Assessing the Effect of Silviculture Treatments and Soil Quality on the Planted Dipterocarp Species after Enrichment

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Assessing the Effect of Silviculture Treatments and Soil Quality on the Planted Dipterocarp Species after Enrichment Planting

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DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Malaysia Sarawak. Except where due acknowledgements have been made, the work is that of the author alone. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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ABSTRACT

An assessment after different silviculture treatment was conducted on the growth performance and survival of planted *Dryobalanops beccarii* on 2005 in Gunung Apeng National Park (GANP). Two study plots with different silviculture treatments and control plot were established namely T1 (bush slashing (control)) and T2 (selective girdling+ bush slashing). The growth performance of planted trees in terms of tree survival, total height and stem diameter were assessed for period of 72 months. Composite and undisturbed soil samples were collected at several random points within each study plots at 0-10 cm and 30-40 cm depth for the determination of soil physicochemical properties. Soil profile description was conducted in each plot to determine the morphological properties of the soils existing in the study area. The findings showed that the survival at T1 and T2 were 82.9% and 79.2%, respectively. Meanwhile, the average diameter and tree height recorded in T1 were 7.5 cm in diameter and 8.3 m in height, followed by T2 with 9.4 cm in diameter and 9.2 m in height. In terms of mean annual increment in diameter and height, T2 showed higher in MaiD and MaiH than T1 ($p < 0.001$). Then, the soil at the study area was acidic with a pH of less than 5, mostly sandy clayed in textural class and a moderate level of the nutrient. The type of soil at the study site was determined as grey-white podzolic soil which with strongly acidic with low nutrient content, deficiency moisture, and aeration. To conclude long terms effects of the selective girdling on the planted tree still rather insufficient due to other ecological factors.

Keywords: *Dryobalanops beccarii*, growth performance, survival, soil properties, silviculture treatment

Menilai Kesan Rawatan Silvikultur dan Kualiti Tanah pada Spesies Dipterokap yang Ditanam Selepas Penanaman Secara Pengayaan

ABSTRAK

Sebuah kajian telah dijalankan mengenai kadar tumbesaran dan kemandirian Dryobalanops beccarii yang ditanam pada 2005 di Taman Negara Gunung Apeng (GANP). Terdapat dua plot kajian yang berbeza rawatan silvikultur iaitu plot T1 (penebasan rumpai (kawalan)) dan plot T2 (menggelang terpilih+ penebasan rumpai). Kadar tumbesaran dari segi kemandirian pokok, tinggi dan lilitan pokok sepanjang 72 bulan telah dikaji. Sampel tanah iaitu sampel tanah komposit dan sampel tanah asal pada kedalaman 0-10 cm dan 30-40 cm telah diambil secara rawak di dalam kawasan kajian bagi mengenal pasti ciri fizikokimia tanah. Deskripsi profil tanah dalam setiap plot kajian telah dilakukan untuk menentukan ciri morfologi tanah dalam kawasan kajian. Hasil kajian menunjukkan kemandirian pokok di T1 ialah 82.9% dan T2 79.2% selepas 72 bulan. Purata lilitan dan tinggi pokok di T1 adalah 7.5 cm bagi ukur lilit dan 8.3 m bagi ketinggian pokok manakala di T2 adalah 9.4 cm bagi ukur lilit dan 9.2 m bagi ketinggian pokok. Purata kenaikan tahunan dalam ukur lilit dan ketinggian pokok, T2 lebih tinggi dalam MaiD dan MaiH berbanding T1 ($p < 0.001$). Untuk fizikokimia tanah, pH tanah di kawasan kajian berasid dengan pH rendah dari 5, tektur berpasir dan nutrisi yang sederhana. Jenis tanah dalam kawasan kajian dikenal pasti sebagai "grey-white podzolic soil" yang bercirikan nutrisi, kelembapan dan pengudaraan yang rendah. Untuk membuat kesimpulan bagi kesan jangka panjang menggelang terpilih belum mencukupi kerana kepelbagaian faktor ekologi.

Kata kunci: *Dryobalanops beccarii, kadar tumbesaran, kemandirian, ciri tanah, rawatan silvikultur*

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LIST OF ABBREVIATIONS

%	Percentage
µs	Micro-semen
Al	Aluminium
Avg	Average
AvP	Available phosphorus
Cmolc	Centi mol per charge
Ca	Calcium
CEC	Cation exchange capacity
cm	Centimetre
D. beccarii	*Dryobalanops beccarii*
ECEC	Effective cation exchange capacity
Exch.	Exchangeable
GANP	Gunung Apeng National Park
g	gram
H	Hydrogen
K	Phosphorus
kg	Kilogram
M. gigantea	Macaranga gigantea
m	Meter
mg	Milligram
ml	Millilitre

MaiD	Mean annual increment in Diameter
Maih	Mean annual increment in Height
Mg	Magnesium
Na	Sodium
RLI	Relative light intensity
sp.	species
SOM	Soil Organic Matter
Stdev	Standard deviation
TN	Total nitrogen
YR	Red yellow

CHAPTER 1

INTRODUCTION

1.1 Study Background

Malaysia is one of the countries in Asian that have a large area covered with tropical forest. Mok (1992) reported that the total natural forest area in Malaysia was estimated at 19.49 million ha or about 56.3% of the total land area. Tropical forests are considered as the most productive among all terrestrial ecosystems as they possess the functional roles for biodiversity conservation, world climate enhancement and soil conservation (Whitmore, 1998). As in Malaysia especially the Sarawak region, it is estimated about 70% of the land is still considered as natural forest (Mok, 1992) but only 256,000 ha have been constituted as the Totally Protected Areas (TPA), 3.96 million ha as State Forest and only 4.5 million ha as Permanent Forest Estate (PFE). The forest that not been declared as protected forest has been used for the development and agricultural activities such as plantation of crops, housing areas and others. To make matter worse, many of the land in Sarawak have been deforested due to the high demand in the timber industries in which associated with logging activity. Moreover, Gaveau et al. (2014) also had reported that, by the year 2010, the forest area had been reduced by 16.8 million ha in which indicated 30.2% forest loss where 164,444 km^2 of the deforestation occur in lowland coastal area (< m a.s.l).

Even though sustainable logging might be able to minimise the environmental impacts, but uncontrolled logging activities will bring catastrophic effects such as reducing the water quality, alter the biodiversity as well as reducing the productivity of the biological populations (Jaya, 2002). Moreover, Montagnini et al. (1997) also stated that the conversion of forested areas to non-forest lands such as to pasture and agriculture has resulted in the permanent reduction of indigenous species. Aside from diminishing the timber product, deforestation also leads to major forest soil problems in which will result specifically the tropical lands become rapidly eroded and infertile. stated that most soils in the tropical regions are infertile, and once the natural forest has been cleared, nutrients can be rapidly lost consequently leading to longer forest recovery time (Sanchez et al., 2003; Juo & Franzlueebber, 2003).

Hence, conservation and preservation activities are necessary for the sake to maintain the stability and productivity of the forest. Without any protection measures, our forest will be undergone depletion in no time. As this occurs, many destructive effects will be happened such as the shortage of timber, loss of natural water catchment area as well as loss of precious biodiversity values. In worst case scenario, depletion of forest can lead to climate change and global warming. Increasing the awareness on the importance of restoring the nature from the bottom part is essential and a sustainable way in managing the forest should be implemented as has been applied by the authorities and NGO. In addition, reforestation is a must in order to rejuvenate our forest back to nature stated. Some researchers also pointed out the importance of reforestation in the tropics comprises productions of timber and other goods and services as well as aiding the recovery of biodiversity by re-establishing forest cover (Lamb et al., 2005; Benayas et al., 2009). By conducting reforestation in degraded land areas due to anthropogenic activities will bring lots of benefits to the humanity in which some of those are enhancing carbon sequestration for climate change mitigation (Silver et al., 2000), and regulation of water cycles (Bruijnzeel, 2004; van Dijk & Keenan, 2007).

Meanwhile, to ensure the successfulness of the reforestation program, it should be accompanied by proper ways or techniques applied such as implementations of enrichment planting and suitable silviculture practices. Enrichment planting is one of the methods used in attempts to supplement natural regeneration as well as to enhance the low tree growth performances in natural succession (Chai & Udarbe, 1977; Appanah & Weinland, 1993). Examples of enrichment planting such as the gap created artificially by human interventions involved in reducing above-ground vegetation (Wyat-Smith, 1963; Adjers et al., 1995) thus, reduce the competition between the planted tree with the adjacent bushes and shrubs. These practices also can be used to rehabilitate logged-over areas in tropical rainforest by using the indigenous tree species where the process involves planting the nursery-raise seedlings in a cleared line or in gaps that been created naturally or artificially (Wyat-Smith, 1963).

Silvicultural practices are one of the various practices aside from enrichment planting which can be used in order to control the establishment, growth, composition and quality of the forest plantation. Moreover, silviculture treatment is also used widely in the management of forest with the aim for the conservation of the indigenous tree species to promote the growth of the indigenous tree species and to maintain and enhance the utility of the forest for any defined management purposes. Generally, the silviculture treatment is the numerous treatments that can be applied to forest stands in order to maintain and enhance their value for any purpose (Smith, 1986). According to Blaser et al. (2011), the silvicultural structure is commonly used to manage the dry inland forest in Malaysia in which mostly dominated by the Dipterocarpaceae family. Colin et al. (2018) reported that silvicultural practices are preferred for forest restoration purposes because they allow the direct manipulation of stand composition and structure.

