exclusively found in each treatment (unique species). In treatment A 13 unique species were found of which ten belonged to the dipterocarps (Table 1). In treatment B, nine unique species were found of which three belonged to the dipterocarps (Table 2).

Table 1. Species exclusively (unique species) found in treatment A (rehabilitated area) and number of stems of each species divided between planted and not planted seedlings. Species belonging to *Dipterocarpaceae* are marked with an asterisk

Unique species for treatment A	Planted (no of stems)	Not planted (no of stems)
Dipterocarpus conformis *	1	0
Endospermum diadenum	0	4
Hopea nervosa *	19	2
Hopea sangal *	11	1
Nauciea subdita	0	3
Shorea faguetiana *	0	1
Shorea ovalis *	2	0
Shorea platyclados *	2	0
Shorea seminis *	15	0
Shorea smithiana *	2	0
Shorea xanthophylla *	2	0
Walsura pinnata	2	0
Vatica sp *	1	0

Table 2. Species exclusively (unique species) found in treatment B (non- rehabilitated area) and number of stems of each species. Asterisk shows which species belongs to the *Dipterocarpaceae*

Unique species in treatment B	Not planted (no of stems)
Alseodaphne bancana	1
Alstonia spatulata	1
Dipterocarpus applanatus *	5
Dipterocarpus globosus *	4
Microcos crassifolia	2
Neolamarckia cadamba	1
Nephelium mutabile	3
Parinari oblongifolia	5
Shorea agamii *	2

4. Stems

In treatment A, 1709 stems were found compared to treatment B, where 2001 stems were found. A tendency (P=0.074) with more stems in treatment B was found of all species. For complete information of the result of the ANOVA, see appendix 7. The ten most common species and species groups (excluding dipterocarps) (Fig. 11), and the ten most common species and species groups of dipterocarps (Fig. 12) were extracted from the data set. In eight out of the ten most common species and species group (excluding species from the dipterocarps) there was a higher number of stems in treatment B (Fig. 11). The species with the largest difference between the treatments were; *Dillenia excelsa* with 121 % more stems, *Mallotus wrayi* with 115 % more stems and *Koilodepas longifolium* with 95 % more stems. All three species had more stems in treatment B (Fig. 11). The genus which usually dominates secondary forests in Borneo, *Macaranga* sp., was not amongst the top 20 species. On the study site, 26 stems were found of Macaranga *sp*. of which 18 where trees. Sixteen of the trees were found in treatment B. *Macaranga* sp. turned out to be one of the dominating genera amongst trees. Appendix 8 shows how number of stems is separated between the two treatments in each subarea.

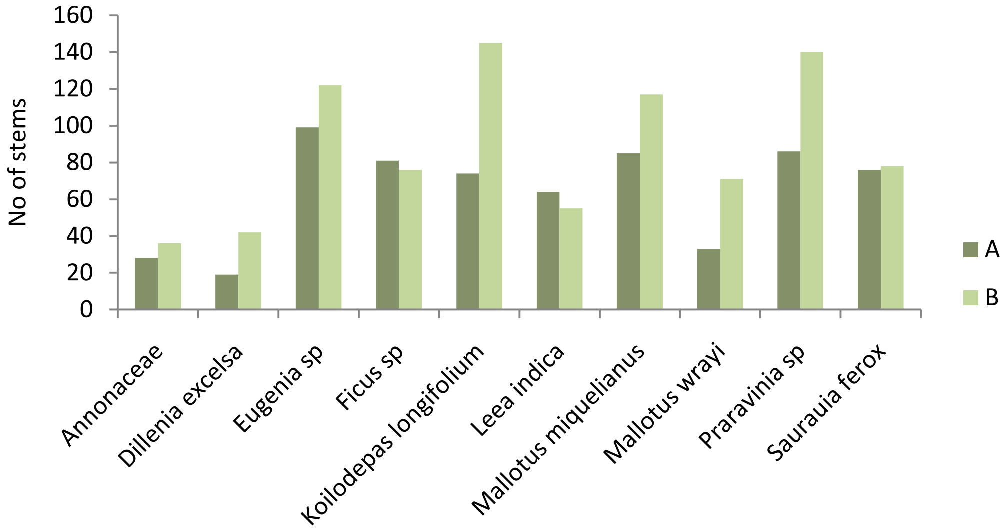

Fig. 11 Number of stems of the ten most common species and species groups in treatment A (rehabilitated area) and B (non- rehabilitated area) excluding *Dipterocarpaceae* and unidentified species.

There were six genera of dipterocarps in all the inventoried plots; *Dipterocarpus*, *Dryabalanops*, *Hopea*, *Parashorea*, *Shorea* and *Vatica*. Three of the genera, *Dryabalanops*, *Parashorea* and *Shorea* composed of 29 % of total number of stems. *Dryabalanops* constituted of 8.3 %, *Parashorea*, 9.4 % and *Shorea* of 11 % of total number of stems. Of the ten most common species of dipterocarps, five had a higher number of stems in treatment B and five had a higher number in treatment A (Fig. 12). The largest difference of number of stems between the treatments were; *Shorea fallax* with 217 % more stems in treatment A and *Parashorea smythiesii* , with 78 % more stems in treatment A.

