Examensarbeten 2015:4

Fakulteten för skogsvetenskap
Institutionen för skogens ekologi och skötsel

Do 25 years old skid tracks restrict growth and survival?

- A study on growth conditions for the planted regeneration in a rainforest rehabilitation project

Foto: Malin Boström

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Do 25 years old skid tracks restrict growth and survival?

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Begränsar 25 år gamla skotningsvägar tillväxt och överlevnad?

- En studie av den planterade återväxtens förutsättningar i ett rehabiliteringsprojekt av regnskog

Malin Boström

Nyckelord / *Keywords:*

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Preface

The realization of this thesis has sometimes been painful but also very rewarding The things I have learnt and all the people I have met during this journey has made it all worthwhile. I therefore which to send a special thank you to:

My fantastic field team who always tried their best even when we did not understand each other. I am grateful for your patience when I did not know what I was doing. -Without you I would still be lost in the forest.

All the villagers in Luasong who were always willing to help. -Your hospitality and commitment helped make 12hour workdays seem like a vacation.

Li for sharing this adventure with me, even if I sometimes struggled to keep up. Your energy and positive attitude makes you a fantastic traveling partner.

My very patient supervisors which I know did more than required, and especially Malin for sharing her data with me and letting me be part of her project.

All my friends that helped me push through even when it seemed hopeless, cheered me up when things went wrong and celebrated the good days with me.

Abstract
The rainforests of the world are important not only to the countries in which they grow but to the world as a whole. They influence oxygen and water circulation as well as carbon sequestration which in turn affect global radiation and global warming. The forest also have great value and in Malaysia as in many other tropical countries large volumes are harvested which leaves great areas of degraded forest with little growth and biological diversity. Due to their low financial value these forests are often transformed and used for other purposes than forestry such as oil palm plantations.

The trees are often transported out of the forest using large bulldozers. They are heavy which causes compaction of the forest floor and during transport the top soil layers are moved to improve mobility. In the years that follows runoff in the skid tracks can be high and leaking of nutrients and other material is often higher in the skid tracks compared to outside. This causes negative effects on the regeneration in terms of growth, survival and diversity. The effects can remain for many years after logging.

In Sabah on Malaysian Borneo a project to rehabilitate forest and restore forest values is running. The project combines replanting trees of high ecosystem values with research. The targeted area has been affected by both logging and forest fires in the eighties but has since then been left until the rehabilitation operation in 1998. One of the methods used is planting in two meters wide cleared lines. This study has been made within this project and focus on the mortality and growth on skid tracks. Is there a detectable difference? Is the ground still more compacted on the skid tracks? Is there any difference in the conditions that might affect growth and mortality such as levels of organic carbon, nitrogen phosphorus and clay?

The location of this study is in an east facing slope that in parts connect to a creak at the bottom. This area was planted in 2008. For all the planted trees in the area light conditions, height, diameter at breast height (Dbh), species and mortality has been recorded as well as whether or not the plant is located on skid track. Ten species has been selected for a more thorough investigation.For each of these species 16 specimens have been choosen and in the soil surrounding these penetration resistance has been measured and soil samples has been taken to measure bulk density and levels of phosphorus, nitrogen and organic carbon.

The results showed no detectable difference in mortality but the trees were both higher and had a larger Dbh on the skid tracks. Light was also higher on skid tracks which could be part of the reason of the higher growth as light showed to increase both Dbh and height. Of the other tested variables only penetration resistance showed correlation with skid tracks. The resistance was higher on the tracks which might be explained by the uneven distribution of skid tracks with more tracks located at the bottom of the slope where there is more sand in the ground.

There was no detectable correlation between any of the tested variables and mortality. Apart from light higher bulk density and lower amounts of organic carbon and available phosphorus was correlated with higher growth. However all the tested soil properties, apart from penetration resistance, showed to be correlated and it is possible that growth is strongly affected with something else that is in turn connected to the measured variables.

Sammanfattning

Världens regnskogar är viktiga tillgångar inte bara för de länder där de växer utan de påverkar även jorden som helhet. De har stor inverkan på syrets och vattnets kretslopp vilket i sin tur påverkar den globala instrålningen. Men regnskogen har också stora ekonomiska värden. I Malaysia liksom i många andra tropiska länder avverkas stora virkesvolymer vilket skapar stora arealer med restskogar som har låg tillväxt och biodiversitet. På grund av dess låga värde omvandlas dessa ofta till andra användningsområden som t.ex. palmplantager istället för att återbygga dess värden.

Virket transporteras ut ur skogen med hjälp av bulldozers med schaktblad vilket skapar negativa effekter som kan bli kvar i många år. På många ställen flyttas de övre jordskikten undan och de tunga transporterna gör att marken blir mer kompakt. Återväxten är ofta sämre och mindre diversifierad på stickvägar jämfört med utanför stickvägarna. Förlust av näring och andra ämnen till följd av bortspolning är också högre på stickvägarna.

I Sabah på Malaysiska Borneo pågår ett projekt med aktiv rehabilitering och återplantering parallellt med forskning om återväxt, tillväxt och diversitet. Området har varit utsatt för både avverkning och skogsbrand under åttiotalet men sedan lämnats orört fram till 1998 när rehabiliteringen började. En av de metoder som används för att öka biodiversiteten är att med tio meters mellanrum röja upp öppningar i form av två meter breda linjer i vilka man sedan planterar trädarter som anses vara ekologiskt vikiga. Denna uppsats är gjord inom projektets ramar och fokuserar tillväxt på och överlevnad på och utanför skotningsvägarna. Är det någon skillnad? Är det fortfarande mer kompakt i skotarvägarna än utanför efter 25år? Är det skillnad i kväve, fosfor och lera.

Det undersökta området planterades 2008 och ligger i en östlig sluttning med den nedre delen delvis i anslutning till ett vattendrag. För alla plantor i området har ljusförhållanden, höjd, brösthöjdsdiameter (Dbh), art och överlevnad registrerats samt om planteringsplatsen är på en skotningsväg. Tio arter har valts ut för mer utförliga tester och vid 16 individer av var och en av dessa arter har även jordprover tagits och penetrationsmotstånd mätts. Ur jordproverna har bulkdensiteten samt halterna av lera, fosfor, kväve och organiskt kol beräknats.

Resultaten visade ingen skillnad i överlevnad men att träden var högre och hade större Dbh på skotningsvägarna. Detta kan bero på att det var högre ljusinsläpp på skotningsvägarna, och ljus visade påverka både Dbh och höjd positivt. Av de övriga testade variablerna var det bara penetrationsmotståndet som visade signifikanta skillnader mellan de platser som testades på och utanför skotningsvägar. Motståndet var lägre på skotningsvägarna vilket till viss del kan förklaras av att de var ojämnt distribuerade och att den största andelen vägar fanns längst ner i sluttningen där sandhalten var högre.

Ingen påverkan på överlevnaden kunde visas för någon av de testade variablerna. Förutom ljuset visade sig högre bulkdensitet och lägre halter av tillgängligt fosfor och kol vara kopplat till högre tillväxt. Samtliga jordvariabler var dock kopplade till varandra och vilken om någon av dessa som har störst påverkan på tillväxt är svårt att avgöra. Det är möjligt att någon annan, otestad variabel som är kopplad till den mätta markkemin har avgörande effekt.

Table of content

1. Introduction

1.1 Background

Rainforest play an important role in the water and oxygen circulation in the world (Bonan 2008). Changes in the forest cover cause changes in cloudiness, net radiation income and other variables participating in the complex system of global warming (Bonan 2008).

The removal of rainforest has also been shown to influence atmospheric emissions of greenhouse gases such as carbon dioxide (Haugston 1991, deFries et al. 2002) and methane (Goreau & Mello 1988). In fact, deforestation and land conversion is the second largest anthropological factor to carbon emissions (Le Quéré el al. 2009). However the potential economic values from rainforest removal can be big, both from logging and by creating other uses for the land (Peters et al. 1989, King 1993).

Malaysia has a large number of endemic species and many researchers consider it to be one of the most important ecosystems in the world (Myers et al. 2000, Mittermeier et al. 2011). Logging is an important income for Malaysia, and the revenue is a bit more than 244 million US$/year (FAO 2010a).

Logging in Malaysia is usually done by harvesting the valuable trees while leaving less valuable trees behind (Sist et al. 2002). Many of the trees left are damaged due to little consideration in the harvesting process and the crawler tractors used to transport the trees out of the forest cause heavy scarring on the land (Sist et al. 2002). The logged over forest is often degraded with lower biodiversity and production (Lamb et al. 2005, Sands 2005). After harvest there is an increase in dead trees and debris on the forest floor. The canopy is also more open which means that the wind speed can be higher. This combination makes logged forests more prone to forest fires which cause further degradation (Woods 1989, Cortlett & Primack 2011).

The degradation can be reversed by rehabilitation (ITTO 2002). By replanting the land it is possible to close the scarring and reduce further damage from mudslides and water runoff. When this is done with the use of species that are important for the ecosystem it is possible to combine this while increasing and restoring both production and biodiversity (ITTO 2002).

These low-values forests are often converted in to other uses (Cortlett & Primack 2011) and there has been a slow but steady decrease in forested area in Malaysia from 1990 to 2010 (FAO 2010b). In 1999 the largest factor driving forest decrease was the plantation of oil palms (McMorrow &Talip 2001), and the area transformed to oil palm plantation is increasing (Morel et al. 2012). Out of the total surface of 32,856 million ha (FAO 2010b) 5 million was planted with oil palms in Malaysia 2011 (Malaysian Palm Oil Board 2013). This translates to more than 15 % and there is still a steady increase.

The removal and degradation of forests causes loss of habitat but also an increased fragmentation in the area which in turn poses a long term threat to many species as this limits genetic exchange (Sands 2005, Cortlett & Primack 2011). As the human population is growing, the pressure of effectiveness on each piece of land increases regardless of the use (Sands 2005). Forests with little value both economically and environmentally therefore need to be rehabilitated to compensate for the forests lost through conversion (Lamb et al. 2005).