The application of the silviculture treatments such as choice of species and site, site preparation, planting technique, spacing, weeding and leaning, thinning, pruning, fertilisation and bush slashing and selective girdling also have been used in the forest plantation in Sarawak. In addition, the main intentions of using the silviculture method are to change and accelerate change or maintain tree and stand conditions. Besides that, silviculture treatment methods give almost no harm to the forest ecosystem and can contribute to sustainable forest management as well as promotes better growth for the planted species in the forest plantation. There are many silvicultural treatments that can be applied to the forest plantation and one of them is through fertilizer application. However, bush slashing, thinning and pruning are among the most common silviculture treatments that are being applied as part of the forest management practices in the forest plantation sector of Sarawak (Ashton, 2004).

Aside from cultural practices in reforestation efforts, understanding the soil nutrient dynamic also important in order to sustainably rejuvenate the disturb secondary forest. According to Ishizuka et al. (2000) and Arifin et al. (2008), once the natural forests have been cleared, soil nutrients are lost through erosion and leaching resulting in low soil nutrient stocks. Therefore, to continuously obtain the economic, environmental, social and cultural benefits of the forest, the damage must be repaired by various technical approaches, such as rehabilitation.

1.2 Problem Statement

Reforestation efforts need comprehensive understanding and assessment on the ecosystem involved as an attempt to provide proper practices in the future. Moreover, reforestation also needs to comprise various aspects such as vegetation composition, species selection, silviculture intervention and soil condition in order to rejuvenate the degraded land in sustainable manners. Numerous measures have been proposed to improve forest management (Graaf, 1986; Lamprecht,1989; Fredericksen & Mostacedo, 2000; Fredericksen & Putz, 2003) but such managements are to ensure future timber yields in forest plantation context (Jackson et al., 2002). Even though there were researchers have presented the progress of reforestation activities for the purpose of rehabilitating degraded areas at tropical region especially Malaysia region (Nik Muhamad et al., 1994; Suhaili et al., 1998; Norisada et al., 2005; Arifin et al., 2008) and Sarawak (Sakurai et al., 2006), there are knowledge gaps on the enrichment planting and in secondary forest as well as the performance of the planted tree species (Ramos & del Amo, 1992; Adjers et al., 1995; Kammesheidt, 2002). Romell (2007) also stressed out on concluding the effect of various silviculture treatment and the optimal conditions for enrichment planting are difficult due to variability in the forest nature and dynamic. Even though the example of enrichment practice either in forest plantation or forest reserve has been reported (Romell, 2007), but to conclude the effect of various silviculture.

In addition, rehabilitation of the degraded forest ecosystems also needs a well-understanding of the soil conditions (Ohta et al., 2000). Most studies are more focusing on the evaluation and assessment of planted trees as well as the changes of the surrounding ecosystem under monoculture plantation of fast-growing exotic species (Cole et al., 1996; Tilki & Fisher, 1998; Norisada et al., 2005; MacNamara et al., 2006), there are less informations in characterizing soil fertility in which portray the soil conditions under the reforestation in less diverse secondary forests. Furthermore, the soil empirical data on the properties of rehabilitated degraded forest land planted with dipterocarp species and non-dipterocarp species is inadequate (Ariffin et al., 2007). Although there are several studies on the soil properties of tropical rainforests in Sarawak have been conducted, but it is rather limited (Ishizuka et al., 2000). The information available on the performance and survivability of planted indigenous tree species under reforestation as executed by the local authorities in Sarawak is ongoing research and the development of the silvicultural practices still in assessment for achieving the most suitable methods for reforestation. Understanding the soil-plant relationship in the dipterocarp forest is essential for better management in order to create sustainable forest rehabilitation.

In this study, we introduced a silvicultural approach to maintain the forest structure and protect its ecological functions. Several studies have been performed on reforestation activities with indigenous tree species using various planting techniques to rehabilitate degraded land areas (McNamara et al., 2006; Hattori et al., 2013; Perumal et al., 2017; Jaffar et al., 2018). Thus, planting the original indigenous species to rejuvenate a specific forest area is essential, as these species can thrive better in the surrounding environment. *Dryobalanops beccarii* was planted to rejuvenate the forest ecosystem in Gunung Apeng National Park (GANP) after anthropogenic events (logging and forest clearance for agricultural purposes) in the area as this tree species indigenously grow on the hill (Ashton 2004). The implementation of selective girdling along with reforestation efforts is important. As Wasli et al. (2014) described in their preliminary assessment of the growth performance of planted trees under forest rehabilitation, proper silvicultural practices along a line planting system can potentially reduce competition between the dominant pioneer trees and the planted *D. beccarii*. Considering this finding, the specific objective of this study is to determine the effectiveness of additional silvicultural treatment, selective girdling, on the growth performance of planted *D. beccarii* in GANP.

1.3 Objective

Reforestation efforts in the tropical region need comprehensive understanding and proper management during pre-planting and post-planting maintenance. This is due to heavy precipitation throughout the year with no clear dry season especially in the Borneo region which can indirectly affect the soil condition and stand growth performances. In addition, the information on the soil properties in the reforestation area also needs to be fully utilised in order to select the suitable species for planting, proper site preparation and post-planting management. Aside from that, managing the forest through enrichment planting and silviculture treatment as a post planting practice also needs to be taken into consideration. Suitable silviculture treatment such as bush slashing and selective girdling can be implemented under line planting technique as it can maximise the output of the treatment. However, to what extent we can apply the treatments and how effective the treatment application is still rather insufficient.

Hence, the overall objectives of this research were:

i. To characterise the soil quality status in the reforestation area under enrichment planting of Dipterocarp species.

ii. To determine the effectiveness of selective girdling practice as an additional silviculture treatment on the growth performance of planted *D. beccarii* at Gunung Apeng national park.

CHAPTER 2

LITERATURE REVIEW

2.1 Tropical Rainforest and its Current Situation in Malaysia

Generally, Malaysia is divided into two mains continents which are the Peninsular Malaysia and Borneo in which still possess magnificent rainforest that have vast kinds of biodiversity and ecosystem. According to Richards (1952), almost half of Peninsular Malaysia is still covered by tropical rainforest. Meanwhile, in East Malaysia that compromise of Sarawak and Sabah is still mostly covered by the rainforests, but the rate of deforestation increases over time. The tropical rainforest in Malaysia can be divided into two main types of forest that are the lowland dipterocarp forest and hill dipterocarp forest in which possesses up to 3000 timber species (Oldfield, 2002).

Besides, the tropical rainforest in Malaysia plays important role in the ecosystem that acts as a water catchment area, sources of food, traditional medicine, habitat for flora and fauna, sources of high-grade timber, as well as living places for the indigenous people (Jomo et al., 2004). Recently, our tropical rainforests have undergone great depletion due to huge increase in demand for the timber, thus resulting in huge areas of the rainforest that have been cleared for timber and agricultural purposes. This resulting in the loss of water catchment area, extinction of the flora and fauna, reduce the clean water supply and other negative impacts on the forest land occurred. Yong (2014) also reported that Malaysia is one of the global hotspots of forest loss because of the deforestation and degradation due to the timber industries and oil palm industries. It is stated that 14.4% of forest loss since the year 2000 till the year 2012 as the result of the logging activities (both legal and illegal) and conversion of the forested land to other land uses such as the oil palm industry.

Meanwhile, Rautner et al. (2005) also stated that the Borneo's forests are disappearing at a very fast rate as compared to the percent of total forest land area in the mid-1980s. That in percentage values only about 50.4% of Borneo is still forested as compared to 57.5% in the year 2000. In additions, 16.8 million ha of forest loss was reported from 1973 – 2010 where part of these losses was mainly due to extensive forest clearance for multipurpose of forest product utilization (Gaveau et al., 2014) and logging of the tree for timber (Jomo et al., 2004).

2.2 Effort of Reforestation of the Degraded Forest in Sarawak

Generally, reforestation is an effort of replanting the tree after some disturbances (ITTO, 2002). Blaser et al. (2011) also stated that Permanent Forest Estate has been certified under the Malaysian Timber Certification Scheme, as the forest plays many important roles in the economy. On the other hand, forest plantation has been practicing a long time ago in Sarawak in which started in 1979. This due to the planted forest is an important element in the tropical area since it can fulfill many of the productive and protective roles of the natural forest. Moreover, Woon & Haron (2002) also stated that reforestation products not only for protection purposes, but it also can be harvested for export purposes if it organised in a sustainable manner. Meanwhile, if it adequately planned, it can help stabilise and improve the environment.

Moreover, the conservation of local flora and fauna and ecological stability require complementary action within integrated land use and development plans (Awang et al., 1981). The Forest Department Sarawak (2014) reported that timber is one of the most valuable products and has high demand across the countries but leading to excessive logging that will be resulting in deforestation. Hence, an effective encounter measure as the action of replanting the tree species in the area that undergone logging activities (Forest Department Sarawak, 2014). Aside from that, another aim in reforestation activity in Sarawak is to recover the degraded land, preserve the environment as well as to produce 15 million cubics of timbers from 1 million hectares of forest plantation (Razali et al., 2015). This reforestation effort might be adequate to cover up the loss in trees due to logging and adequate supply for timbers in the future.

As in Sarawak, the Forest Department of Sarawak (1999) reported that the total area which had been reforested was about 18,969 hectares, consisting of 2,222 hectares of rattan species and 16,747 hectares of timber species since the period of reforestation program implementation. Among the species being planted were *Shorea macrophylla*, *Acacia mangium*, *Dryobalanops* spp., *Durio zibethinus*, *Shorea pinanga*, and *Hevea brasiliensis* in the aim to rejuvenate the forest in Sarawak after anthropogenic activities.