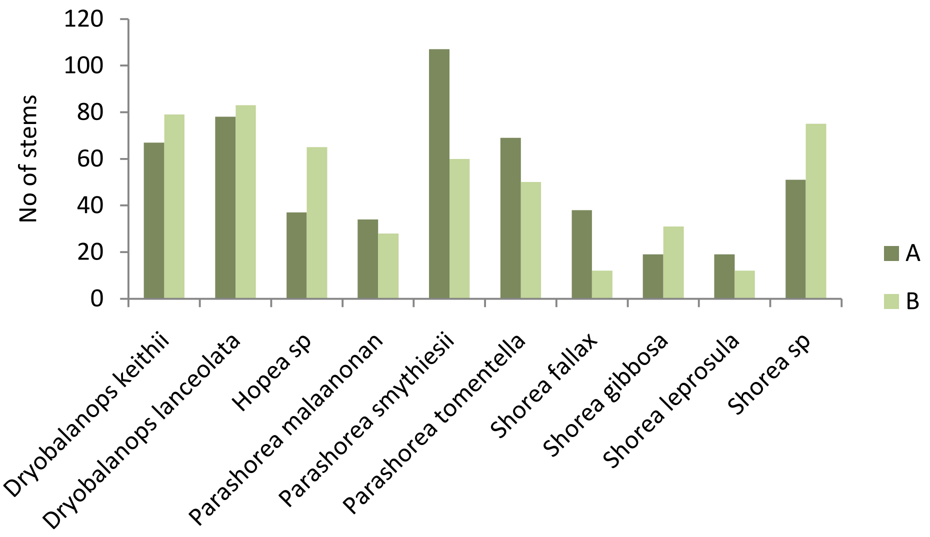

Fig. 12 Number of stems of the ten main existing dipterocarp species and genera in treatment A (rehabilitated area) and B (non-rehabilitated area). *Shorea* sp. and *Hopea* sp. are individuals which could only be identified to a genera.

There were 22 % more stems of dipterocarps in treatment A compared to treatment B but there difference was not statistical significant (P=0.29). The complete result of the ANOVA can be seen in appendix 9. However, of the dipterocarps in treatment A, 45 % were planted and the rest of the dipterocarps were of natural regeneration (Fig. 13). Just comparing the natural regeneration, there were 50 % more stems in treatment B. See appendix 10 for more information of how the number of stems of dipterocarps were divided between subareas and treatments.

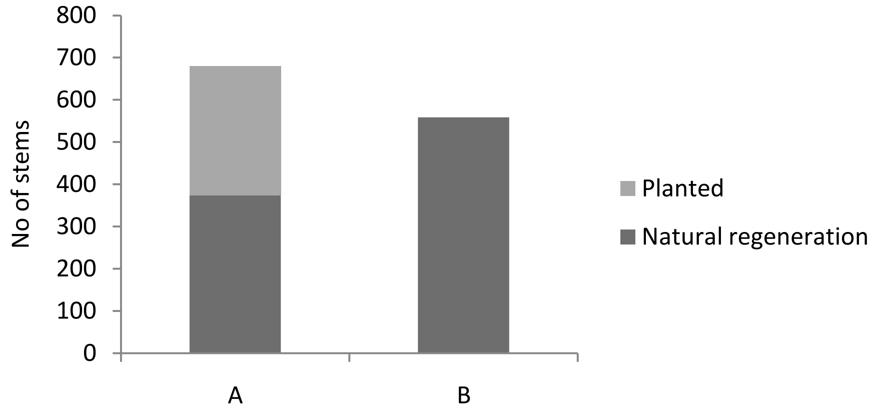

Fig. 13 Number of stems of *Dipterocarpaceae* in treatment A (rehabilitated area) and B (non-rehabilitated area), the stems are also separated between planted individuals and natural regeneration in treatment A.

5. Stems classified into size classes

Stems of all families were separated into four size classes (seedlings, saplings, poles and trees) in both treatments (Fig. 14). A chi^2 test was done to see if the distribution of stems were equal for the two treatments. The distribution was not equal and the hypothesis of equality could be rejected ($\chi^2 = 67.0$, DF=3, P<0.001). A GLM could only be done in the two classes of seedling and sapling. In the classes of poles and trees there were too few observations of stems. No statistical significant difference could be found in the class seedling (*P*= 0.38) (complete result of the ANOVA, see appendix 11). However, in the class sapling there were 78 % more stems in treatment B which turned out to be a significant difference (*P*= 0.023) (complete result of the ANOVA, see appendix 12). In treatment A, there were both planted individuals and natural regeneration (Fig. 15). A majority of the natural regeneration were found in the class seedling, only 30 of the individuals were planted seedlings. A majority of the planted material were found in the class sapling.