1.2 Growth and survival in logged over forests

1.2.1 Growth

After logging recovery is poorer in species richness on skid tracks and log transport roads and the effect can still be seen after more than 15 years (Guariguata 1997, Pinard et al. 2000).The difference between skid tracks and the surrounding forest can also be seen in species composition where different species are more frequent in one location than the other (Pinard et al. 2000). This stresses the importance of active rehabilitation.

Rehabilitation is usually done by planting trees with high biodiversity values and the success of rehabilitation depends on achieving sufficient growth and survival of the planted trees (ITTO 2002). Tree growth is limited by a wide range of parameters such as light (Kobe 1999), soil properties, nutrient availability, water availability (Toledo et al. 2011), and interaction with other organisms (Raven et al. 2005). Which composition of site parameters that is the ultimate and the response to changes varies between species (Nussbaum et al. 1995, Poorter 1999). In many species the response also differs with age or size (Taiz & Zeiger 2006).

1.2.2 Light

Light is one of the most important regulators of growth and the driving force of many ecosystems. With the energy input from the sun's radiation carbohydrates are built in the photosynthesis (Raven et al. 2005). The carbohydrates, and thereby the energy stored in them, can then be transported and transformed to store or release energy in other places in the organism (Raven et al. 2005). As the organism is consumed or decomposed this energy is made available to other organisms and reactions.

Primary rainforests are uneven in height, density and species distribution (Richards 1996). This gives very different light conditions in different areas of the forest. The effect of a certain light composition differs between species (Taiz & Zeiger 2006).Whereas plants of some species can tolerate darker areas others need gaps with plenty of light to develop (Ghasoul & Sheil 2011). Species with high demands for light usually have high mortality but quick growth for the plants that survive (Rost et al. 2006).

1.2.3 Soil

Nutrient availability and composition in the rainforest soil largely depends on the age of the soil (Richardson et al. 2004) and the characteristics of the bedrock as well as biotic life at the site (Brady & Weil 2002).

When felling the rainforest regardless of reason a broad variety of changes are done in the soil. Some physical examples are increased erosion, compaction by heavy machinery (Malmer 1996, Pinard et al. 2000) and changes in the litter layer (Pinard et al. 2000). Chemical effects of logging are changes in the soil nutrient cycling and increased leakage of important nutrients such as nitrogen, potassium, calcium and magnesium (Malmer 1996). The effect is most prevalent in skid tracks (Malmer 1996, Pinard et al. 2000). The low amounts of nutrients on skid tracks have been shown to restrict seedling development (Nussbaum et al. 1995).

Resident soil properties also play an important role in an ecosystems capacity to recover. The soil's capacity to hold water and nutrients depend largely on bulk density and soil type. It also affects mobility for water and nutrients (Brady & Weil 2002). Water availability is a limiting factor for growth and survival even in an undisturbed rainforest (Nakagawa et al. 2000). Especially in the seedling phase water shortage can have large effects on survival (Ioth 1995).

Nitrogen is one of the essential macro nutrients and plays a vital role in many functions as part of chlorophyll, amino acids, proteins and more (Raven et al. 2005) and low amounts of nitrogen can have a negative effect on survival in rainforest although primarily in interaction with other conditions (Ceccon et al. 2004). This in combination with increased nitrogen leakage caused by the deforestation, the nitrogen lost in the fires and the removal of nitrogen with the harvested trees suggest that there could be a nitrogen deficiency on logged over areas. As the leakage often is bigger in the skid tracks (Malmer 1996) it is likely that the deficiency would be even higher in those.

Phosphorus is commonly limiting growth in tropical rainforest (Baker et al. 2003). Phosphorus becomes available to the ecosystem from weathering minerals (Armson 1977). In undisturbed forests the, to plants available, phosphorus is relatively constant and sufficient to the ecosystem as the recycling through decomposition and uptake by plants is equal (Brady & Weil 2002). As a result of logging of the rainforest phosphorus is lost from the system by the removal of the trees but also from leakage and erosion (Malmer 1996). It has also been shown that shortages of phosphorus can have a negative effect on seedling survival (Ceccon et al. 2004).

Nutrient circulation in the rainforest is extremely efficient and soil organic carbon plays a vital role in this by acting as a type of storage (Ghazoul & Sheil 2011). Organic matter is also the source of carbon and nutrients for all organisms in the soil as it decomposes (Brady & Weil 2002). Just as for nutrients, carbon is removed with the harvested trees but also by leaking from the damaged soil (Douglas et al. 1992). By removing the trees the soil is deprived of carbon sources both from the constant litter fall and from the tree itself as it decomposes upon death. In time soil organic carbon increases in the soil as the succession develops (Lamb 1980).

Clay and organic compounds both affects the soil's physical as well as chemical properties and resistance to environmental changes. The amount and properties of clay and organic compounds affect the soil ion exchange capability (which in turn affect the nutrient availability), penetration resistance and degree of aggregation (Armson 1977, Brady & Weil 2002). Clay and organic matter also plays an important role in aggregation of the soil.

The soil structure does not only set the frames for the chemical and biological processes that occur in the soil, it also has a physical impact on the organisms in it (Brady & Weil 2002). High densities in the soil, and thereby smaller pores, mean less aeration and thereby a decrease on oxygen and a buildup of toxic gases which has negative effects on the organisms (Brady & Weil 2002). Studies have shown that the bulk density, which largely depends on the proportion of pores, are higher the first years after logging and that pores are smaller on skid tracks (Matangaran & Kobayashi 1999, Ilstedt et al. 2004).Root growth can also be restricted by compaction as smaller pores make the soil less penetrable to the roots (Stirzaker et al. 1996).

Penetration resistance of the soil has been shown to be higher in skid tracks for many years after logging (Alexander 2012). As the root grows it invades and enlarges the pores of the soil. How hard this is depends on the soil's resistance to deformation (Brady & Weil 2002). In the penetration process the soil's resistance to deformation and pore size together sets the physical limitation for root growth and when the combined resistance is too high root growth is limited (Sinnett et al. 2008).

1.3 INIKEA Rehabilitation Project

There are a number of rehabilitation programs to rehabilitate degraded rainforests in the in the world. One of them is the INIKEA *Sow a seed project* (Alloysius et al. 2010). In a cooperation between the Swedish University of Agriculture and the Sow a seed project sponsored by IKEA and Yayasan Sabah there is a rehabilitation program started in 1998. The Program is located in the south east part of Sabah (fig. 1.1) in Borneo and consists of 18.500 ha connected forest. The area was first logged in the seventies and in the 1982/1983 drought it was burned by forest fires (Garcia & Falck 2003). A few years later a salvation logging was done to harvest economically valuable trees before losing their value from damages or death caused by the fires.

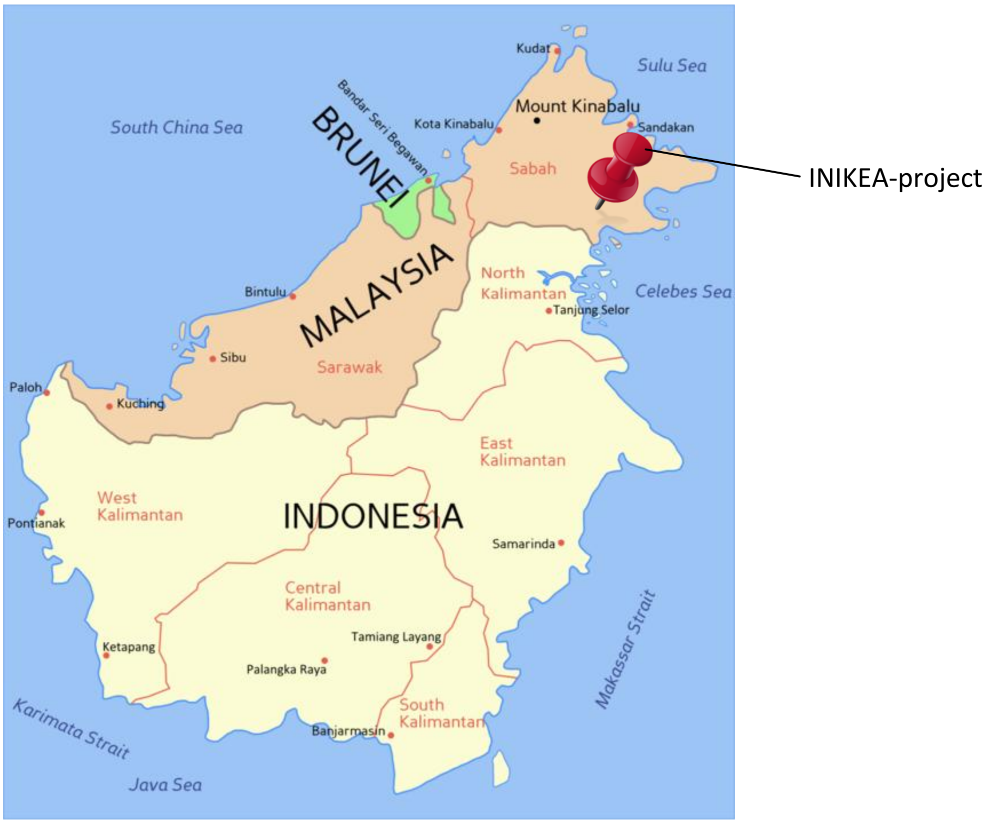

Figure 1.1. *Map of Borneo (Wikipedia commons 2012) and the location of the INIKEA rehabilitation project.*

The rehabilitation is carried out by enrichment planting underneath the remaining degraded stand in order to increase biodiversity (Alloysius et al. 2010). There are two planting strategies used in the program. The most common is the gap cluster method, where three plants of different species are planted in a gap. The gaps can be artificial, artificially enlarged or natural and are spaced at an average of ten meters (Alloysius et al. 2010). The other strategy is the line planting method in which plant competition is artificially reduced in evenly distributed lines in which the planting has been done.