2.3 General Information and Description on Dipterocarpaceae: *Dryobalanops beccarii* Dyer

The Dipterocarpaceae family plays an important role in the ecology and economies of Asian forest (Poore, 1989). This family tree species contributes to the timber industry for domestic needs in seasonal evergreen forests in Asia. In addition, Panayotou & Ashton (1992) stated that the forest also sources of variety of minor products on which many forest dwellers are directly dependent for its survival. Besides that, the dipterocarps also consist of important timbers for domestic needs in the seasonal forest of Asia. The Dipterocarpaceae family distribution usually can be found in the lowland forest of Borneo, a shade-tolerant tree and it is the dominant tree family in Southeast Asia that forms high proportions of the emergent and main canopy strata of the forest (Manokaran, 1996). Apart from that, the family Dipterocarpaceae is well known for the timber values since it has a good quality of lumber (Pusttaswamy et al., 2010). The common species from the Dipterocarpaceae are *Anisoptera* spp, *Dipterocarpus* spp, *Dryobalanops* spp, *Hopea* spp and *Shorea* spp.

On the other hand, *Dryobalanops beccarii* Dyer also known as kapur bukit by the local people in Sarawak since it grows on the hill (Ashton, 2004). According to Chua & Saw (2003), this tree species has a wide range of distribution from Peninsular Malaysia to Borneo land. Ashton (2004) stated that in Sarawak, *Dryobalanops beccarii* is recorded from Bau, Bintulu, Kapit, Kuching, Lundu and Miri districts. In addition, *Dryobalanops beccarii* is a large terrestrial tree which can reach up to 40-65 meter in height and more than one meter in diameter (Chua & Saw, 2003). According to Ashton (2004), the bark has dark yellowish tawny and prominently irregularly flaky, rarely shaggy and certain parts of the bark gave faintly aromatic smell. Apart from that, the leaves are thinly coriaceous, glabrous surface and the leaf has cuneate base while the margin is often waxy as well as apex with slender acumen. In addition, it has buds' spindle-shaped flowers and ovoid to globose nuts.

Mainly its habitat is on the lowland to hill forest as well as also in mixed dipterocarp forest. Besides, *Dryobalanops beccarii* is one of those valuable timber species since it was recognised as Medium Hardwood by the Malaysian Grading Rules (Harwood, 1998). Thus, *Dryobalanops beccarii* is widely held for the construction of the building, manufacturing of furniture and the sawn wood are also fit for the firewood. This tree also one of the potential species that has been selected in large scale forest plantation since it has fast-growing characteristics. Then, Chua & Saw (2003) reported that *Dryobalanops beccarii* grown on ridges in several booths in the Panti Forest Reserve, Johor. Moreover, in Sarawak, Talip et al. (2011) reported that the Sarawak Forest Department with other several international agencies have implemented reforestation on the abandoned shifting cultivation areas to reestablish the tropical rainforest by planting several types of tree species as well as the *Dryobalanops beccarii* in Gunung Apeng Forest Reserve.

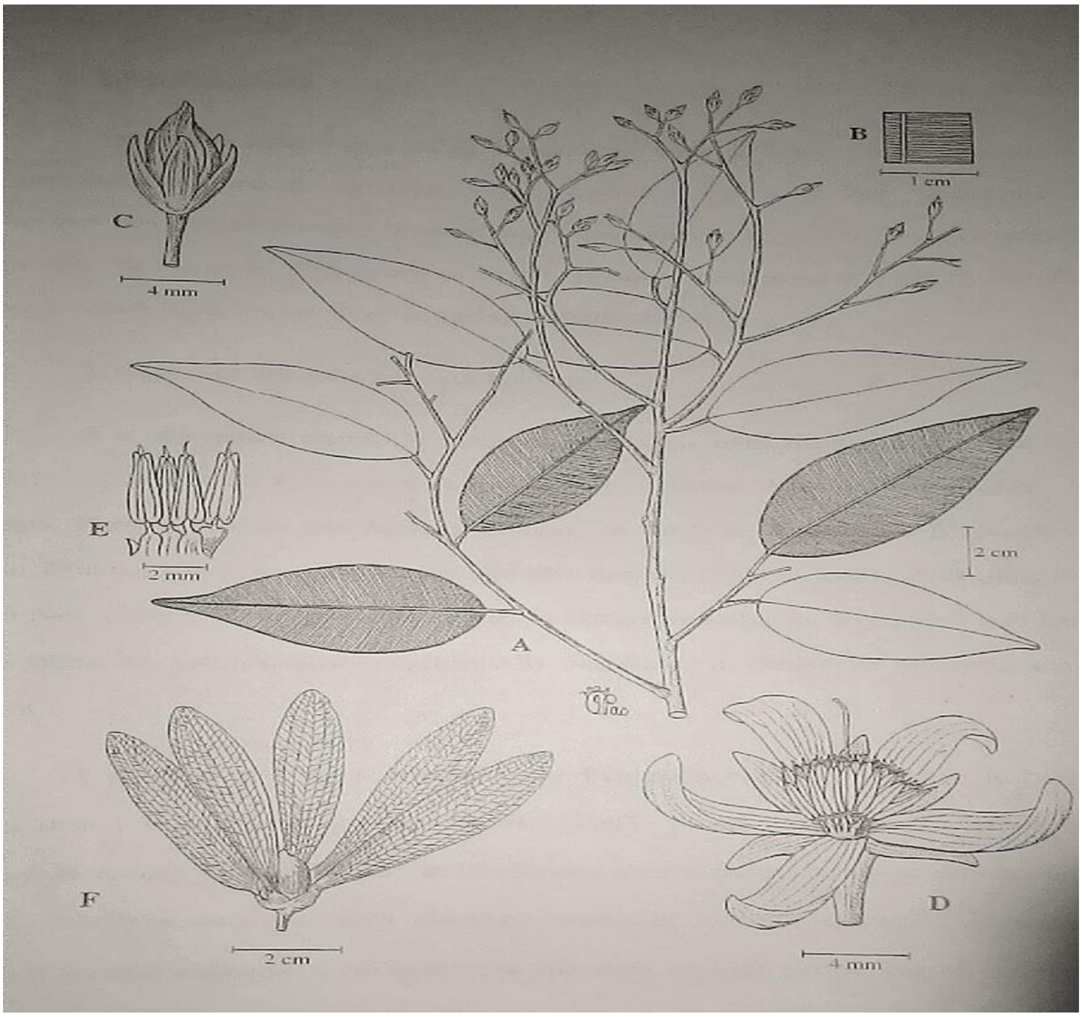

Figure 2.1: *Dryobalanops beccarii*. A, flowering leafy twigs; B, detail of venation on lower leaf surface; C, flower bud; D, open flower; E, adaxial view of stamens; F, mature fruit

(Ashton, 2014)

2.4 Enrichment Planting in Regenerating the Forest

To ensure the successfulness of the reforestation program, it should be accompanied by proper ways or techniques applied such as implementations of enrichment planting and suitable silviculture practices. Enrichment planting is one of the methods used in attempts to supplement natural regeneration as well as to enhance the low tree growth performances in natural succession (Chai & Udarbe, 1977; Appanah & Weinland, 1993). Examples of enrichment planting such as the gap created artificially by human interventions involved in reducing above-ground vegetation (Wyat-Smith, 1963; Adjers et al., 1995) thus, reduce the competition between the planted tree with the adjacent bushes and shrubs. These practices also can be used to rehabilitate logged-over areas in tropical rainforest by using the indigenous tree species where the process involves planting the nursery-raise seedlings in a cleared line or in gaps that been created naturally or artificially (Wyat-Smith, 1963).

As in Malaysia, enrichment planting used to improve regenerating forests for future timber production, and by the desire to restore and thereby protect degraded unproductive areas (Appanah & Weinland, 1993; Kollert et al., 1996). Ådjers et al. (1995) stated that among the principal species used in enrichment planting is the common faster growing and shade tolerant Dipterocarps such as *Shorea macrophylla*, *Parashorea tomentella*, *Dryobalanops beccarii* and *Dryobalanops lanceolata*. Meanwhile, under this enrichment planting there are several types of plantings usually used in reforestation such as line planting method, gap planting method, patch and cluster or nest planting method and island-corridor planting method.

Line planting method is the most popular technique to enrich secondary forests in the absence of seedlings and saplings on the forest floor. According to Lamprecht (1989), the best known enrichment planting is line planting which has several variants throughout the tropics. It is significant to determine the width and the direction of line as the lines are determined from an East to West direction and are 10 m in width to ensure an adequate supply of sunlight (Kobayashi, 1994). Various line planting implementation has reported as in peninsular (DANIDA, 2005) and east Malaysia (Sakurai et al., 1999; Romell, 2007).

Next for gap planting, this technique also importation in reforestation as the forest itself regenerate from the gap created (Whitmore, 1984). The seedlings in the gap received enough sunlight to grow quickly if the gap size is equal to the height of the upper story (Ochiai, 1990). Furthermore, open space planting, lines or gaps planting shows much better result of the growth and survival rate of Dipterocarp species because Dipterocarp species are shade tolerant (Hamzah et al., 2009). This type of planting technique is also used in logged-over forests and usually applied where there are no seedlings of commercial species. In addition, gap planting has also been found more efficient and effective than line planting in terms of cost and keeping the undergrowth suppressed.