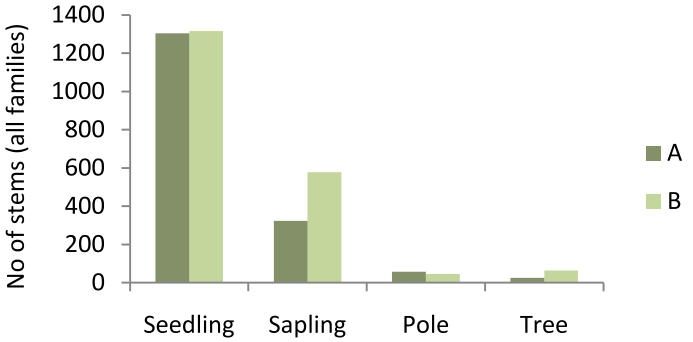

Fig. 14 Number of stems of all families and in each treatment (rehabilitated- and non- rehabilitated area) and the four size classes; seedling; 20.0-149.9 cm high, sapling; 150.0 cm high up to a diameter at breast height (DBH) of 4.9 cm, pole; DBH ranging from 5 cm – 9.9 cm and tree; 10 cm and above in DBH.

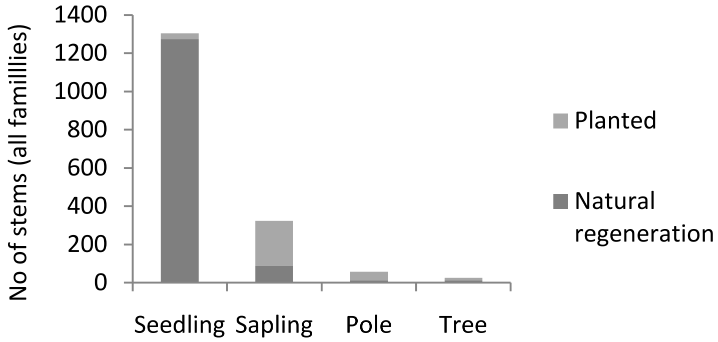

Fig. 15 Number of stems in treatment A (rehabilitated area), of all families divided between planted individuals and natural regeneration in the four size classes (seedling sapling pole and tree) See the description of the four size classes in Fig 14.

All the stems of the dipterocarps were extracted from the data set and the same analysis was done as for all families. The distribution of dipterocarps were not equal in the two treatments and the hypothesis of equality was rejected ($\chi^2 = 51.2$, *DF*=3, *P*<0.001) (Fig. 16). There was no significant difference of seedling (*P*= 0.67) (for complete result of the ANOVA, see appendix 13) on the other hand a tendency (*P*= 0.054) (for complete result of the ANOVA, see appendix 14) of sapling was found, with 77 % more stems in treatment A. The highest proportion of planted dipterocarps was found in the class sapling (Fig. 17).

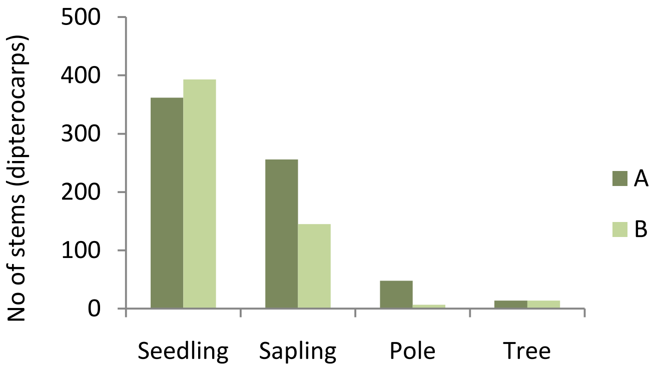

Fig. 16 Number of stems of dipterocarps in treatment A (rehabilitated area) and B (non- rehabilitated area) divided between the four size classes (seedling, sapling, pole and tree). See the description of the four size classes in Fig. 14.

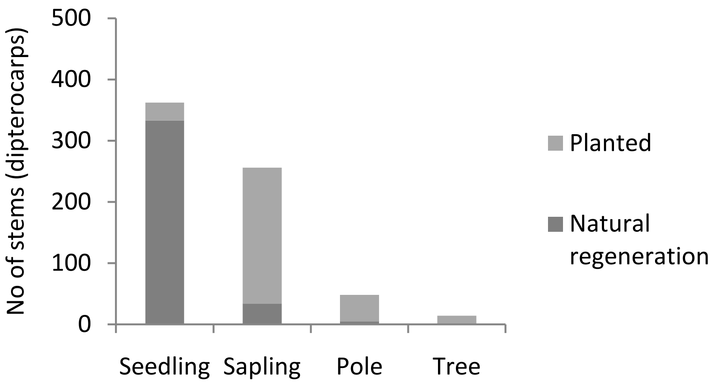

Fig. 17 Number of stems of planted individuals and natural regeneration of dipterocarps in treatment A (rehabilitated area) divided between the four size classes (seedling, sapling, pole and tree). See the description of the four size classes in Fig. 14.