One of the demands of the project is that it is cost effective and research that could increase the success rate is continuously being carried out and incorporated in the project (Alloysius et al. 2010). One example is a PhD project by Malin Gustafsson[1] that focuses on the effects of light. My study has been done in association with her project but targets the growth and survival on skid tracks in the area.

To sum up; It is well documented that trees growing on skid tracks are more negatively affected by logging than in the rest of the logged area, and that the regeneration is most affected. Although there are plenty of studies that investigate the immediate effects, few have been done on the long term effect of logging.

The following questions are addressed in this thesis:

Can the effects of skidding on soil properties, such as bulk density, penetration resistance, amounts of nitrogen, phosphorus and organic compounds, still be seen after 30 years?

Is growth and survival of the enrichment plants lower on the skid tracks?

Are there higher amounts of light that could influence survival and growth on the skid tracks?

[1] Phd student; Forest Ecology & Management, Swedish University of Agriculture

2. Materials and methods

2.1 Study area

The area studied was planted in 2008 with 34 species (attachment 1) using the line planting method. The studied area is located at lat 4°36´N, long 117°14'E and the precipitation is approximately 2890 mm/year (Romell 2007). Apart from research it is also used to demonstrate the efforts made by the INIKEA project and is known as the "species demo plot". Before planting preparation was made by the creation of 2 meter wide lines with a spacing of 10 meters from one center to the next (fig 2.1). A total of 37 lines were created and all lines runs from the creek and uphill. The plants were planted with a spacing of three meters with a total of 20 plants in each line. To reduce mortality of the rehabilitation spots marked for planting that are extremely steep or subject to much of the surface run off were considered to be unsuitable for planting and these spots was left out and the next spot was used. To ensure good rehabilitation results the area was inventoried and dead plants replaced after three months. Most plants was replaced with a new plant of the same species but if there was no new plants of the same species in the nursery as the dead plant another species was used.

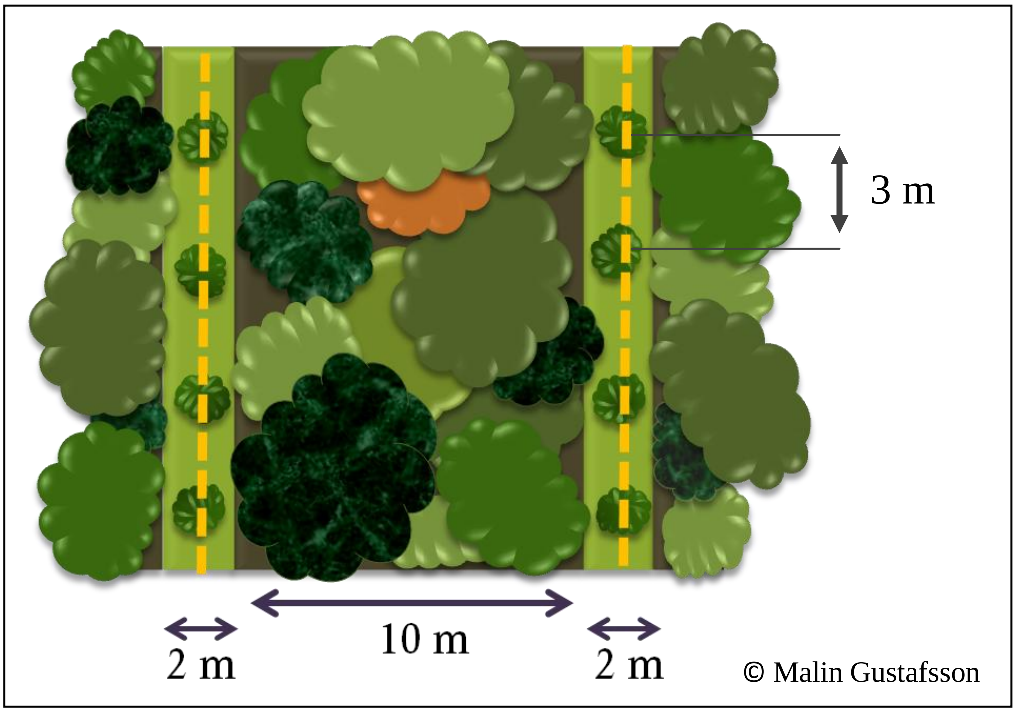

Figure 2.1 *View of the line planting method used in the INKEA rehabilitation project. The new trees are planted, with a spacing of three meters, in lines that have been cleared of small trees, bushes, shrubs and other competing vegetation before planting.*

The main part of the area studied was located in an east facing slope that ranges from moderately to very steep. A smaller part of the area, at the bottom of the slope, was relatively flat. The eastern border of the area was made up by a creek and some of the planting spots were only a few meters from the creek. At the steeper parts of the area some planted trees have died from mud sliding.

Out of the 37 lines only 34 lines were planted. In three lines a large number of spots marked for planting were considered to be unsuitable for planting and the entire line was left unplanted. The lines that were unplanted are 22, 23 and 30. The plants in each line were labeled with both tree number in the line from 1 to 20 and the spot number which included the unplanted spots. This means that although all lines consisted of 20 planted trees, the number of marked spots in the lines ranged from 20 to 34.

All plants used were collected either as seeds or wild seedlings in the field and brought up in the project nursery. The planting was done by hand in 2008. After three months dead plants were replaced. During the first two years weeding of competing vegetation was done three times per year by removing shrubs, bushes and smaller trees. The following years weeding were also carried out but less frequent as the plants were higher and the need was lower. In 2012, when the planted trees were well established, a shade adjustment was made to increase light and ensure continued good development.

In March 2012, before the shade adjustment, light measurements were made in the area by Malin Gustafsson using fisheye photos. She then calculated Ground cover using HemiWiew[2]. This is an estimation of proportion of the sky that is obscured by canopy and is explained in the Hemiway manual as *"the proportion of ground covered by canopy elements as seen from a great height".* As some of the trees of the planted trees are several meters high, and thereby higher than the measurement equipment, measurements at the stem of the trees planted in these spots would have shown the shade effect from the tree rather than on the tree. The fisheye photos were therefore taken at 1.5 meters distance from the plants (between the marked planting spots; see above) and an average of the photos taken on each side was used when calculating the Ground cover.

2.2 Field work

For this study the planted area was inventoried and for each planted spot it was registered whether or not the spot is located on a skid track or a waterway. Waterways were defined as areas where fast flowing water frequently flushes the litter layer away which gives the area unique properties. 15 of the 680 planted spots were classified as waterways and 228 were considered to be on skid track. This information was then combined with a map of what species was planted at each spot and the species that had at least eight individuals planted on skid tracks and at least eight individuals outside skid tracks out of which none was on waterways were selected for sampling.

The following nine species matched the requirements:

Dipterocarpus conformis
Dryobalanops lanceolata
Durio spp
Hopea ferruginea
Intsia palembanica
Shorea leptoderma
Shorea macrophylla
Shorea macroptera
Shorea xanthophylla

A tenth species, *Baccaurea angulata*, was selected despite having only seven individuals planted on skid tracks. For each of the nine species eight spots on skid track and eight spots

[2] HemiView 2.1; Delta-T Devices Ltd.

outside skid tracks were sampled, for *B. angulata* seven spots on skid track and nine outside were sampled.

Soil samples were collected directly underneath the organic layer in at a distance of 70cm from the stem or, if the plant was dead, the marked planting spot. To reduce the impact of sampling errors and local variations two samples were taken at each spot in different directions from the tree. The sampling was done using a cylinder with the volume of 100cm^3 and the samples were placed in a plastic bag which was then sealed and marked. Both samples were put in the same bag and from here on "sample" will refer to the combined sample.

The soil's physical restricting impact on root growth was measured in two ways. For the top soil the pore size was measured by calculating bulk density (see below) from the soil samples. For the deeper layers penetration resistance was measured using a penetrograph[3]. This way the soil's resistance to deformation was included in the measurements compared to only pore size.

At each selected planting spot soil penetration resistance was measured in five directions at a distance of 70cm from the stem or the marked planting spot. The graphs created were then manually transcribed to resistance at 5, 10, 15, 20, 25, 30, 40 & 50cm soil depth. For practical reasons (as the measuring is heavy work and 800 measurements were done) the highest recorded resistance was set to 70N/cm^2. The number of penetrations, of the five at each spot, which within the first 50cm had a resistance harder than passed 30, 50 and 70N/cm^2 was also recorded.

At the end of every day the samples collected were weighed including the plastic bag. The estimated weight of the bag was then subtracted to establish the weight of the actual sample. After this each sample was homogenized and then a small portion was weighed, dried over night at 105^{o}C and weighed again to establish water content and calculate dry weight for the entire sample. The dry weight was then used in the calculations of bulk density (see formulas below). Drying was done in tinfoil cups and each cup was weighed before adding the soil.

$$Bulk\ density = \frac{dry\ weight\ of\ sample}{volume\ (in\ these\ calculations\ 0{,}1dm^3)}$$

$$dry\ weight\ of\ sample =$$

$$= weight\ of\ sample\ before\ drying * \frac{weight\ of\ the\ portion\ after\ drying}{weight\ of\ the\ portion\ before\ drying}$$

The dried part of the samples were then packed in double plastic bags and sent to the Sabah Forest Department Research Center (FRC) at Sandakan for analyzes where the following analyzes where made; *Total Phosphorus* (TP) HNO3/HClO4 extraction.

[3] Penetrograph type Stiboka, 06.02 Eijkelkamp B.V., Netherlands

Available Phosphorus (AP) by NH_4Fl/HCl extraction. *Total Nitrogen* (TN) using CN-analyzer. *Organic carbon* (OC) by the Wakley-Black method. *Clay* by Particle size distribution (pipette method)

Parallel with the soil sampling and penetration measurements a large number of measurements were made on the planted trees in the area including status (live or dead) and height of live trees (Videkull 2014) diameter at breast height (Dbh) defined as diameter at 130cm has also been measured for the live trees that had reached this height. These measurements have been correlated and compared with the measurements of Ground cover as well as with the chemical and physical data collected at each spot.