2.5 Practice of Silviculture in Forest Plantation

According to Smith (1986), silviculture treatment is one of the sustainable ways to manage the forest plantation in combating the loss of tree species due to raging activity of modernisations and intensive logging by the timber industries. These practices are usually applied in a forest plantation to accelerate tree growth. Moreover, Nyland (1996) stated that the silvicultural treatments are applied to change, accelerate change and maintain the condition of trees and stands. According to Smith (1986), there are many silvicultural treatments that can be applied to forest plantation such as choice of species and site, site preparation, planting technique, spacing, weeding and leaning, thinning, pruning, fertilisation and bush slashing and selective girdling. These treatments can change, accelerate change or maintain tree and stand conditions. The most important aspect is by applying this silvicultural treatment to the forest stand, which may produce as much as four times the yield than the yield of the forest stands without these treatments (Oliver, 1992). One of the cultural treatments is thinning that is applied conducted in stands past the sapling stage, which made to reduce the stand density of trees primarily to improve growth, enhance forest health as well as recover possible mortality (Matthews, 1989). To be more concise, it involves the removal of trees to temporarily reduce stocking to concentrate growth on the more desirable trees and normally this treatment does not alter the gross production of wood volume. Moreover, thinning also affects the stand growth, structure development and as a result it will increase economic yields.

Next is pruning in which involves the process of improving the timber quality and value. Smith (1986) stated that this treatment involves the removal, close to the branch collar, of side branches and multiple leaders from a standing tree. In addition, pruning applied in aimed to control disease as well as improve aesthetics value and accessibility. On the other hand, the tree branches are removed to avoid them forming a knot that can defect the lumber and ultimately reduce the timber value. Apart from that, bush slashing treatment usually practice for an area in which have a high amount of competing vegetation. The shrubs, grasses as well as other unwanted tree species are determined as the competing species. Lee (2013) also stated that the bush slashing treatment is a maintenance works, removing the grasses, shrubs and climber that disturb the planted trees along the line. As a result, low competitions for sources among the planted trees and the weeds. This will provide an optimum environment for the planted tree to grow.

For the selective girdling, other trees at the area aside the planted tree will be girdled to inhibit the unwanted tree species and ultimately will die. The girdling is the removal of a ring of the bark of the tree with a diameter over five centimetres at breast height thus lagging the nutrients supply for the tree to live (Nyland, 1996). As a result, the tree that has been undergone selective girdling will die and gradually disintegrate into the soil. The most important is this treatment not only minimise the damage when the tree dies, but it also returns the nutrient to the soil.

In addition, they are various technique or treatment that can be applied in silvicultural practice, but we need to be precise in choosing the treatment depending on the type of species of planted tree in the forest plantation. Matthews (1989) also stated that the silviculture treatment should verify that it is ecologically fitting in the long run as well as endure the ecosystem's health and productivity.

2.6 The Important of Soil Properties in Dipterocarp Forest

In general, the trees and other vegetation gain their nutrient need from the soil as the soil contains various types of essentials of macro-nutrient and micro-nutrient. On the other hand, in term of soil classification, the type of soil in Borneo land especially for Sarawak, it is classified as Podzolic soil group based on the Sarawak Soil Classification System (Scott, 1963). The soil properties in the forest are rich in organic matter that useful for plant growth. FAO (2005) stated that high accumulation of organic matter on the ground surface and high activity of microorganisms was caused by the decomposition of the organic materials such as leaves, litter and animal manure. The high amount of rainfall and poor drainage also affect the organic matter. Besides that, the unstable or changing in the climate also contribute to high salinity soil. Moreover, high salinity soil can significantly inhibit tree growth and composition.

In addition, the soil properties located at natural vegetation or natural forest, it has high porosity and high biological activity as well as less or no interference by man (FAO, 2002). The interference of man usually comes in terms of forest plantation, agricultural activity and other types of plantation. Marin-Spiotta et al. (2009) also mentioned that any disturbance that occurs during reforestation will result in nutrient limitation which may affect forest recovery and soil carbon accumulation. Sanchez et al. (2003), Juo and

Franzlueebber (2003) stated that most soils in the tropical regions are infertile, and once the natural forest has been cleared, nutrients can be rapidly lost consequently leading to longer forest recovery time. Disturbances that occur led to damage in soil resources to a degree which delays the establishment of new succession forests after abandonment (Geist & Lambin, 2002; ITTO, 2002).

Meanwhile, Aragao (2009) also stated that the soil types are highly variable in the tropical rainforest due to various factors such as climate, vegetation, topographic position, parent material and soil age. Moran et al. (2000a, 2000b) stated that succession of forest plays a vital role in soil restoration through an accumulation of biomass, build-up of litter and organic matter. Besides, most soils in the tropical regions are considered infertile, then once the forests have been cleared and being utilized continuously, depletion of organic matter in the surface soil by soil erosion will occur due to high temperature, humidity and heavy rain. These results in rapid loss of nutrients which would consequently lead to degradation on the soil in the tropics (Wasli et al., 2009).

CHAPTER 3

MATERIALS AND METHODS

3.1 Study Area

This study was conducted at Gunung Apeng National Park (GANP), Serian, Sarawak, (N00°55’24.7’’, E110°38’32.2’’). GANP is a reforestation site for conservation and its total size is estimated to be 1800 ha. In addition, Gunung Apeng Forest Reserve was established in 2005 with the cooperation of the Japan-Malaysia Association and Forest Department Sarawak. The average annual rainfall recorded was 3,500 mm, with monthly minimum rainfall in the area exceeded 100 mm except for a period between mid-June to end of July (Department of Irrigation and Drainage, 2010). Moreover, the annual temperatures ranged between 23 °C (73 °F) in the early hours of the morning and rise to around 33 °C (91 °F) during mid-afternoon with a little monthly variation.

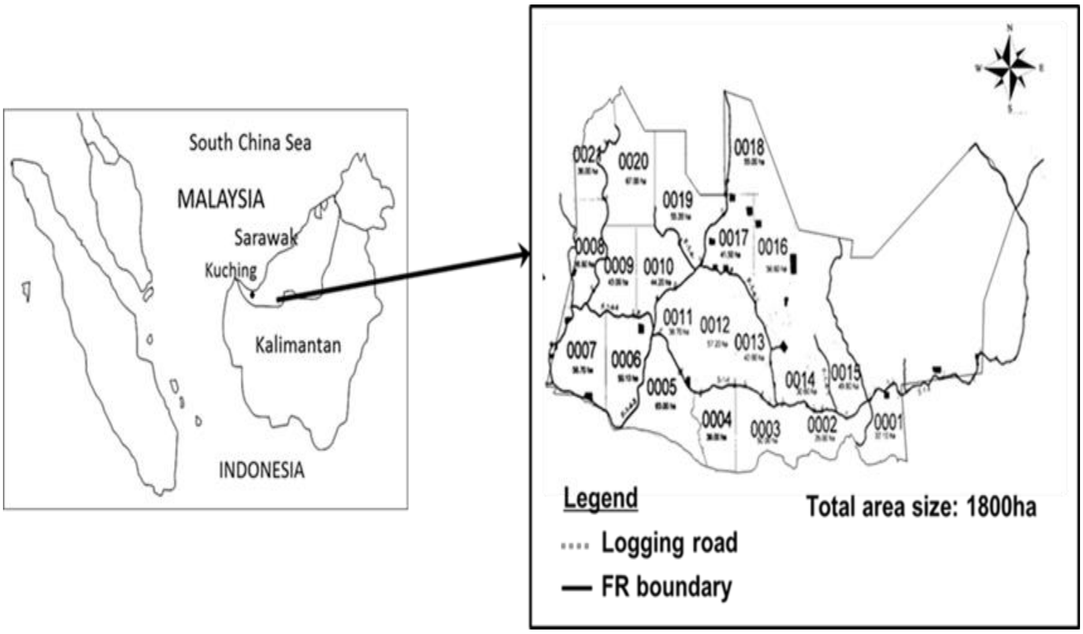

Figure 3.1: Location of Gunung Apeng National Park

3.2 Experimental Design

In the case of our study, the trees stand was planted in 2005 and accompany with bush slashing practice where the silviculture treatment specifically selective girdling was only applied in 2012 to cope with the low survival and growth performance. Besides, the type of soil at the study site was determined as grey-white podzolic soil which has more prominently sandy texture with strongly acidic with low nutrient content, deficiency moisture, and aeration. Two study plots with the size of 30 m × 50 m were established within the compartment planted with *D. beccarii* in the year 2005. Two types of silviculture treatments were implemented which were T1: bush slashing only which acts as a control plot and the second treatment was T2: bush slashing with additional of selective girdling practices on the existing pioneer species between or on the planting line. The experimental layout was presented in Figure 3.2 and the description of the silviculture practices show in Table 3.1.