Discussion

Dipterocarps are the dominating family in lowland tropical forest in Borneo (Appanah & Weinland 1993; Whitmore 1998; Slik *et al*. 2003). Trees of this family are the ones that are and have been most frequently logged (Appanah & Weinland 1993; Maury-Lechon & Curtet 1998). The diminished resource of dipterocarps is the cause to reintroduce them into secondary forests through enrichment plantings. The result of this study showed that the method of enrichment planting and treatment used in this study can be an effective tool to increase the number of dipterocarp species and also to increase the growth of them in a secondary tropical rainforest.

A general pattern throughout Southeast Asia are two families dominating primary evergreen rainforest, firstly *Dipterocarpaceae,* and on second place *Euphorbiaceae* (Whitmore 1984; MacKinnon *et al.* 1996; Slik *et al.* 2003). Despite severely disturbances of fire and logging in the project area the same pattern were found, with *Dipterocarpaceae* dominating and *Euphorbiaceae* on second place, both in rehabilitated and non- rehabilitated area.

A lowland tropical primary rainforest in Borneo inhabits approximately 40 families of trees (Slik *et al.* 2003), whereas in the secondary forest where this study was performed, 33 families were found. Three more families were exclusively found on the untreated area and a mean of 10 % more families were found in each untreated plot, which also proved to be a significant difference. The main goal of the rehabilitation was to increase biodiversity through planting dipterocarps and to maintain them, yet it has been at a cost of loosing families on the treated area. The result indicated that maintaining the treated area through slashing and girdling decrease the number of families. Although, another reason for the lower number of families might be that more open areas were chosen for the gaps or artificially created and therefore less families were found ten years later in the treated area.

Considering all species, a few more were found in the rehabilitated area compared to the non rehabilitated area, unlike for families where more were found in non- rehabilitated area, but for all species no significant difference could be found. One reason why no statistically significant difference was found could be that processes of natural regeneration are always active in the rainforest, thus gaps are promptly filled (Ashton 1998). The difference of dipterocarp species between the treatments was another matter, here a strong significant difference was found. In average almost the double amount of dipterocarp species were found in treated areas. Outcomes which further strengthen the result of a higher number of dipterocarp species found in the rehabilitated area were the number of unique species found in each treatment. In the rehabilitated area, a majority of the unique species belonged to the dipterocarp family and the reverse could be seen in the non rehabilitated area- few species belonged to the dipterocarp family. The double amount of dipterocarps and the higher number of unique dipterocarps which were found in the rehabilitated area indicates that the enrichment planting probably have contributed to a higher biodiversity in the inventoried subareas.

A tendency with 300 more stems in the untreated area was found. Certain species, not belonging to the dipterocarp family, had far more number of stems in the untreated area compared to the treated area and the reason could once again be the regular restock of natural regeneration (Ashton 1998). The reason why there were so many more stems of some species in the untreated area could be explained by the fact that species not belonging to the dipterocarp species, have been removed through slashing in the enrichment planted areas. A second reason could be that these species prefer the environment in the non-rehabilitated area. Another explanation could also be that more open areas were chosen for the gaps or artificially created and therefore there were less number of stems of these species in the treated area.

In the project area there was clearly a natural regeneration of dipterocarps. Although the enrichment planting had a higher number of stems of dipterocarps, the difference was not significant. Just comparing the natural regeneration there was almost 50 % more stems in the untreated area. Even though the directive of maintenance said that dipterocarps should not be slashed the result showed that it probably occurred. The largest part of natural regeneration of dipterocarps in both treatments was found in the class seedling. The large number of seedlings might indicate that there have been one or several mast fruitings of dipterocarps since the rehabilitation started. The location of dipterocarp trees which could act as seed source would have influenced the distribution of natural regeneration. The distribution of natural regeneration act to a great extent on a local scale as the result indicated (see appendix 7), at most 33 seedlings were found in one plot and in several plots no stems were found. The project area was disturbed in various extent and consequently there have been different amount of trees which could have acted as a seed source in the subareas. Therefore the natural regeneration of dipterocarps would have varied in the subareas, in some the regeneration would have contributed a great deal to the recovery of the degraded forest whereas in others the enrichment plantings would have been more important. Trees which could have acted as seed source and natural regeneration of dipterocarps in the project area might have been underestimated in 1999, before the enrichment planting was done. The natural regeneration and the fact that dipterocarp seedlings can survive more than ten years under a canopy might be a cause of why there was no statistical significance of number of stems of dipterocarps between the treatments.

Species from the *Macaranga* sp. genus generally dominates the secondary forests in Borneo (Slik *et al.* 2002, Slik & Eichhorn 2003). A study made 2002 by Romell, of the basal area on a small area at the INIKEA area showed that *Macaranga* sp. was the dominating genera (Romell 2007). The result of this inventory indicated that *Macaranga* sp. might still dominate amongst trees and canopy layer, at least in the untreated area. On the other hand there was evidently a scarce regeneration of the *Macaranga* genus in both the rehabilitated and non- rehabilitated area. Having dipterocarps dominating the forest and a scarce regeneration of *Macaranga* sp. point to that the secondary forest have moved to a new phase of succession since the disturbances.