Since different tree species grow at different rate new, relative, variables that take this into account was created. This was done by dividing each of the growth measurement (height and Dbh) with the corresponding mean for each species, creating relative Dbh (rDbh) and relative height (rHeight).

Many people have been involved in the collection of data and creation of variables. Due to misunderstandings and technical difficulties some data have been excluded in the analyzes. Two of the penetration graphs were unreadable due to rain. Two of the soil samples were excluded due to double labeling and three were contaminated in the lab. Some of the fisheye photos were considered to be too unfocused.

2.3 Analyzes

All collected data were entered into Excel[4]. This program was used to create the relative growth variables and mortality- and skid track maps.

Some of the parameters were used to create interpolation maps to facilitate visual comparisons. To create the interpolation maps line and mark number have been multiplied with the distance between them; ten meters for lines and three meters for mark number. These make up the axis in the maps, with the first marked number in the first line as origo.

Since some lines are longer than others the distance between the measured spots are often longer between spots with number higher than 20 than between those with lower numbers. To minimize the effect of this and to give the maps a consistent relevance all spot number higher than 23 has been disregarded in the creation of these. For the soil measurements nine spots were disregarded, for the growth and light variables 24 spots were disregarded. The target when selecting the spots for soil sampling was to have the same number of sampled spots on and outside skid tracks. This lead to an uneven areal distribution of the spots where some parts of the area have more measurements than others which delivers an interpolation map of varying relevance even after removing the nine spots. The spots where sampling was done have therefore been marked in the map to able for the readers to evaluate the relevance themselves.

Numeric correlations have been tested using Minitab[5]. Two sample T-tests have been used to calculate the significance of skid tracks and survival, whereas other correlations have been tested using general regression. The limit of relevance has been set to $p=0,05$

[4] Microsoft Office Excel 2007

T-tests (students two tailed t-test; Hays, Winkler 1970) have been performed for the subscripts mortality and location (on or outside skid track) separately. The tested variables are AP, TP, TN, OC, Bulk density, Clay, groundCover, & Passes 70N/cm3 (how many out of the five penetrations made at each spot that was harder than the 70/N/cm3 limit). For the subscript *location* the variables rDbh & rHeight was also tested. The null hypothesis was that there is no difference in the mean of the tested variable *near live and dead plants* or *on and outside skid track*. The null hypothesis of the first t-test would thereby be; The mean of AP measurements in the soil near dead plants is the same as the mean of AP measurements in the soil near live plants.

Each of the variables (AP, TP, TN, OC, Bulk density, Clay, groundCover, rDbh, rHeight & Passes 70N/cm3) have then been tested against the other, one at the time, using correlation. The exception is the growth variables (rDbh & rHeight) that are considered to be two ways of measuring the same thing (growth) and thereby correlated by definition. This has been done using a general-least-square-model ($y_i=\beta_0 + \beta_1 x_i + \varepsilon_i \; where \; i = 1, \dots, n$). The null hypothesis in these tests were that were no reletationship between the two variables.

Mortality refers to plants that have died *after* the three month inventory/replacement.

All analyses have been done on as much data as possible. This means that in the comparison between groundCover and rHeight a larger number of spots are used than in the comparison between penetration resistance and rHeight, since the number of spots where data of both groundCover and rHeight is recorded higher than the number of spots where both penetration resistance and rHeight is recorded.

[5] Minitab© 16.2.4 (2013) Minitab Inc

3. Results

3.1 Skid tracks

The total number of planted spots in the area were 680, out of these 228 were located on skid tracks. The majority of spots on skid tracks were located on the lower parts of the area and most of the spots at the lower parts were located on skid tracks (fig. 3.1). Apart from the first three lines the southern part of the area had no planted spots located on skid tracks in the higher terrain. In the northern part the skid tracks had a more even distribution with more skid tracks in the upper part of the area.

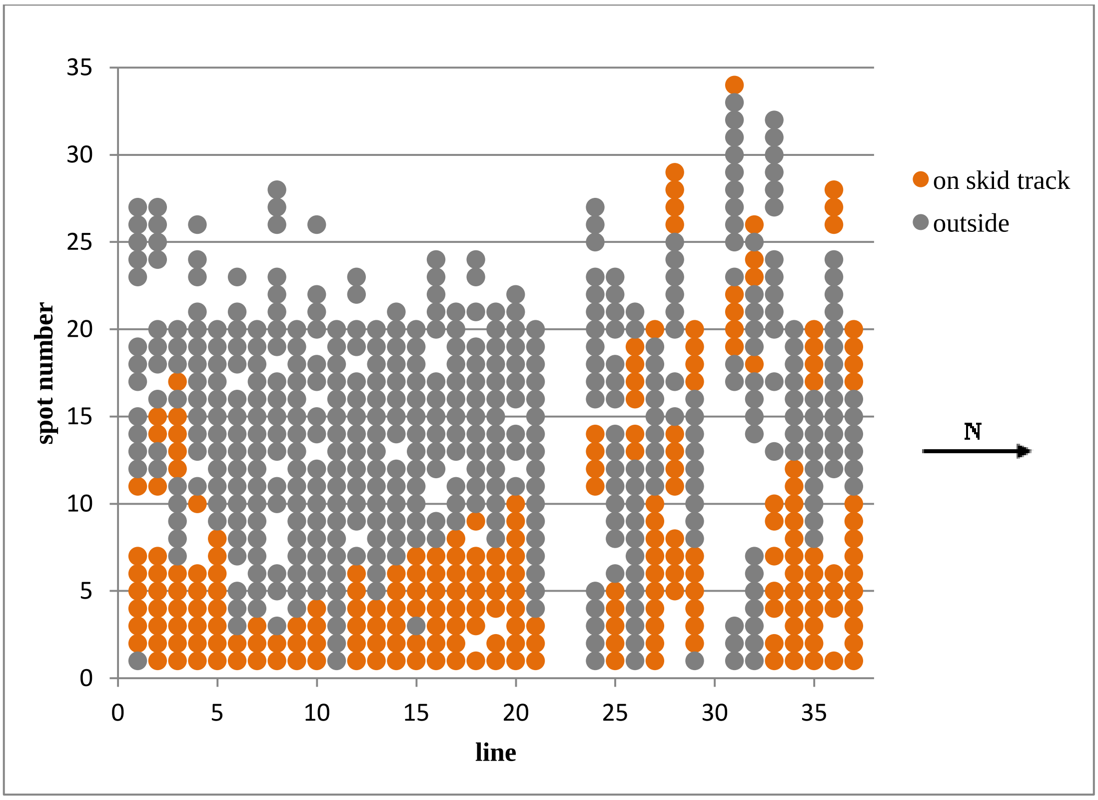

Figure 3.1 *Distribution of planted spots in the INIKEA species demo plot color coded depending on location (on or outside skid track). The INIKEA species demo plot is located in an east facing slope in a tropical rainforest in Malaysian Borneo. The spacing is 10m between the lines and 3m between the spots. Note that the map is constructed only from planted spots and spots that have not been planted are not presented in the map, nor is skid tracks (if present) that pass between these spots.*

3.2 Mortality

The mortality was 32% for all the plants and 33% for the sampled spots. The mortality was higher in the northern part of the area (fig. 3.2). On the south side (left in the figure) of the unplanted lines (22 & 23) mortality was 26% on the north side mortality is 40%. There was no visible relation between skid tracks and mortality. As the number of plants from each species was relative small in the area no analyses have been done on species related differences in the effect of skid tracks on mortality. There was however some species that stand out and where mortality was remarkably higher either for the individuals planted in skid tracks or for the individuals outside (attachment 2).

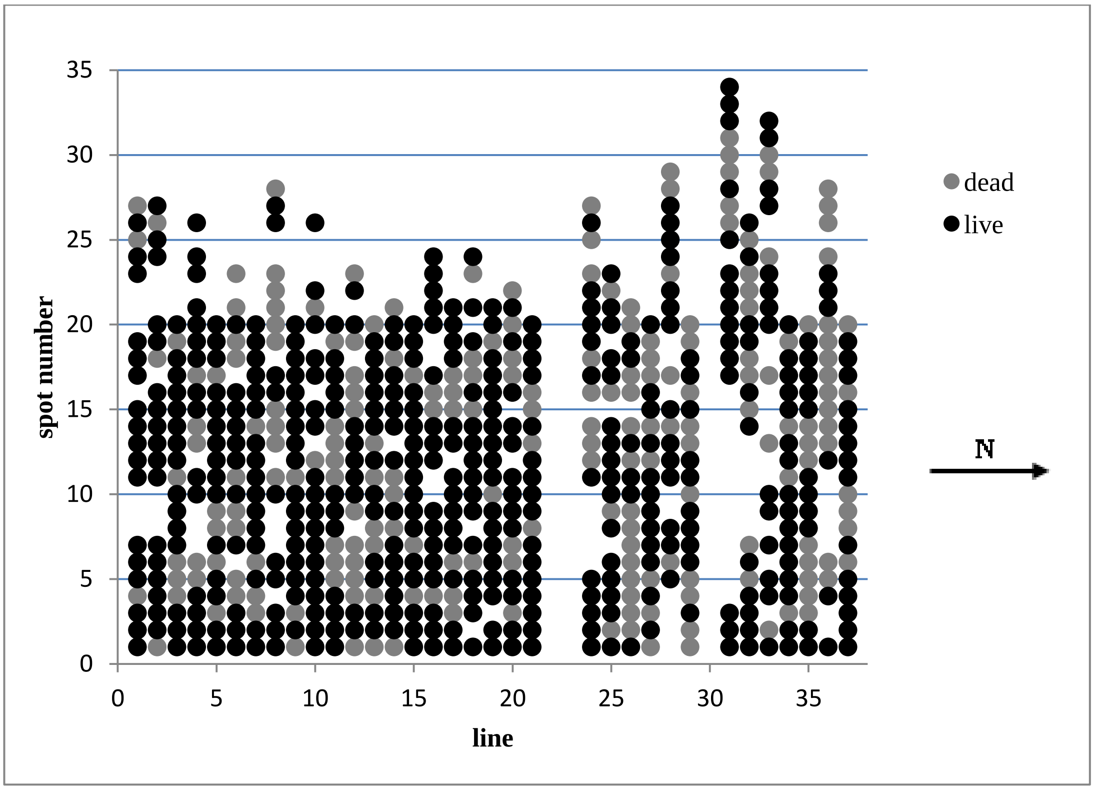

Figure 3.2 *Distribution of (planted) enrichment plants in the INIKEA species demo plot which is located in an east facing slope in a tropical rainforest in Malaysian Borneo. Planting has been done in cleared lines underneath the remaining canopy after logging.The dots are color coded based on the plans status (live or dead) five years after planting. The spacing is 10m between the lines (x-axis) and 3m between the spots (y-axis)*

Most species had a mortality of 20-35% (attachment 2) although some species stand out. The most extreme species are *Pentace laxiflora* with a mortality of only 5% and *Intsia palembanica* with a mortality of 89%.