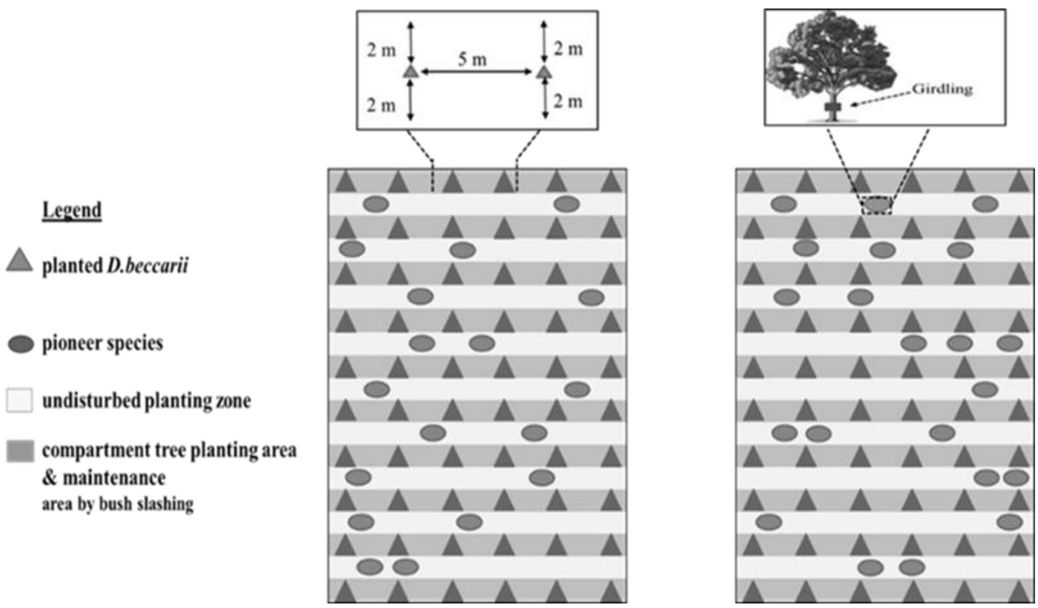

Figure 3.2: Experimental plot and planting layout

Table 3.1: Type of silviculture treatment applied

Treatment	Applications
Treatment I – bush/ undergrowth slashing (T1)	The lower story trees or unwanted trees were chosen to slash. All herbaceous species and saplings of pioneer species were cleared along the planting line with radius of 2 m from the planted tree by manual slashing using bush knife. The bush slashing was done annually. The width of the cleared area was shown in Figure 1.
Treatment II – Bush slashing + selective girdling (T2)	Bush slashing practices as applied in T1 and for selective girdling only one-time application at the initial stage of the experiment. The, a single bladed knife was used to girdle the tree. The ring of the bark entirely around the trunk was removed. The girdling must be completed to remove the bark of encircle trunk to a depth of at least ½ inch on small trees and 1 to 1 ½ inches on larger trees. Girdling only applied to most dominant pioneer species with DBH more than 10 cm with large crown cover. The girdling was applied once at the initial stage of this study.

3.3 Method of Tree Assessment

For the assessment on the growth performance of planted *Dryobalanops beccarii* in the study plots, measurements such as stem diameter and the total height of the trees were assessed. The stem diameter of the trees was measured at a constant height of 1m and 30cm above the ground of the trees. The measurement of the height of the tree was taken using a clinometer by measuring the angles from the horizontal to the tip of the tree. The survivals percentage of planted *Dryobalanops beccarii* was calculated by the formula:

$X = Z / (Y) \times 100\%$

Where:

X = Percentage of survival rate of *Dryobalanops beccarii*

Y = Total number of planted *Dryobalanops beccarii*

Z = Total number of planted *Dryobalanops beccarii* that is still survived

On the other hand, for measuring the light intensity, Lux/Foot-Candle (FC) meter was used. Firstly, the light intensity was measured on the open space. Then, it was continued within each plot on every planted tree inside the study plots, then open space again after finish measuring all the trees. In addition, the light intensity was taken at the same time frame which was conducted at the morning for all assessment. The Foot-Candle unit was converted into micro Einstein to get the percentage in the respective plot.

Percentage of light intensity=X/ (Open space light intensity) ×100%

X = Light intensity in micro Einstein

Micro Einstein = 0.2 × FC unit

3.4 Methods for Soil Sampling

For soil sampling, it was conducted within the same studied plot for the assessment of growth performance. The composite soil samples were collected from the depth of 0 – 10 cm and 30 – 40cm, respectively. The soil samples were collected randomly on each subplot on the planting lines by using a soil auger. Undisturbed soil samples were collected using a 100cc core sampler and were brought to the laboratory for further soil analysis. For soil profile description, a soil pit with a depth of 80 cm was dug at the center of each study plot. Soil profile descriptions were conducted adopting the standard procedures by ISSS (Schoeneberger et al., 2002). Next, the soil penetration resistance was analysed using Hasegawa penetrometer and the soil penetration resistance was calculated by the following formula (E = M x G x H x C) where E is the soil penetration resistance (J), M is the mass of the penetrometer (2.0 kg), G is the gravitational acceleration (9.8 ms^{-2}), H is the vertical drop of the penetrometer weight (0.5 m), and C is the count of strikes for each depth.

3.5 Soil Analyses

The collected soil samples were air-dried for a week, crushed, homogenized and passed through a 2 mm mesh-sieve before the soil physicochemical analyses were conducted. All plant materials such as fine roots, twigs and leaves were removed carefully. Soil bulk density was determined on the undisturbed samples, collected at each soil horizon depth using a 100cc core sampler with the ratio of the dry mass of soil to the bulk volume of soil core. Soil pH was measured in distilled water, H2O and (soil to solution ratio of 1:5) by the glass electrode method (denoted as pHw). Total Carbon (T-C) content in soil was determined using loss on ignition method (McKeague, 1976). In addition, the soil Total Nitrogen (T-N) content was determined by Kjeldahl acid digestion and tested with Hach DR/900 Colorimeter. Available Phosphorus content in soil was determined by the Bray II method (Bray & Kurtz, 1987; Kuo, 1996) with UV-Vis Spectrophotometer at a wavelength of 710 nm (Jasco V-630). The contents of soil exchangeable bases (Ca, Mg, K and Na) were extracted three times with 1 M ammonium acetate, NH4-OAc adjusted to pH 7.0 and 10% NaCl and the concentrations of Ca, Mg, K and Na were determined with the atomic absorption spectrophotometer (AAS) (Thermo Scientific, ICE Series 3500). Titration methods were used to determine the cation exchange capacity (CEC) of the soil. The filtrate from the pH (KCl) measurement was used for soil exchangeable Al analysis. Exchange acidity (Al + H) was determined using the titration method with 0.01 M NaOH and the content of the exchangeable Al with 0.01 M HCl.

3.6 Data Analysis

All data of soil physicochemical properties, the relative growth rate in height and diameter, and survival rate were statistically analysed in treatment 1 and 2 were statistically compared using an independent student's t-test. Next, all growth performance for both treatments which include the DBH, height, MAID and MAIH were analyzed using independent Student t-test at 5% of confident interval. Next, as the independent variables were not distributed normally, nonparametric tests of significance were utilized. Mann–Whitney U test was used to assess differentiate the growth performance data between T1 and T2 for each assessment in term of DBH and height. All data were analyses using SPSS version 21.0 and the descriptive statistic was performed using Minitab version 18.0.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Soil Morphology Properties in the Study Area

Table 4.1 shows the summary of soil morphological properties at T1 (bush slashing) which act as a control plot and T2 (bush slashing + selective girdling) plot. At the T1 plot, (N00°55.137’, E 110°39.713’), the soil profile has five (5) horizons which are horizon O, A, AB, B1 and B2 horizon. The horizon O with a depth of 0 – 4 cm mainly consists of litters and undecomposed fallen leaves. Then, the horizon A with a depth of 4 – 11 cm. Based on the “feel” touch method, the boundary of the surface layer was classified as clear - gradual wavy and the colour is 10YR4/3. Moreover, the soil at the horizon A was classified as a Silty Clay Loam. Next is horizon AB with a depth of 11 – 20 cm, the boundary was determined as clear wavy and the colour is 10YR5/4. The soil at AB horizon classified as Silty Clay Loam. For the B1 horizon with a depth of 20 – 51 cm, the boundary was classified as diffuse wavy and the colour is 10YR6/6. Then, the soil was classified as Silty Clay. The next horizon observed is horizon B2 with a depth of 51 – 80 cm, the boundary was classified as diffuse wavy with the colour is 10YR8/2. The soil texture was classified as Silty Clay. Then, for the overall soil profile properties, the consistence recorded was very sticky as well as very plasticity at horizon B1 and B2. Besides that, for the structure, the grade was determined as weak at horizon A, medium to weak at horizon AB, as well as moderate at horizon B1 and B2. Next, the hardness for horizon A, AB, B1 and B2 were 9.0 mm, 13.5 mm, 19.0 mm and 17.0 mm respectively. No rock fragment was observed at each of the horizons. Apart from that, the organic matter recorded as high at horizon A, low at horizon AB, B1 and B2 as well as organic layer (<2) at O horizon. The root composition from observation at the horizon in term of size and abundance were recorded. At horizon A, the size was coarse to fine and the abundance was common. Then, the size fine to very fine and the abundance were few at horizon AB. At horizon B1, the root size is fine, and the abundance was very few whiles at horizon B2 the size of the root and its abundance is very fine. For the moisture, it was recorded as moderately moist at horizon O, A, AB, B1 and B2.