The distribution of stems in the four classes (seedling, sapling, pole and tree) were not equal in the two treatments both considered all families and for the dipterocarps. Due to the effect of treatment, enrichment planting and maintenance, the distribution was not equal. The difference in distribution could also be an effect of that enrichment planting took place on more open sights; therefore hardly any saplings, poles or trees should have existed on the rehabilitated area ten years ago. Of the few trees found, 64 of 89 trees were found in the non-rehabilitated area. This was a result of trees being girdled and more open sights were chosen or artificially created for the enrichment planting. A third reason why only a small number of trees were found in the rehabilitated area was because very few seedlings planted 10 years ago had yet reached the size of a tree. Of all families there were significantly more stems of saplings in the non-rehabilitated area, possibly due to maintenance. All seedlings and saplings not belonging to the dipterocarps in the treated area got slashed, therefore more saplings were found in treatment B. A second reason might, once again, be that more open sights were chosen for the gaps or artificially created. Of the dipterocarps the reverse result could be seen of saplings, there was a tendency with 77 % more stems in treatment A. In general the interaction treatment by subarea was highly significant which means that the differences between the treatments were dissimilar for the subareas, therefore it was difficult to get significant differences (see appendices 12 & 14). All the classes of dipterocarps except seedlings had a majority of planted stems, the explanation could be that planted dipterocarps been given an advantage in their growth taking away surrounding competition. An artificial opening around planted seedlings through slashing and girdling, seems to enhance the growth which gives an expectation that the area will recover faster than without rehabilitation. Partial reduction of sub canopy in a secondary *Macaranga* sp. forest is found to have a positive effect on dipterocarp seedlings; survival, height and biomass increment (Romell 2007). Canopy treatment using both girdling and felling trees in the same study had a positive effect on the light condition and height increment but no positive influence on survival could be found (Romell 2007).

The distribution of climax species varies in a burnt forest. Slik & Eichorn (2003) found that the density of climax tree species were low on hills and ridges but high in swamps and river valleys. Based on the information that the degradation in the project area varied, some areas were logged, others burnt and some areas were almost untouched, the forest structure and also the distribution of climax species would differ in the project area. The degree of disturbance, the distribution of patches of untouched forest and climax species in the area, will affect the time of recovery. Studies of secondary forest differ in outcome of their results. Brown & Lugo (1990) found that secondary forest can recover within a span of 80 years or less. At this time the forest had approached the number of woody species as a mature forest inhabits, some areas had even more species then before the disturbance. If the disturbance is not too intense, for example once burnt or logged-over primary forest, the tree species composition might be distorted but the recovery still appeared to be good (Woods 1989; Slik *et al.* 2002; Slik *et al.* 2003). However, if the disturbance has been too intense or too frequent, the recovery of forest does not have the same prospect (Woods 1989; Slik *et al.* 2002; Slik *et al.* 2003). Based on this information, areas in the rehabilitation project which have both been logged and severely burnt have probably been in need of both enrichment planting and maintenance, whereas areas which have been disturbed by either logging or fire, might only have been in need of liberation and not enrichment planting. It can be mentioned that, as the map in Fig. 3 shows, liberation was performed in areas where a satisfying natural regeneration was found. The result of this study showed that there was a natural regeneration of dipterocarps on the areas which were inventoried and the number of stems did not differ between rehabilitated and non-rehabilitated areas. Yet, it should not be forgotten that the main objective with the rehabilitation is to enhance the biodiversity in the area through planting dipterocarps. Hopefully the higher number of dipterocarp species found on the rehabilitated area will do so. However, can the economical resources which are put in the project of planting seedlings and maintaining them for ten years be justified? It might be more reasonable in some subareas to liberate the natural regeneration of dipterocarps which exists today.

Data uncertainties

One of the difficulties with this study was that there was no reference area and no proper inventory done before treating the area. Using untreated area in between treated as a reference, solved a part of the dilemma, however, girdled trees close to the lines and gaps have not only affected the treated area but also the untreated which have to be considered.

The rehabilitated area in reality consists of the treated and untreated area and is therefore a mixture of both.

The two enrichments methods used in the project area was unlike, which might have affected the results. At certain circumstances in gap cluster planting, no plots could be inventoried due to that no treated area existed and therefore no gap could be located. There was no such problem in line-planting due to the whole line had been treated with slashing and girdling. However, in a gap, three planted seedlings could exist in plot A, whereas in line planting a maximum of one planted seedling could exist in plot A, this have probably affected the result in some extent.

Not being able to identify species is and has been a problem in the tropics due to species richness. In this study, five percent could not be identified at all. In total few species were found compared to other studies made in Borneo (Slik et al 2003; Forshed 2006). Some individuals could only be identified belonging to a certain family or genera. A reason for the low number of species might be the severe degradation the forest suffered from both fire and logging. Areas which have been degraded of repeated disturbances have had a decline of number of species (Woods 1989; Slik *et al.* 2002; Slik *et al.* 2003). However, mistakes of species identification can have been made and could have caused the low number of species found.