3.3 Growth

Interpolation maps (fig. 3.3 and 3.4) of rHeight and rDbh show high values as well as low values in roughly the same areas. In combination they show that growth was highest at the southeast corner of the area and at the lower parts of line 37. Apart from line 37 most of the trees with high rDbh were found in the southern lines and line 24-30.

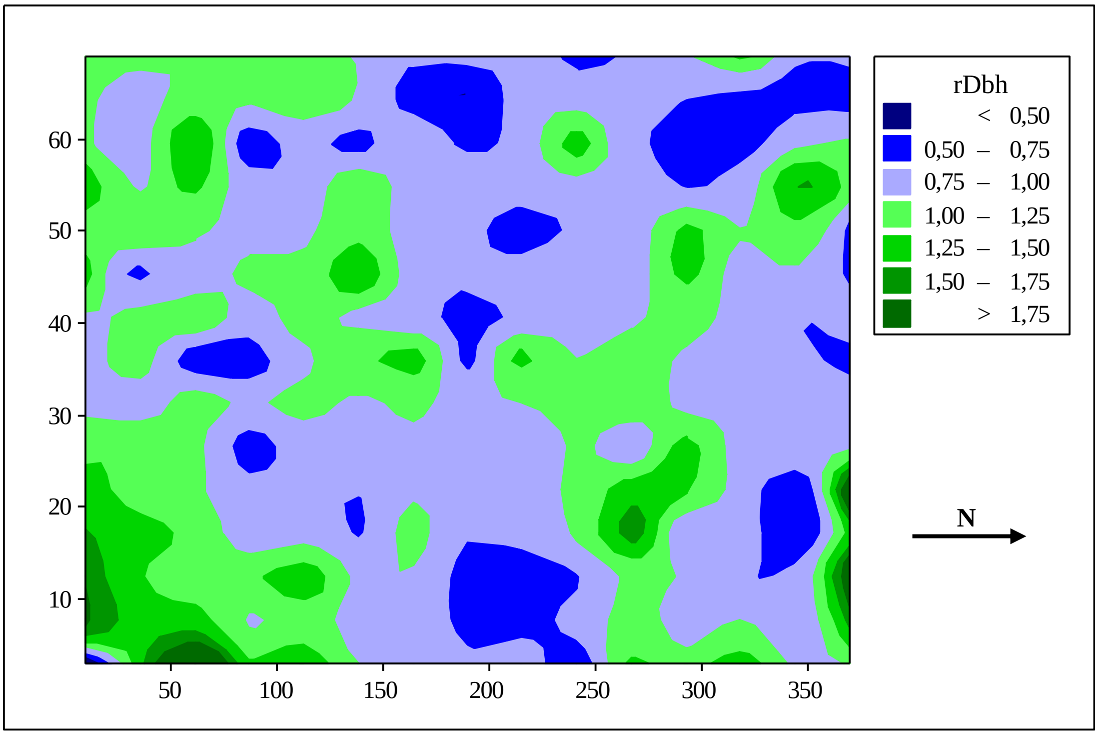

Figure 3.3 *Interpolation map of the (planted) rehabilitation plants relative diameter at 130cm (rDbh) five years after planting in the INIKEA species demo plot which is located in an east facing slope in a tropical rainforest in Malaysian Borneo. Planting has been done in cleared lines underneath the remaining canopy 25 years after logging. rDbh have been created by dividing diameter of the individual tree with the mean for that particular species. The interpolation is made based on measurements of 341 trees and the distance (x- and y-axes) between them in meters.*

rHeight was high along the entire line in the first lines and in line 12. In line 8-10 rHeight was low apart from the eastern part. The rHeight was generally low in the northern lines and in most other lines rHeight is high in the middle.

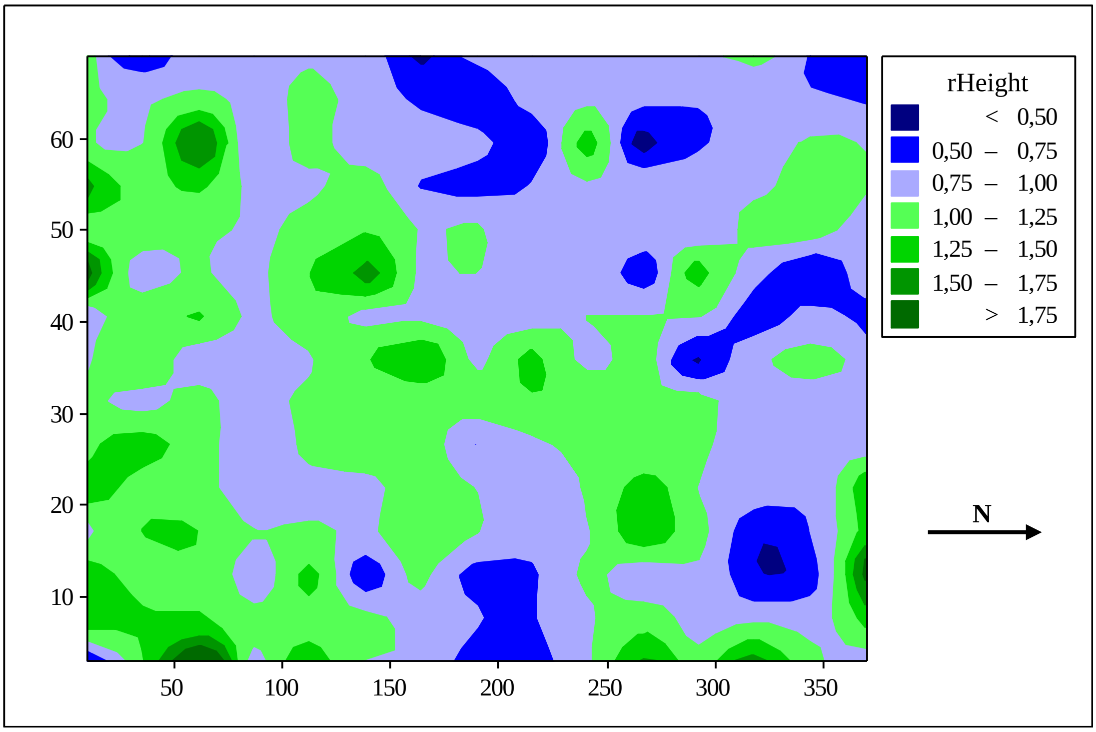

Figure 3.4 *Interpolation map of the (planted) rehabilitation plants relative height (rHeight) five years after planting in the INIKEA species demo plot which is located in an east facing slope in a tropical rainforest in Malaysian Borneo. Planting has been done in cleared lines underneath the remaining canopy 25 years after logging. rHeight is created by dividing diameter of the individual tree with the mean for that particular species. The interpolation is made based on measurements of 434 trees and the distance (x- and y-axes) between them in meters.*

For all the live trees in the area higher than 130cm rDbh was significantly higher on spots that were located on skid tracks (p=0,026 N=362). rHeight was also higher although not significant (p= 0,157 N=461).

3.4 Light

The interpolation map (fig. 3.5) show that in the southern part of the area and in the lines following the unplanted lines 22 and 23 most of the lines have lower Ground Cover i.e. more light than the rest of the area. Low Ground Cover is also frequent in the higher (western) parts of lines 30-37 and the lower (eastern) parts of line 7-21.