At the T2 plot (N00°55.118', E 110°39.700') the profile has five (5) horizons which are horizon O, A, B1, B2 and BC horizon. The horizon O with a depth of 0 – 5 cm mainly consists of litters and undecomposed fallen leaves. Then, the horizon A with a depth of 5 – 16 cm. Based on the "feel" touch method, the boundary of the surface layer was classified as clear wavy and the colour is 10YR3/4. Moreover, the soil at the horizon A has classified a Loamy Sand. Next is horizon B1 with a depth of 16 – 29 cm, the boundary was determined as gradual wavy and the colour is 10YR6/4. The soil at the B1 horizon classified as Sandy Clay Loam. For the B2 horizon with a depth of 29 – 58 cm, the boundary was classified as gradual to diffuse wavy and the colour is 10YR7/4. Then, the soil was classified as Silty Clay. The next horizon observed is horizon BC with the depth of 58 – 80 cm, the boundary was classified as gradual to diffuse wavy with the colour is 10YR8/4 and the soil texture was classified as Silty Clay. Then, for the overall soil profile properties, the consistence recorded was slightly sticky and slightly plastic at horizon B1, sticky and plastic at horizon B2 as well as sticky and very plasticity at horizon BC. Besides that, for the structure, the grade was determined as weak to moderate and at horizon A, and moderate at horizon B1, B2and BC. Moreover, the type of the soil structure is subangular blocky at horizon A, B1, B2 and BC. Next, the hardness for horizon A, B1, B2 and BC were 10.0 mm, 15.0 mm, 16.8 mm and 19.5 mm respectively. Rock fragment only found at horizon BC with the size range gravel to fine gravel. Apart from that, the organic matter recorded as medium at horizon A and low at horizon B1, B2 and BC. Besides that, the organic layer (<2) was determined at the O horizon. The root composition from observation at the horizon in term of size and abundance were recorded. At horizon A, the size was coarse to medium and the abundance was common. Next, the size is coarse to very fine and the abundance was from very few to few at horizon B1and at horizon B2, the root size is very fine, and the abundance was very few while none root was observed at horizon BC

Based on the Sarawak soil classification system, the soils in the area were classified into the Nyalau family of the Grey-White Podzolic Soil group (Teng, 2004). The soils in the study area were derived from sedimentary rocks mainly of mixed shale and sandstone (Wasli et al., 2014). Moreover, the soil of this group mainly consisted at low hills and dissected hills behind the coastal alluvium and coastal swamps which extended throughout the length of the northeast-southwest axis of the Sarawak region. In addition, the main landforms of this zone consisted of low hills and dissected hills ranging from 30-150 m above sea level and are highly separated by narrow bottomland tracts along major tributary streams. Soils under such classification are generally acidic with poor natural fertility (Teng, 1994). This soil group corresponds to the soil group of Paleudults based on the USDA classification system (Soil Survey Staff, 2006). Soils of these features consist of friable to firm consistency, and weakly to a moderately developed structure. The soils are well-drained to moderately well-drained and have variable soil depths. According to Wasli et al. (2014), such This type of soil do not possess densic, lithic, paralithic, or petroferric contact within 150 cm of the mineral soil surface and do not have a clay decrease of 20 percent or more from the maximum clay content (Soil Survey Staff, 2006).

Table 4.1: Summary of soil profile description for T1 and T2 study plot

Treat-ment	Horizon	Depth (cm)	Colour	Field texture a)	Con-sistency b)	Structure c)	Root d)	Boundary e)	Rock fragment f)	Hardness (mm) g)
T1 bush slashing	**(N00°55.137', E 110°39.713')**									
	O	0 – 4	Litterfall				C/M	CI	N	
	A	4 – 11	10YR4/3	SiCL		1/SB/VF	C-F/C	CW/GW	N	9
	AB	11– 20	10YR5/4	SiCL		1/SB/VF	F-VF/F	CW/GW	N	13.5
	B1	20 – 51	10YR6/6	SiC	VS	2/SB/F	F/VF	DW	N	19
	B2	51 – 80	10YR7/6	SiC	VS	2/SB/F	VF/VF	DW	N	17
T2 Bush slashing + selective girdling	**(N00°55.118', E 110°39.700')**									
	O	0 – 5	Litterfall					CI		
	A	5 – 16	10YR3/4	LS		1/SB	C-M/C	CW	N	10
	B1	16 – 29	10YR6/4	SCL	SS	2/SB	L/VF-VF/F	GW	N	15
	B2	29 – 58	10YR7/4	SC	S	2/SB	VF/VF	GW-DW	N	16.8
	BC	58 – 80	10YR8/4	SC	S	2/SB	None	GW-DW	G-FG	19.5

Abbreviation: a) Texture: SiC: Silty Clay, SCL: Sandy Clay Loam, SiCL: Silty Clay Loam, LS: Loamy Sand, SC: Sandy Clay; b) Consistency: ss: slightly sticky, s: sticky, vs: very sticky, vs: very plastic; c) Structure: Grade: 1:weak, 2: moderate, Type: Sb: subangular blocky, Size: vf: very fine, f: f:fine, m: medium; d)Root size and abundance: C: Coarse, F: Fine, VF: very fine; abundance: C:Common, M: Many, F: Few, VF: Very Few; e) Boundary: abrupt, c: clear, g:gradual, d: diffuse, w: wavy, s: smooth; f)Rock fragment: Abundance: D: Dominant, Shape: SA: subangular, Size: G-FG: Gravel to fine gravel; g)Hardness was measured using a Yamanaka-Push Cone type penetrometer

T1: Bush slashing treatment	T2: Bush slashing + selective girdling
	

Figure 4.1: Image of soil pits for soil profile description for each treatment in the study site

4.2 Soil Physicochemical Properties in the Study Site

Table 4.2 shows the average value of the physicochemical properties of soils both in T1 (bush slashing treatment) and T2 (bush slashing + selective girdling). The soil sample were collected at surface (0-10 cm) and at subsurface (30-40 cm) only as it is the two horizon layer of the soil in which the soil parameters such as physical or chemical properties were distinguishable. In additions, the soil profile that has been dug up to 1 m depth (Figure 4.1) showed that there was very fine root penetration at 80 cm and above for T1, and no root observed above 80 cm depth in T2. Meanwhile, despite different silviculture treatments were applied, the result showed that no significant influence of either bush slashing or selective girdling on the soil properties. Soils at both treatments were slightly acidic with the pH (water) ranging from 4.57 to 4.44 at surface soil and average 4.72 for the subsurface soil. The acidic nature of the soil properties may due to the loss of exchangeable bases through nutrient uptake processes by the plant and leaching under a tropical environment (Hamzah et al., 2009). The sand content both in surface and subsurface soils was around 50%, while the clay content was more than 30%.

Next, total carbon in surface and subsurface soil ranged from 24.9 to 27.3 and 15.4 to 18.7 g/kg, respectively. Total nitrogen ranged from 0.8 to 1.0 and 0.2 to 0.3 g/kg in surface and subsurface respectively. The exchangeable bases either in surface or subsurface soils were low compared with the exchangeable Al, thus resulting in high Al saturation both in T1 and T2. Al saturation was more than 80% at surface and subsurface for both treatments. The CEC ranged from 7.6 to 8.0 $cmol_c\ kg^{-1}$ and 5.3 to 6.5 $cmol_c\ kg^{-1}$ at surface and subsurface respectively. The clay content at surface and subsurface soils were 15.3 to 23.0% and 24.4 to 19.3%, respectively. The available CEC that contribute to the soil fertility was largely dependent on the organic matter and clay percentage in the soil. As for tropical soils which naturally under the acidic nature, soil fertility is largely affected by the negative charges derived from the organic matter and clay content (Arifin et al., 2007; Tanaka et al., 2007, 2009).

Table 4.2: Soil physicochemical properties at T1 (bush slashing) and T2 (bush slashing +selective girdling). Different letter indicates significant difference at 5% using independence student t-test, ns: not significance.

Soil physicochemical properties		T1	T2
0 - 10 cm depth			
pH Water		4.57 ± 0.46ns	4.44 ± 0.32ns
pH KCl		3.54 ± 0.24ns	3.50 ± 0.24ns
EC	µs/cm	32.3 ± 11.55b	38.9 ± 6.53a
Soil organic matter	%	4.70 ± 1.01a	4.29 ± 0.1b
Total carbon	g/kg	27.3 ± 5.86a	24.9 ± 0.57b
Total Nitrogen	g/kg	1.0 ± 0.97ns	0.8 ± 0.21ns
C/N ratio		39.7 ± 21.6a	31.4 ± 6.67b
CEC	$cmol_c$/kg	8.00 ± 0.94ns	7.60 ± 1.35ns
Exch. Calsium	$cmol_c$/kg	0.55 ± 0.26ns	0.50 ± 0.03ns
Exch. Magnesium	$cmol_c$/kg	0.04 ± 0.01b	0.05 ± 0.03a
Exch. Potassium	$cmol_c$/ kg	0.13 ± 0.07ns	0.12 ± 0.05ns
Exch. Sodium	$cmol_c$/kg	0.08 ± 0.03ns	0.09 ± 0.02ns
Exch. Aluminium	$cmol_c$/kg	3.29 ± 0.93ns	3.32 ± 0.80ns
Sum of bases	$cmol_c$/kg	0.80 ± 0.29ns	0.76 ± 0.13ns
ECEC	$cmol_c$/kg	4.1 ± 0.96ns	4.1 ± 0.75ns
Bases Saturation	%	9.8 ± 2.58ns	10.3 ± 2.85ns
Available P	mg P/kg	11.12 ± 1.94a	8.82 ± 2.99b
Aluminium Saturation	%	80.2 ± 6.76ns	80.7 ± 5.78ns
Clay	%	23 ± 9.35a	15.25 ± 1.44b
Silt	%	23.25 ± 2.25b	26 ± 2.12a
Sand	%	53.75 ± 10.74b	58.75 ± 3.5a
Bulk density	g/cm^3	1.10 ± 0.10ns	1.15 ± 0.16ns
Particle density	g/mL	2.95±0.19ns	2.92±0.33ns
Mositure content	%	2.33 ± 0.78a	1.87 ±0.34b
30 - 40 cm depth			
pH Water		4.72 ± 0.38ns	4.72 ± 0.35ns
pH KCL		3.55 ± 0.25ns	3.63 ± 0.23ns
EC	µs/cm	14.5 ± 4a	11.8 ± 3b
Soil organic matter	%	3.22 ± 0.37ns	2.65 ± 0.18ns
Total carbon	g/kg	18.7 ±21.6ns	15.4 ± 1.06ns
Total Nitrogen	g/kg	0.2 ± 0.15ns	0.3 ± 0.22ns
C/N ratio		108.2 ± 76.2a	76.7 ± 40.26b
CEC	$cmol_c$/kg	6.45 ± 0.66ns	5.25 ± 0.19ns
Exch. Calsium	$cmol_c$/kg	0.42 ± 0.15a	0.25 ± 0.06b
Exch. Magnesium	$cmol_c$/ kg	0.003 ± 0.03b	0.028 ± 0.01a
Exch. Potassium	$cmol_c$/kg	0.06 ± 0.03ns	0.08 ± 0.07ns
Exch. Sodium	$cmol_c$/kg	0.05 ± 0.01ns	0.07 ± 0.02ns
Exch. Aluminium	cmolc/kg	3.73 ± 0.92a	2.90 ± 0.61b