For further studies a suggestion is to run an ANOVA for each enrichment method. Preliminary result shows that there are differences in some of the variables compared to the results presented in this thesis. Although in this study the objective was to investigate how the enrichment planting of both line and gap cluster planting and the maintenance have contributed to the rehabilitated area.

Conclusions

- The enrichment planting method did not increase the number of stems (stems includes the four size classes), neither considering all species nor dipterocarps solely.
- The number of families in the treated area might have decreased due to maintenance.
- In some of the subareas there might already be an adequate regeneration of dipterocarps and therefore enrichment planting is not necessary in these areas.
- The enrichment planting of dipterocarps significantly increased the number of dipterocarp species in treated areas.
- The planted seedlings got a growth advantage through the liberation process compared to natural un-liberated seedlings.
- Enrichment planting in a line or gap system combined with maintenance is a possible way to rehabilitate a secondary dipterocarp rainforest.

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Appendices

Appendix 1. Shows data for the 17 subareas inventoried; the total area, enrichment method used, which month in 1999 the area was planted, number of lines, number time of slashing and girdling during a ten years period

Subarea	Total area (ha)	Method	Planted	Amount of Lines	No of slashing	No of girdling
2C	37,5	Gap	Feb 1999	34	9	3
2E	26,4	Gap	Mar 1999	33	8	3
3A	30,9	Gap	Sep 1999	76	11	2
3B	53,9	Gap	Jan 1999	79	8	3
3C	17,7	Gap	Mar 1999	47	9	3
3D	14,2	Gap	Mar 1999	28	8	3
4A	10,3	Gap	Mar 1999	42	8	3
4B	11,4	Line	Dec 1999	41	8	3
5A	29,9	Gap	Apr 1999	46	9	2
5B	29,5	Gap	Dec 1999	40	8	2
5C	26,3	Gap	Nov 1999	39	8	2
6A	19,1	Line	Maj 1999	75	11	2
6B	24,0	Gap	Maj 1999	28	7	1
6C	41,8	Gap	Jun 1999	62	7	1
6D	56,4	Gap	Jul 1999	74	10	1
6E	94,3	Gap	Okt 1999	164	12	4
Demo 2	17,8	Mix	Jan 1999	62	10	2

Appendix 2. ANOVOA- table for number of families per plot according to model 1

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Treatment (A/B)	1	11,26	11,644	11,644	7,12	0,012 x
Subarea	16	230,674	184,426	11,527	4,33	0,007 x
Treatment (A/B)* Subarea	16	25,473	25,833	1,615	0,78	0,700 x
Line nr (Subarea)	29	93,167	93,167	3,213	1,13	0,351 x
Treatment (A/B)* Line nr (Subarea)	29	61,938	61,938	2,136	1,53	0,042
ID (Subarea Line nr)	416	879,978	879,987	2,115	1,51	0
Error	416	582,329	582,329	1,4		
Total	923	1884,818				

Appendix 3. The 17 subareas inventoried and in each, number of families in total and separated in treatment A (rehabilitated area) and B (non- rehabilitated area)

Subarea	No of families in treatment A	No of families in treatment B	Total no of families
2C	16	19	21
2E	14	13	18
3A	15	18	21
3B	13	19	21
3C	17	16	21
3D	8	10	12
4A	7	11	12
4B	13	15	18
5A	13	21	23
5B	16	19	21
5C	15	20	21
6A	13	21	23
6B	5	9	11
6C	13	18	18
6D	18	27	27
6E	19	20	25
Demo 2	13	13	14

Appendix 4. ANOVOA- table for number of all species per plot according to model 1

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Treatment (A/B)	1	1,251	0,002	0,002	0	0,979 x
Subarea	16	363,407	289,252	18,078	4,79	0,002 x
Treatment (A/B)* Subarea	16	39,872	40,912	2,557	1,08	0,413 x
Line nr (Subarea)	29	105,913	105,913	3,652	1,02	0,457 x
Treatment (A/B)* Line nr (Subarea)	29	70,352	70,352	2,426	1,42	0,076
ID (Subarea Line nr)	416	1184,784	1184,784	2,848	1,67	0
Error	416	711,525	711,525	1,71		
Total	923	2477,104				

Appendix 5. ANOVOA- table for number of dipterocarp species per plot according to model 1

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Treatment (A/B)	1	51,9058	46,9536	46,9536	30,95	0,000 x
Subarea	16	82,1639	75,2052	4,7003	1,87	0,086 x
Treatment (A/B)* Subarea	16	30,2237	29,8221	1,8639	2,82	0,006 x
Line nr (Subarea)	29	39,6414	39,6414	1,3669	1,49	0,108 x
Treatment (A/B)* Line nr (Subarea)	29	19,6941	19,6941	0,6791	1,62	0,024
ID (Subarea Line nr)	416	273,6546	273,6546	0,6578	1,57	0
Error	416	174,6763	174,6763	0,4199		
Total	923	671,96				