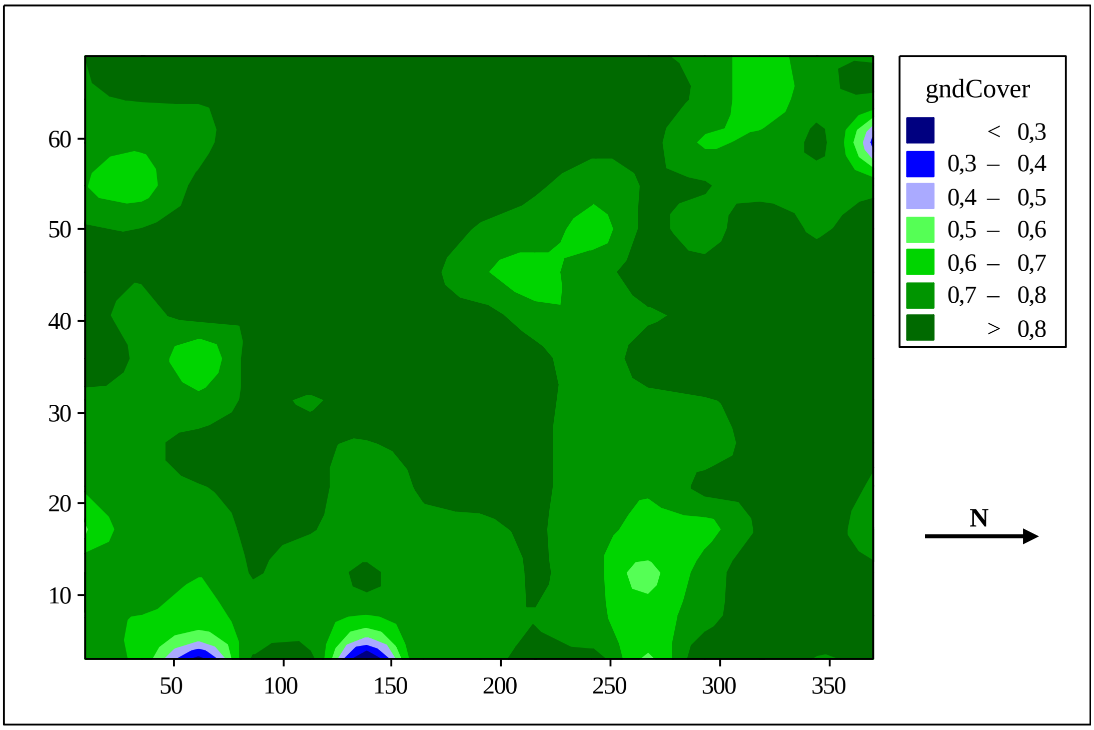

Figure 3.5 *Interpolation map of Ground Cover (gndCover) five years after planting in the INIKEA species demo plot, which is located in an east facing slope, as proportion of the sky that is obscured by the canopy calculated from fisheye photos taken at the planted spots. The interpolation is made based on measurements of 641 spots and the distance (x- and y-axes) between them in meters. The INIKEA rehabilitation project, including this area is located in a logged over tropical rainforest in Malaysian Borneo.*

Ground Cover was higher on planted spots outside the skid tracks (p=0,000 N=641).

Mortality showed no relation with Ground cover. On the other hand rDbh (p=0,000 N=343) and rHeight (p=0,000 N=436) were highly related. In darker areas both rDbh and rHeight was lower.

3.5 Soil properties

The tested variables of soil properties were all correlated with each other (table 3.3) and the mean, max and min values for each variable are displayed in table 3.4.

Table 3.3 *P-values and Explained variance (R^2) (negative or positive) between Organic carbon (OC), Total nitrogen (TN), Available Phosphorus (AP), Total Phosphorus (TP) and Bulk density (BD) and clay (N=155) using a general-least-square-model. Soil samples are taken from the top 10cm directly underneath the organic layer at a distance of 70cm from enrichment planted spots in the species demo plot in INIKEA rehabilitation project. Planting has been done in cleared lines underneath the remaining canopy 25 years after logging in a tropical rainforest in Malaysian Borneo.*

	TP	**AP**	**Clay**	**TN**	**OC**
BD	- 0,067	- 0,00	- 0,012	- 0,00	- 0,00
OC	+ 0,00	+ 0,00	+ 0,00	+ 0,00	
TN	+ 0,00	+ 0,00	+ 0,00		
Clay	+ 0,00	+ 0,27			
AP	+ 0,003				

Table 3.4. *Comparison of mean, standard deviation, maximum and minimum value of the tested soil properties on and outside skid tracks. Organic carbon (OC), Total nitrogen (TN) and clay are presented as percent of the total weight. Bulk density (BD), Total Phosphorus (TP) and Available Phosphorus (AP) are defined in the table. Soil samples are taken from the top 10cm directly underneath the organic layer at a distance of 70cm from enrichment planted spots in the species demo plot in INIKEA rehabilitation project. 80 (81 for BD) spots have been sampled on skid track and 75 (76 for BD) outside. Planting has been done in cleared lines underneath the remaining canopy 25 years after logging in a tropical rainforest in Malaysian Borneo. Soil samples have been dried over night in 105°C before analyzed.*

	OC %		**TN%**		**clay %**	
	on	**outside**	**on**	**outside**	**on**	**outside**
mean	1,41	1,34	0,17	0,17	25,01	26,79
SD	0,40	0,43	0,04	0,04	4,25	4,58
min	0,62	0,62	0,06	0,10	14,78	19,16
max	2,46	2,68	0,31	0,29	35,13	39,69

	AP µg/g		**TP µg/g**		**BD g/dm3**	
	on	**outside**	**on**	**outside**	**on**	**outside**
mean	9,38	9,55	224,82	250,27	1,00	1,03
SD	3,10	3,90	68,23	61,70	0,14	0,12
min	4,11	3,20	104,20	129,76	0,49	0,73
max	20,41	17,99	459,48	393,66	1,35	1,31

None of the soil variables showed significant relation with survival. Only TP showed significant relation with skid tracks (N=155 P=0,016).

Spots where rDbh was higher also have higher bulk density (p=0,012 N=86) and lower amounts of AP (p=0,007 N=85) and OC (p=0,011 N=85). Total nitrogen also show lower values with higher rDbh although not significant (p=0,085 N=85).

Ground cover is correlated with total P (p=0,005 N=148) and clay (p=0,01 N=148) Darker spots have higher amounts of phosphorus and clay.

3.6 Penetration

The Interpolation map (fig. 3.6) shows that the number of penetrations that passes 70N/cm^2 is lower in spots in the northern and most southern parts of the area. Apart from line 7-15 the number of penetrations that passes 70N/cm^2 was higher at spots in the lower part of the area. The majority of spots where many of the penetrations passes 70N/cm^2 are in lines 6-17.

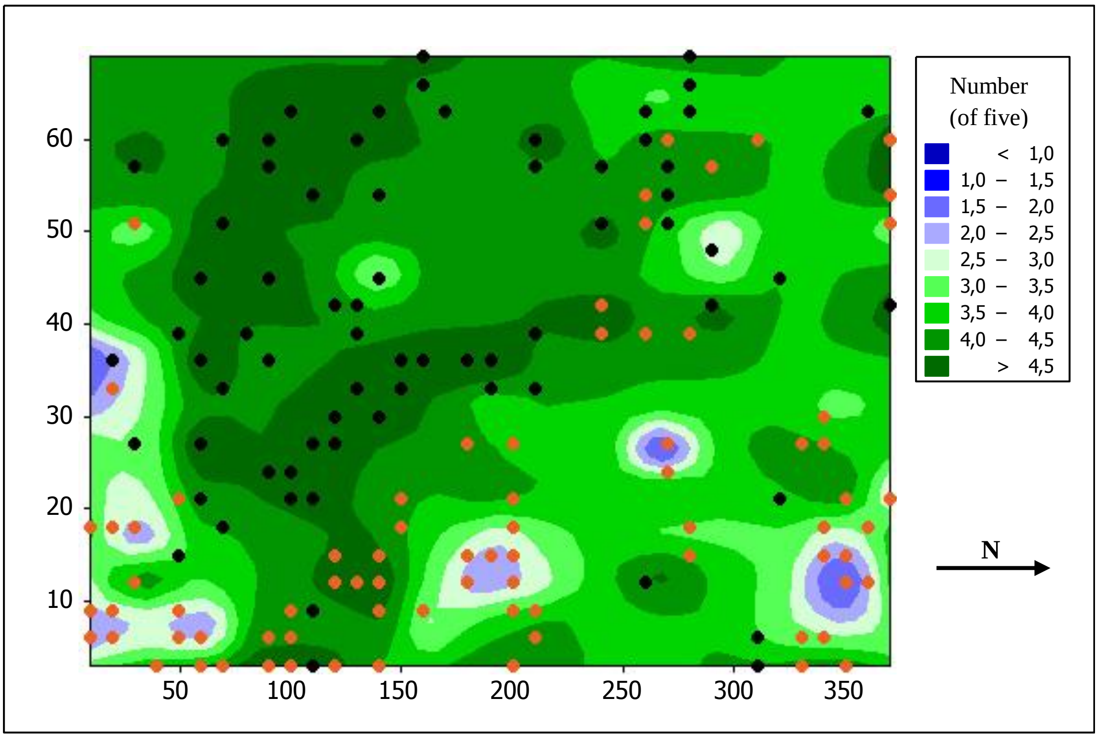

Fig 3.6 *Interpolation map of soil penetration resistance in the INIKEA species demo plot as measured by the number (how many) out of five penetrations that was harder than 70N/cm^2 at each spot. Measurements were made at a distance of 70cm from enrichment planted spots in five directions. (As this is an interpolation the classes have decimals even though the measurements are discrete) Planting has been done in cleared lines underneath the remaining canopy 25 years after logging in an east facing slope in a tropical rainforest in Malaysian Borneo. The 147 dots show the location of the sampled spots from which the interpolation is made. The orange dots are located on a skid track whereas the black dots are not. The axes show distance in meters from the tree selected as origo.*

The number of penetrations of five that was harder than 70N/cm^2 is lower on skid tracks (p=0,001 N=156). The number of penetrations that was harder than 50N/cm^2 is also lower (p=0,009 N=156). In 58% of the 156 spots where penetration resistance was measured, all five penetrations passed the 70N/cm^2 limit. Table 3.4 shows the percentage on and outside skid tracks at different depth.

Table 3.4 *Percent of the sampled spots where all of the five penetrations were harder than 70N/cm^2 at different depths. Measurements were made at a distance of 70cm from enrichment planted spots in five directions from 80 spots on skid track and 76 outside. Planting has been done in cleared lines underneath the remaining canopy 25 years after logging in an east facing slope in a tropical rainforest in Malaysian Borneo.*

	10cm	15cm	20cm	25cm	30cm	40cm	50cm
On skid-track	3,75	5,00	13,75	16,25	23,75	37,50	47,50
Outside	1,32	9,21	14,47	22,37	5,53	59,21	69,74

Penetration resistance show no significant correlations with any measured variables apart from skid tracks.