Table 4.2 continued

Sum of bases	$cmol_c$/ kg	0.52 ± 0.2a	0.37 ± 0.15b
ECEC	$cmol_c$ /kg	4.2 ± 0.80ns	3.3 ± 0.63ns
Bases Saturation	%	8.3 ± 3.73a	7.1 ± 2.85b
Available P	mg P/kg	5.59 ± 0.99ns	5.45 ± 1.43ns
Aluminium Saturation	%	87.2 ± 5.51ns	88.5 ± 4.42ns
Clay	%	24.4 ± 3.12ns	19.3 ± 2.36ns
Silt	%	26.3 ± 4.13ns	25.6 ± 1.93ns
Sand	%	49.3 ± 6.88ns	55.1 ± 3.64ns
Bulk density	g/cm^3	1.30 ± 0.3ns	1.42 ± 0.8ns
Particle density	g/mL	2.84 ± 0.18ns	2.88 ± 0.25ns
Moisture content	%	1.82 ± 0.39a	1.40 ± 0.24b

4.3 Soil Hardness in the Study Site

The soil compaction also plays a role in plant growth and survival. A compact soil can cause inhibition of the tree root to penetrate the soil for nutrients uptake. The deeper the root penetrates onto the soil reduce the risk of fallen thus contribute to its survival means. From Figure 4.2, the soil compaction nearly the same for each treatment plot in the study area. The soil in the study area quite compact especially at the silviculture treatment plot (T2 and T3). This may occur due to the soil at the study site contained a high amount of clay as the soil mostly range from sandy clay loam to loamy sand in texture. At the surface soil as observed, the soil hardness for T2 was more compacted than T1. Next for the sub-surface soil (30 cm and below), the trend of penetration tends to increase in hardness which may indirectly affect the root development of the planted tree. This is consistence with the bulk density presented in Table 4.2 where higher bulk density value recorded at the sub-surface soil compare to surface soil.

In overall the soil compaction properties in the study site still considered preferable for the root penetration of the planted tree at both treatments. This is due to from 0 – 100 cm of the soil, the soil penetration resistance was less than 15.000 J/cm since soil penetration more than 15.000 J/cm was considered can inhibit the root development (Canarache, 1990). Besides, the higher soil penetration resistance at sub-surface soil may due to the gravel material in the soil (Benghough, 2001). This was consistence with the soil profile pits presented in Table 4.1 where the soil profile was limited to 80 cm due to the present of rock fragment. Despite that, the land used history also can interfere with the soil hardness in the reforestation area. As reported by Wasli et al. (2014) in the Gunung Apeng once was a placed for the shifting cultivation by the indigenous people.

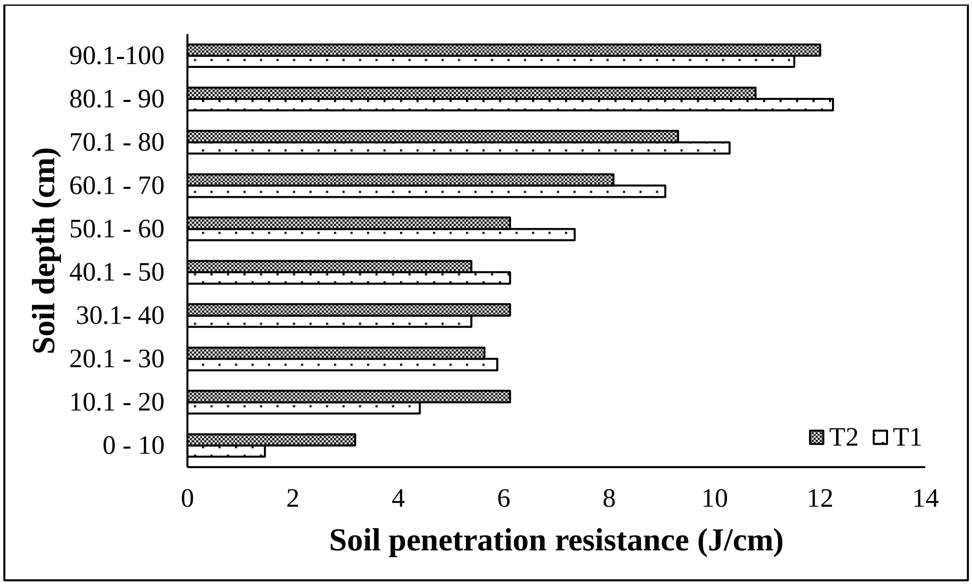

Figure 4.2: Soil hardness properties for both treatments in the study site.

4.4 General Overview of the Soil Status in the Study Site for Both Treatments

Based on the soil profile description conducted, it can be concluded that the soil type at T1 and T2 plots considered as the same group of soil. Moreover, the type of soil at the study site was determined as grey-white podzolic soil which has more prominently sandy texture with strongly acidic with low nutrient content, deficiency moisture, and aeration. In addition, relative similarities between other morphological properties at this A horizon, such as structure and the soil roots were observed both soil profiles, with the soil texture ranged from sandy clay loam to loamy sand which allows the penetration of roots around 5 – 10% and absorption of water to maintain soil moisture. Fine roots were observed in the uppermost layer of the soils across the study areas to the deeper part of the solum, except at the lower part of soil at T1 and T2 plots. This was due to the moderate grade of soil structures, resulting from the silty clay loam to loamy sand texture in all the sites. In term of the soil hardness between all study plot, all plots showed almost the same soil hardness which was range from 9mm – 19mm except for T1 in which the hardness was the highest portrayed (21 mm) at horizon BC.

Next, from Table 4.2, the organic matter content in the soil for both treatments showed almost in the same range of organic content. Organic matter is one of the indicators of the soil health condition in the forest. Moreover, Paniagua et al. (1999) also stated that Soil Organic Matter (SOM) is regarded as the single most important indicator of soil fertility and a major component in the assessment of soil quality in the tropical regions (Paniagua et al., 1999). It also considers normal for the soil organic matter at surface soils was relatively higher as compared with that of the subsurface soils due to accumulation of decomposing nutrient usually occur on the surface soil. Meanwhile, at both treatments, the bulk density considered low value in which indicates the soil in the study plot was less compact than other soil types. This may due to the high sand percentage for the soil texture at both treatment areas which more than 40%. Moreover, Alexander (1989) also stated that higher organic matter content consequently decreased the value of the bulk density of soils. This is consistent with secondary forest soil conduction in which has high organic content due to many sources of litter at the surface soil.

Next, it is observed that high total carbon content in which more than 15 g/kg for both treatments. The higher content of T-C especially in the secondary forest was presumably due to a large contribution of fresh organic matter and its accumulation in soils from the permanent vegetation in the former than the latter (Arifin et al., 2008). Vice versa, the total nitrogen was low for both treatments with the C/N ratio value higher than 30. This situation indicated that slow nutrient recycling occurs inside the study area. The low nutrient recycling rate may due to various factors in which one of the main causes is acidity. As observed, both treatment pH value was lower than 5 with high Al saturation. The high Al content may indicate weathering status of the soils (Aiza et al., 2013). However, the toxicity of Al will restrict and disturb the seedling growth (Akbar et al., 2010). Despite high acidity observed, the high available phosphorus (P) contents in the soil may counter back the soil acidity conditions. As the P important for the root growth will allow the planted tree to survive the harsh condition environment in the secondary forest. The growth performance might be slow, but in terms of reforestation the survival percentage also an important indicator.

Overall, both soil properties in term of morphological and physicochemical properties at both treatments were almost the same. Even though there were some of the soil parameters for T1 and T2 has significant different, however they were still in same range value of the data. The pH at both study plots were under pH 5 in which the soil relatively acidic. Then, both plots have high C/N ratio with value more than 30 indicated the nutrient recycling properties at each plot is slow. Besides, the exchangeable cation such as Mg, Ca, Na and K for both plots are relatively low. The high Aluminum concentration at both study plots probably the main source of the low acidity, low exchangeable bases and aluminum toxicity may slow down the growth of the planted tree. Furthermore, the soil at both study plots categorized onto the same category of soil which determined as “grey white podzolic soil” that further explain why the chemical properties were almost the identical. Hence, the similar soil properties in both treatments will support the growth performance of the planted *Dryobalanops beccarii* at the same rate or pace.

4.5 The Effect of Silviculture Treatments on the Neighbouring Pioneer Species after 72 Months of Silviculture Intervention

Table 4.3 shows ten (10) the most encountered non planted or pioneer tree species existing in the T2 (girdling + bush slashing) and T1 (bush slashing only) at the initial and 72 months of assessment in the experimental plot. As shown in Table 4.3, *Macaranga gigantea* was selected for being girded as it was the most dominant pioneer tree during the initial assessment of the trial plot. The dominant distribution of the *Macaranga gigantea* may due to the experimental plot was established in a secondary forest as Zakaria et al. (2008) reported that genus *Macaranga* prefers to grow in not forested areas or semi forested areas (secondary forest). Besides, some researchers also reported that the stand of *M. gigantea* was commonly found in open areas (Whitmore, 1988) and it is also generally associated as one of the major species dominating secondary forests that were affected by logging activities (Tagawa, 1988; Wermer, 1997). In addition, most *Macaranga* species have large lobed leaves forming a main canopy where this characteristic structure and density may allow the development of a dense sub-canopy layer with transparent leaves foliage that will potentially inhibit the light availability for lower understory and seedlings (Slik et al., 2000).