Appendix 6. All families and species found in the 924 plots and the number of stems of each family and species found in treatment A (rehabilitated area) and B (non- rehabilitated area) are noted

Family	Species	A	B
Alangiaceae		**4**	**8**
	Alangium javanicum	4	8
Anacardiaceae		**18**	**24**
	Gluta wallichii	1	5
	Koordersiodendron pinnatum	11	15
	Parishia insignis	6	4
Annonaceae		**28**	**36**
	Annonaceae	28	36
Apocynaceae			1
	Alstonia spatulata		1
Bombacaceae		**2**	**4**
	Durio sp	2	4
Burseraceae		20	33
	Canarium sp	20	33
Chrysobalanaceae			**5**
	Parinari oblongifolia		5
Crypteroniaceae		**2**	**8**
	Dactylocladus stenostachys	2	8
Dilleniaceae		19	42
	Dillenia excelsa	19	42
Dipterocarpaceae		**680**	**559**
	Diptercarpus caudiferus	5	3
	Dipterocarpus applanatus		5
	Dipterocarpus conformis	1	
	Dipterocarpus globosus		4
	Dipterocarpus sp	5	
	Dryobalanops keithii	67	79
	Dryobalanops lanceolata	78	83
	Hopea nervosa	21	
	Hopea sangal	12	
	Hopea sp	37	65
	Parashorea malaanonan	34	28
	Parashorea smythiesii	107	60
	Parashorea tomentella	69	50
	Shorea agamii		2
	Shorea argentifolia	5	1
	Shorea beccariana	2	3
	Shorea faguetiana	1	
	Shorea falciferoides	24	5
	Shorea fallax	38	12
	Shorea gibbosa	19	31
	Shorea johorensis	7	1

	Shorea leprosula	19	12
	Shorea leptoderma	10	6
	Shorea macrophylla	3	3
	Shorea macroptera	12	7
	Shorea ovalis	2	
	Shorea parvifolia	14	15
	Shorea pauciflora	8	4
	Shorea platyclados	2	
	Shorea seminis	15	
	Shorea smithiana	2	
	Shorea sp	51	75
	Shorea superba	7	5
	Shorea xanthophylla	2	
	Vatica sp	1	
Ebenaceae		**5**	**22**
	Diospyros sp	5	22
Euphorbiaceae		**214**	**406**
	Aporusa grandistipula	4	15
	Baccaurea parviflora	6	22
	Endospermum diadenum	4	
	Koilodepas longifolium	74	145
	Macaranga sp	5	21
	Mallotus miquelianus	85	117
	Mallotus sp	3	15
	Mallotus wrayi	33	71
Fagaceae		**14**	**17**
	Lithocarpus sp	14	17
Flacourtiaceae		**14**	**18**
	Ryparosa acuminata	14	18
Lauraceae		13	45
	Actinodaphne	1	11
	Alseodaphne bancana		1
	Eusideroxylon zwageri	12	33
Leeaceae		**64**	**55**
	Leea indica	64	55
Leguminosae		42	27
	Copaifera palustris	4	4
	Croton argyratus	28	14
	Cynometra inaequifolia	6	4
	Koompassia excelsa	4	5
Melastomataceae		**2**	**12**
	Pternandra coerulescens	2	12
Meliaceae		**13**	**4**
	Aglaia sp	11	4
	Walsura pinnata	2	
Moraceae		**98**	**91**

	Artocarpus anisophyllus	12	13
	Ficus sp	81	76
	Parartocarpus bracteatus	5	2
Myrcinaceae		**3**	**9**
	Ardisia elliptica	3	9
Myristicaceae		**1**	**8**
	Myristica iners	1	8
Myrtaceae		**99**	**122**
	Eugenia sp	99	122
Rubiaceae		**91**	**161**
	Nauciea subdita	3	
	Neolamarckia cadamba		1
	Neonauclea bernardoi	2	20
	Praravinia sp	86	140
Sapindaceae			**3**
	Nephelium mutabile		3
Sapotaceae		**6**	**50**
	Palaquium gutta	6	50
Saurauiaceae		**76**	**78**
	Saurauia ferox	76	78
Simaroubaceae		**2**	**5**
	Eurycoma longifolia	2	5
Sonneratiaceae		**2**	**3**
	Duabanga moluccanan	2	3
Sterculiaceae		**12**	**7**
	Heritiera simplicifolia	6	6
	Pterospermum sp	6	1
Symplocaceae		**4**	**3**
	Symplocos fasciculata	4	3
Tiliaceae		**51**	**32**
	Microcos crassifolia		2
	Pentace adenophora	23	16
	Pentace laxiflora	28	14
Unidentified		**109**	**94**
	Unidentified	109	94
Verbenaceae		**1**	**9**
	Geunsia pentandra	1	9