4. Discussion

4.1 Mortality and growth

Mortality was higher in the northern area (fig 3.2). This area was also more affected by skid tracks (3.1), which could suggest that mortality was related to whether or not the planted the sampled spot was on skid track. However there were no visible differences between the, by skid track, heavily affected area at the bottom of the hill and the less affected area uphill which suggest that the similarities were coincidental. An inventory by Malin Gustafsson 2012 also showed that damages to living trees was also more frequent in the northern area which implies that the differences in mortality was caused mainly by the terrain or other local influences and not by the presence of skid tracks.

The high number of species in this study compared to the low number of individuals from each species might be one of the reasons why no variables that influence mortality were found. The requirements and limits vary between species (Ghazoul & Sheil 2011) and it is possible that survival was limited by different variables in the area depending on species. The high variation in mortality between the species in this study suggests that further research could improve rehabilitation success in the area and possibly the development of other planting strategies.

As can be seen in attachment 2 some species had large differences in mortality between the individuals planted in the skid tracks in comparison to the individuals planted outside. Although the number of individuals in each species was too small to make any reliable analyzes on skid track influence on a species level, the differences shown in this study are large enough to suggest that there might have been such a correlation and that this could be a subject of further research.

Rehabilitation is costly and the area in need of rehabilitation is large. It is therefore important to be efficient in the efforts (Alloysius et al. 2010). Mortality of young trees is naturally high in tropical forests although this varies greatly between species (Richards 1996). The environmental benefits of the plants must be weighed against the planting cost and high mortality rates means higher costs for each surviving plant. The use of species with higher mortality can be motivated if the environmental values of that particular species are high enough (ITTO 2002).

It might be expected that areas with higher mortality would also had lower growth. As it is not possible to measure growth on dead plants no numeric analyzes has been performed on this theory but when comparing the maps of growth variables and survival it is hard to see any similarities. rDbh showed correlations with skid tracks, Bulk density and AP whereas rHeight did not. The lack of significant correlations could be due to damages and breakage to the tree making it shorter which would thereby make weaker relations harder to detect. One of the reasons could be that for some reason the top has been damaged. As the top of a tree is broken of a hormonal process start that leads to the plant developing a new top shoot (Taiz & Zieger 2006) and after a few years this might be hard to detect. Both maps of growth variables are however quite similar which suggests that the influence has been small.

Something else that could have influenced the results and hidden correlations is that species have different growth patterns (Taiz & Zieger 2006). It also differs between species at which age they grow the most and the localization of growth in the plant. The effect of this has partly been reduced as growth parameters were measured as relative and by selecting the same number of individuals from each species. Complete elimination was however not possible.

In earlier studies it has been shown that natural regeneration is negatively affected by skid tracks even after more than 15 years. Both the total biomass and the species variation are often lower on skid tracks (Guariguata 1997, Pinard et al. 2000). The trees in my study actually had higher growth on skid tracks than outside which could indicate that it is mainly the germination and seedling phase of the natural regeneration that is negatively affected by skid tracks. The seeds in my study have had their germination and seedling phase in the nursery rather than in their current environment. If it is mainly the germination and early growth that is limited this would have given the plants in my study an advantage since any influence from the skid tracks would not only have an on the studied trees but also on the surrounding vegetation. If the natural regeneration have been restricted in their germination it is likely that the competition by these on my trees was lower on skid tracks, which could explain the higher growth.

4.2 Light

The results indicate that light had little effect on mortality but high effect on growth of the enrichment plants, which is interesting. This suggests that light was sufficient for the survival in most parts of this forest, but low enough to limit growth.

That growth was lower in the spots with higher Ground cover is to be expected as it is a well known fact that low light restricts growth. The interpolation maps of Ground cover (fig 3.5) compared to the growth maps (fig 3.3 & 3.4) show much similarity but there are also visible differences. This indicates that although light explaied much of the variation there was other factors that played a vital role in controlling growth. For instance, Videkull (2014) has shown that the response to different light conditions varies between the species of this study.

That rDbh was higher on skid tracks could be due to favorable conditions caused by the creation of skid tracks, like lower penetration resistance. But it could also be due to the higher amounts of light on the sampled spots located on skid tracks. Although light in this study was largely influenced by the light treatments made to promote growth of our plants, the surrounding vegetation does play a part in the total light reaching the forest floor.

After the fires 1982/1983 and the salvation logging that followed no treatment was done before the planting 2008 and the surrounding vegetation that has come up is the result of previous conditions rather than rehabilitation efforts. According to a study by Pinard et al. (2000) even after 18 years the regeneration is negatively affected on skid tracks. If this was the case in my study too, a less successful regeneration by the surrounding vegetation caused by the location on skid tracks suggests higher radiation even without artificial treatment. It is also important to remember that outside the skid tracks some trees were left in the harvest whereas on skid tracks all trees were removed. This also helps explain why light was less restricted on skid tracks.

4.3 Soil properties

The physical and chemical properties are often correlated in the soil and the results seen in table 3.3 are therefore to be expected. This makes it very hard to decide what specific component that was most limiting. It might also be that other variables, also linked with the tested variables, were limiting growth in the area.

Organic material is lighter than mineral particles, the connection between low content of organic carbon and high bulk density could partly be explained by this relation. Bulk density also showed a closer relation with organic content than with clay content. Also, undisturbed soils with high amounts of clay, especially in combination with high levels of organic material, are usually well aggregated (Brady & Weil 2002). This leads to low bulk density as aggregation leads to bigger pores in the soil (Brady & Weil 2002). The relatively weak relation between clay content and bulk density was most likely due to the fact that some of the samples contained rocks, which are of high density and some samples contained roots, which is of low density. A larger number of samples would reduce this effect.

Decaying organic material is the primary source of nutrients in tropical forests (Ghazoul & Sheil 2011) which could explain the tight relation between low amounts of nutrients and rDbh. Low amounts of nutrients and organic material in the soil samples could suggest a quicker turnover which in turn could come from the faster growth of the trees by which the soil sample was taken. However, I have found no studies from forests that support this theory and though it is possible it is not likely that the measured differences of phosphorus levels are caused by differences in growth of the studied tree.

Phosphorus is known to be limiting in many tropical forests (Vitousek 1984) and the largest part of phosphorus in tropical soils is in forms that are not accessible to plants. Much of the inaccessible Phosphorus in soil is found closely bound to soil particles of which clay is rich (Brady & Weil 2002). In my study TP ranged from 104,2 to 459,48 whereas AP ranged from 3,2 to 20,4 and made up only 4% of TP. Although nitrogen is also bound this way the bonds are more frequently broken and nitrogen made accessible to the plants (Armson 1977).

In experiments with added Phosphorus Wright et al. (2011) and showed that an addition of phosphorus led to an increase in tree growth, which completely contradicts my findings as growth was actually higher with lower values of AP. On the other hand Mirimanto et al. (1999) could show no effect significant increase in growth with added phosphorus. In both fertilization experiments (Wright et al. & Mirimanto et al.) growth was measured on all trees in the area whereas I have only measured the planted trees. The comparison is therefore somewhat lacking and it is possible that the amounts of AP has had an effect on the community as a whole in the area I have studied. On the other hand the Mirimanto experiment is located in Borneo and it is likely that the species have more similarities with the trees in my study in ways of growth pattern and requirements on nutrient composition. As the amounts of AP in my study were many times higher it makes sense that I could also not find any differences.

Both Wright et al. (2011) and Mirimanto et al. (1999) also tested the effect of increased nitrogen on growth. Like me they found no support for the theory that higher levels of nitrogen gave higher growth. However Wright et al. found that the combination of added N and K gave an increase in growth.

In my study there was not only no evidence of higher amounts of phosphorus leading to higher growth. The growth was actually lower. This could be an effect of higher growth on skid track where AP also was lower, or it could be due to something I have not measured. As all my measured soil properties were closely linked it is likely that they were also linked with something else that could increase growth. It should also be remembered that soil/growth relations in this study was based on a combination of ten species and that it is possible that the species has responded differently to variations in the soil components. As soil samples were only taken at 16 planted spots for each species and growth was only measured on live trees no analyzes have been done to examine this.

Although mortality can also be influenced by levels of P (Ceccon et al. 2004) I have found no support for this in the studied area. Again the required amounts differ between the species, but the effect on growth should have been detectable before the effect on mortality.

It should also be remembered that trees and other living organisms interacts with the soil rather than just react (Brady & Weil 2002). These types of interactions have not been considered in this thesis which could affect the results. The effect of surrounding vegetation, which consists of many different species and sizes, has also not been taken in consideration. Diameter height and spacing of the surrounding trees have not been measured. As the soil is not only affected by the trees in the study but also by the surrounding vegetation changes *caused* by the studied trees in the study might be hard to detect.

4.4 Penetration

Compaction caused by logging has a negative influence on seedling development and many studies show that shortly after usage the skid tracks are more compacted than the surrounding area (Nussbaum et al. 1995, Matangaran & Kobayashi 1999). Some studies show that the effect diminishes after a while (Matangaran & Kobayashi 1999) while others suggest a more long term effect (Guarigata 1997). The vast majority of studies on the subject have measured compaction by measuring bulk density (e.g. Matangaran & Kobayashi 1999, Nussbaum et al. 1995, Pinard et al. 2000). I have found only three studies that include actual measurements of penetration resistance. They all show that the penetration resistance is lower outside the skid tracks for the first years following harvest (Jusoff & Majid 1986, Jusoff 1988, Alexander 2012).

The study made by Alexander also included an area with older old skid tracks which showed little recovery after 40 years. My study showed that skid tracks were actually less compacted. Based on available literature it is unlikely that this was a direct effect of skidding but possibly a result of changes and differences caused by the creation and usage of skid track that continues for a long time. This could be entirely coincidental or an effect of the uneven distribution of skid tracks in the area. It could be that the large unaffected area was harder due to some completely unrelated factor or that the flatter bottom area that was for some reason softer. It might also be an effect of higher sand content at the bottom. (A comparison can be made in attachment 3) If penetration resistance is in fact negatively influenced by the creation of skid tracks this is certainly an important finding and information that can be used when rehabilitating degraded tropical forests.