Appendix 7. ANOVOA- table for number of stems per plot according to model 1

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Treatment (A/B)	1	90,391	71,512	71,512	3,55	0,074 x
Subarea	16	2710,427	2303,164	143,948	5,02	0,001 x
Treatment (A/B)* Subarea	16	362,664	389,529	24,346	2,97	0,004 x
Line nr (Subarea)	29	358,585	358,585	12,365	0,87	0,658 x
Treatment (A/B)* Line nr (Subarea)	29	237,833	237,833	8,201	1	0,462
ID (Subarea Line nr)	416	5918,176	5918,176	14,226	1,74	0
Error	416	3396,612	3396,612	8,165		
Total	923	13074,687				

Appendix 8. Number of stems separated between treatment A (rehabilitated area) and B (non- rehabilitated area) in each subarea inventoried

Subarea	No of stems in treatment A	No stems of in treatment B
2C	115	121
2E	83	72
3A	134	190
3B	133	160
3C	192	319
3D	39	24
4A	28	43
4B	84	94
5A	48	68
5B	164	148
5C	90	94
6A	85	80
6B	24	35
6C	117	108
6D	130	168
6E	162	209
Demo 2	81	68

Appendix 9. ANOVOA- table for number of dipterocarp stems per plot according to model 1

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Treatment (A/B)	1	15,845	13,045	13,045	1,2	0,286 x
Subarea	16	666,923	573,744	35,861	1,84	0,082 x
Treatment (A/B)* Subarea	16	234,764	213,797	13,362	3,23	0,002 x
Line nr (Subarea)	29	304,243	304,243	10,491	1,26	0,203 x
Treatment (A/B)* Line nr (Subarea)	29	121,902	121,902	4,204	1,3	0,143
ID (Subarea Line nr)	416	3060,948	3060,948	7,358	2,27	0
Error	416	1348,988	1348,988	3,243		
Total	923	5753,614				

Appendix 10. Number of *Dipterocarpaceae* stems separated between treatment A (rehabilitated area) and B (non- rehabilitated area) in each subarea inventoried.

Subarea	Dipterocarps in treatment A	Dipterocarps in treatment B
2C	47	36
2E	37	10
3A	40	48
3B	89	60
3C	59	148
3D	18	2
4A	8	13
4B	33	15
5A	10	0
5B	48	36
5C	34	20
6A	37	17
6B	15	18
6C	71	38
6D	57	47
6E	64	49
Demo 2	13	2

Appendix 11. ANOVOA- table for number of seedlings of all families per plot according to model 1

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Treatment (A/B)	1	0,277	11,144	11,144	0,79	0,383 x
Subarea	16	2130,021	1808,123	113,008	5,65	0,000 x
Treatment (A/B)* Subarea	16	233,727	265,857	16,616	2,69	0,007 x
Line nr (Subarea)	29	271,25	271,25	9,353	0,82	0,716 x
Treatment (A/B)* Line nr (Subarea)	29	177,174	177,174	6,109	0,87	0,656
ID (Subarea Line nr)	416	5093,062	5093,062	12,243	1,75	0
Error	416	2904,822	2904,822	6,983		
Total	923	10810,333				

Appendix 12 . ANOVOA- table for number of saplings of all families per plot according to model 1

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Treatment (A/B)	1	67,101	25,335	25,335	6,11	0,023 x
Subarea	16	116,225	104,472	6,53	1,28	0,319 x
Treatment (A/B)* Subarea	16	84,3	81,852	5,116	3,62	0,001 x
Line nr (Subarea)	29	39,826	39,826	1,373	0,77	0,761 x
Treatment (A/B)* Line nr (Subarea)	29	41,109	41,109	1,418	1,05	0,399
ID (Subarea Line nr)	416	709,487	709,487	1,706	1,26	0,009
Error	416	561,99	561,99	561,99	1,351	
Total	923	1620,427				

Appendix 13. ANOVOA- table for number of number seedlings of dipterocarps per plot according to model 1

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Treatment (A/B)	1	0,91	1,043	1,043	0,19	0,666 x
Subarea	16	404,085	346,197	21,637	1,82	0,078 x
Treatment (A/B)* Subarea	16	115,758	102,578	6,411	2,37	0,017 x
Line nr (Subarea)	29	240,911	240,911	8,307	1,27	0,184 x
Treatment (A/B)* Line nr (Subarea)	29	78,678	78,678	2,713	1,06	0,39
ID (Subarea Line nr)	416	2653,858	2653,858	6,379	2,48	0
Error	416	1069,154	1069,154	2,57		
Total	923	4563,354				

Appendix 14. ANOVOA- table for number of number saplings of dipterocarps per plot according to model 1

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Treatment (A/B)	1	12,8582	9,4884	9,4884	4,23	0,054 x
Subarea	16	57,8309	53,5519	3,347	1,15	0,390 x
Treatment (A/B)* Subarea	16	46,0057	45,0747	2,8172	5,22	0,000 x
Line nr (Subarea)	29	17,9964	17,9964	0,6206	0,9	0,614 x
Treatment (A/B)* Line nr (Subarea)	29	15,3976	15,3976	0,531	0,82	0,735
ID (Subarea Line nr)	416	335,9054	335,9054	0,8075	1,25	0,012
Error	416	269,2385	269,2385	0,6472		
Total	923	755,2327				

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