However, even if the use of skidding does create lower penetration resistance in the longer term, it is not an argument against minimizing the influence of skid tracks. Most studies agree (e.g. Matangaran & Kobayashi 1999, Pinard et al. 2000, Alexander 2012) that the first years after logging there is an compaction effect in skid tracks and since leaving the ground untreated for 25 years before planting is not likely to ever be a good and often used strategy it is likely that the negative effects of a higher resistance in the first years after logging outweighs the positive effects of lower resistance that possibly occurs later.

That penetration resistance showed no relation with growth is most likely due to the maximum resistance measured. The resistance of $70N/cm^2$ or 0,7MPa is not high enough to reduce growth. Studies show a reduction in root growth at somewhere between 1 and 2MPa depending on species (Sinnett et al. 2008).

4.5 Conclusions

This is a study where the most recent skid tracks are approximately 25 years old. Most of the changes in conditions that are caused by skidding seem to have disappeared and the status of phosphorus, nitrogen and organic compounds as well as the compaction showed no detectable differences between the sampled spots located on skid tracks and outside. Penetration resistance however was significantly lower on skid tracks.

I could also show no differences in survival on and outside the skid tracks for the entire population, however there were large differences in survival between the species and it is entirely possible that there was such a connection on a species level.

I have also not seen any negative effects on growth of the enrichment plants caused by the skid tracks in my area. Other studies have shown that the negative effect of growth can still be seen after 15-20 years, whereas I have shown a higher growth on enrichment plants after 25 years. This could be an effect of that light is higher on the skid tracks compared to the rest of the area in my study. The higher light measured in this study could be an effect from regeneration restriction from e.g. soil compaction in the years that followed the loggings and fires, but it could also be an effect of that skid tracks were completely stripped on trees whereas this is not necessarily the case in the rest of the area.

Each area is unique and more studies needs to be made to determine whether these results are applicable on larger areas or an effect of the conditions at this particular the sampled spot, however there was nothing that support the theory that it would be more effective to premiere planting the sampled spots outside skid tracks in the continued rehabilitation of rainforest.

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Attachments

Attachment 1; *Complete list of species planted in the INIKEA species demo plot*

Baccaurea angulata

Baccaurea sp

Canarium sp

Diospyros sp

Dipterocarpus conformis

Dryobalanops keithii

Dryobalanops lanceolata

Durio spp

Heritiera sp

Hopea ferruginea

Intsia palembanica

Koompasia excelsa

Mangifera odorata

Mangifera panjang

Parashorea malaanonan

Parashorea smythiesii

Parashorea tomentella

Pentace adenophora

Pentace laxiflora

Shorea beccariana

Shorea falciferoides

Shorea fallax

Shorea leprosula

Shorea leptoderma

Shorea macrophylla

Shorea macroptera

Shorea ovalis

Shorea parvifolia

Shorea pauciflora

Shorea platyclados

Shorea sp

Shorea xanthophylla

Sindora iripicina

Walsara pinnata

Attachment 2; *Number of dead and live individuals of each species separated over whether or not the tree is planted on skid track in the INIKEA species demo plot. Planting has been done in cleared lines underneath the remaining canopy 25 years after logging in an east facing slope in a tropical rainforest in Malaysian Borneo. The species are sorted by total mortality with the lowest mortality at the top.*

	on skid track			outside skid track			total		
	Dead	Live	%	Dead	Live	%	Dead	Live	%
P. laxiflora	0	7	0	1	13	7	1	20	5
Heritiera sp	0	7	0	2	11	15	2	18	10
S. ovalis	2	3	40	0	15	0	2	18	10
S. macrophylla	2	8	20	1	9	10	3	17	15
P. malaanonan	0	6	0	3	11	21	3	17	15
W. pinnata	1	8	11	2	6	25	3	14	18
B. angulata	0	7	0	4	9	31	4	16	20
Canarium sp	0	2	0	4	14	22	4	16	20
S. leptoderma	3	5	38	1	11	8	4	16	20
K. excelsa	0	5	0	5	12	29	5	17	23
M. odorata	0	5	0	5	11	31	5	16	24
M. panjang	2	5	29	3	10	23	5	15	25
Durio spp	3	7	30	2	8	20	5	15	25
D. lanceolata	2	8	20	3	7	30	5	15	25
S. pauciflora	1	4	20	4	11	27	5	15	25
S. xanthophylla	4	5	44	1	10	9	5	15	25
P. adenophora	2	4	33	3	10	23	5	14	26
Diospyros sp	0	6	0	6	8	43	6	14	30
S. falciferoides	2	1	67	4	13	24	6	14	30
S. fallax	1	6	14	5	8	38	6	14	30
Baccaurea sp	1	3	25	5	11	31	6	14	30
D. keithii	0	4	0	6	9	40	6	13	32
D. conformis	4	6	40	3	7	30	7	13	35
S. macroptera	3	6	33	4	7	36	7	13	35
P. tomentella	2	4	33	5	9	36	7	13	35
P. smythiesii	3	3	50	5	10	33	8	13	38
Shorea sp	2	2	50	7	9	44	9	11	45
S. leprosula	5	2	71	4	9	31	9	11	45
H. ferruginea	3	5	38	7	5	58	10	10	50
S. beccariana	4	2	67	6	8	43	10	10	50
S. platyclados	3	2	60	8	7	53	11	9	55
S. iripicina	4	2	67	7	7	50	11	9	55
S. parvifolia	6	6	50	7	1	88	13	7	65
I. palembanica	5	1	83	11	1	92	16	2	89
SUM	**70**	**157**		**144**	**307**		**214**	**464**	
MEAN			**30**			**32**			**32**

Attachment 3; *Sand content*

Although sand was not targeted in this study and no analyses have been done on how sand content relates to other variables it was delivered as a byproduct of the clay measurements. This made it possible to make a contour plot (fig. A 1) that can be compared to the contour plot of soil penetration resistance (fig 3.6). In the creation of this plot (like the creation of the plot for soil penetration resistance) spots with a higher number than 23 have been disregarded. In the figure it can be seen that there is a higher sand concentration in the lower parts of the area. It can also be seen that most of the spots sampled in the lower areas were considered to be located on skid track which could help explain why the penetration resistance was lower in the lower areas.

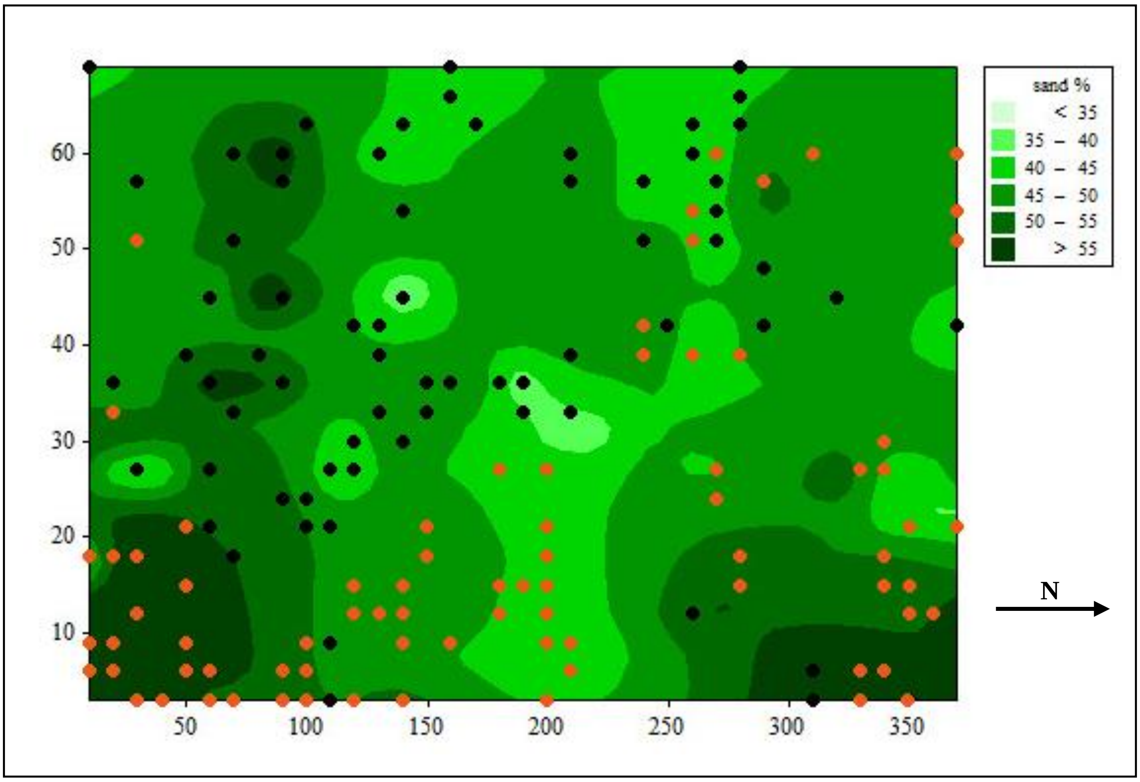

Fig A.1 *Interpolation map of soil sand content in the INIKEA species demo plot. Soil samples are taken from the top 10cm directly underneath the organic layer at a distance of 70cm from enrichment planted spots in the species demo plot. Planting has been done in cleared lines underneath the remaining canopy 25 years after logging in an east facing slope in a tropical rainforest in Malaysian Borneo. Soil samples have been dried over night in 105°C before analyzed. The 148 dots show the location of the sampled spots from which the interpolation is made. The orange dots are located on a skid track whereas the black dots are not. The axes show distance in meters from the tree selected as origo.*

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