In this trial plot, 36 *Macaranga gigantea* was encountered at the initial assessment and 18 of those with the most dominant either in diameter size or canopy crown cover were selected and later, applied the required silviculture treatment by means of girdling. After 72 months of assessment, only 15 trees felled naturally while another 3 trees were still standing but with no fresh leaves visible. Girdling practice does not instantly deconstruct or decomposed the unwanted trees as this practice will inhibit the nutrient uptake by the targeted tree and then, resulted in defoliation and slow death of the girded tree. Aoyagi et al. (2012) reported that the presence of *Macaranga* patches can affect the performance of dipterocarp seedlings through the forest floor condition due to the nutrient accumulation rate beneath the litter layers was slow in which resulted to the slow recovery of the nutrient availability of the forest floor. Hence by applied girdling, immediate defoliation of the *Macaranga* tree will reduce the possibility of slow nutrient recovery since the defoliate leaves degraded faster than naturally fallen fresh leave.

Besides, the result obtained from the field monitoring and data obtained, girdling practices on the unwanted tree showed its positive impact in controlling the pioneer species especially *M. gigantea* along the planting line. In the T1 plot where no girdling applied, the occurrences of *Macaranga gigantea* showed an increase in number after 72 months of this study. Moreover, controlling the emergent of a pioneer with dense canopy layer is important to improve the light condition at the forest floor as the light intensity was the main factor influencing the seedling mortality and growth in the first 24 months of planting (Hattori et al., 2009).

Removing the pioneer species via girdling will gradually improve the light intensity as girdling practices did not provide a direct increase in light availability on the forest floor. By gradually increasing the light intensity, it will provide an optimum condition for the planted *D. beccarii* since this species is considered as a shade-tolerant tree at the seedling stage and over exposure to sunlight will induce scorching on the leaves. Hence, by incorporating selective girdling on the dominant *Macaranga* trees in the experimental plot, this may allow the girdled trees to decease slowly and reduce the impact when fall onto the ground thus can provide a more favorable environment for the planting seedling to grow.

Furthermore, a decrease in stand density to an intermediate level can enhance the growth rate of under-planted seedlings (Paquette et al., 2006).

Even though there were some increase in number of others pioneer tree (Table 4.3) such as *Ficus aurata*, *Dactylocladus stenostachy*, *Lithocarpus* sp. and *Horsfieldia* sp. in the study plot after 72 months of the silviculture implementation, it considered as normal phenomenon in the secondary forest where the number of plant species will rise during the young secondary regrowth phase (Wermer, 1997). Moreover, pioneer species proliferated shortly after silvicultural interventions, but then diminished to primary forest levels by 20 – 30 year post-treatment (Phillips et al., 2003; Van Gardingen et al., 2003). Aside from that, the girdling practices accompanied by slashing also important aspects since the slashing will as it freed the regenerations or planted tree species from competition (Carandang et al., 2007).

Next, Figure 4.3 shows the trend of occurrence for the neighboring pioneer tree species with DBH more than 10 cm along the planting line for both treatments at the initial stage and 72 months of experimental silviculture implementation. During the initial assessment, the number of pioneer species was prominently identified mostly in T2 plot than in the T1 plot. This may be ascribed to the dominant occurrences of *Macaranga gigantea* tree in the T2 plot as shown in Table 4.3 contribute to the pattern of occurrences in the pioneer tree encountered. Meanwhile, after 72 months the pattern of occurrences changed drastically where the trend shows increased in the occurrences of bigger pioneer species with DBH more than 20 cm in T1 plot if compared to percentage occurrences at initial assessment. Vice versa, in the T2 plot, the percentage of pioneer species with DBH more than 20 cm as observed has reduced in occurrences. Thus, the trend of occurrences as shown in Figure 4.3

indicated that the number of bigger pioneer species in the T1 plot increased after 72 months as compared to the T2 plot. This may due to the ungirded pioneer species in T1 induce the emergent of new sapling inside the study plot. This situation, if persist, can influence the growth performance of the planted *D. beccarii* since the pioneer species will create competition in terms of light and space.

Table 4.3: Non planted tree species encountered in plot planted with *D. beccarii* in 2005 at initial and 72 months of silviculture implementation

Tree species	No. encountered at initial	No. encountered at 72 months
	T1 (Bush slashing only)	
Macaranga gigantea	16	30
Ficus aurata	3	9
Euodia sp.	-	5
Dactylocladus stenostachy	4	11
Endospermum diadenum	1	7
Horsfieldia sp.	-	4
Calophyllum sp.	4	6
Litsea sp.	5	5
Lithocarpus sp.	2	3
Artocarpus elasticus	-	3
	T2 (Selective gridling + bush slashing)	
Macaranga gigantea	36	39
Ficus aurata	18	9
Callicarpa sp.	12	2
Ficus auriculata	4	2
Euodia sp.	4	3
Sterculia sp.	2	1
Artocarpus kemando	2	1
Aglaia sp.	2	1
Horsfieldia sp.	1	7
Endospermum diadenum	1	1

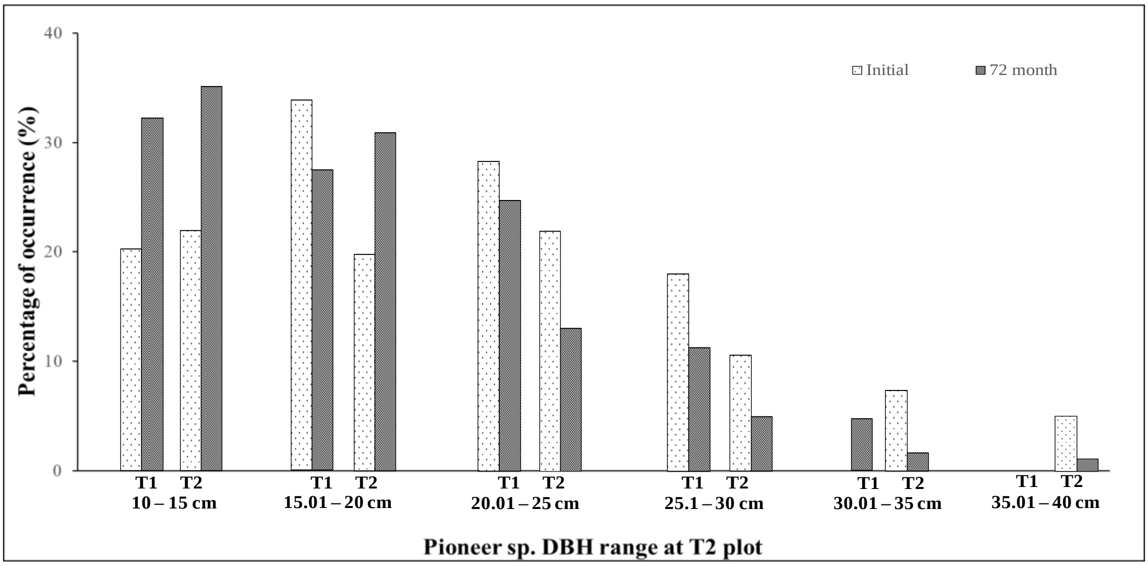

Figure 4.3: Percentage of pioneer species occurrence with DBH < 10 cm at initial of silviculture implementation and period of 72 month

4.6 Survival Rate of Planted *Dryobalanops beccarii* in T1 and T2

Figure 4.5 shows the survival trend of planted *D. beccarii* for each subsequent month during the duration of this study. At both treatments, the survival rate for planted trees after 36 months showed a zero mortality rate. Later, the survival rate of planted trees in T2 decreased to 84.9% while no changes were observed in survival rate was observed in T1. Our field observation during the monitoring process suggested that the girded trees started to decease and some of it may have fallen directly to the planted tree from the stump residue observation and damaged the planted trees. At 48 and 60 months, the survival percentage in the T2 plot sustained at 81.1% with a slight decrease to 79.2% at 72 months. The slight decrease in survival is normal in a secondary forest as the mortality rate will keep increasing where only the fittest planted tree will survive in the succession stage. In contrast to T2, the survival rate in T1 start to decrease gradually at 48 months and a sudden decrease in survival rate to 82.9% at 72 months after the silviculture implementation was observed. From the field survey, some of the pioneer species mainly the *Macaranga* species in the T1 plot have fallen naturally and its impact had affected the overall survival rate of the planted tree.

Figure 4.4: (a) Fallen girded tree which fully rotten in T2, (b) naturally fallen M. gigantea which induce mortality in T1

Davies (2001) also reported that *Macaranga* mortality rates in secondary forests of up to 21% with particularly high mortality among common species like *M. triloba* (20.6%), *M. beccariana* (17.9%) and *M. winkleri* (16.7%). Despite the sudden increase in the mortality rate for both plots, the overall survival still higher than other some experimental planting which reported from line planting (Adjers et al., 1995) and gap planting (Otsamo, 2000) in Borneo. Otsamo (2000) reported only 71% survival among *Shorea parvifolia* after 19 months while Adjers et al. (1995) stated that survival rates between 40-85% for *Shorea johorensis*, *Shorea leprosula* and *Shorea parvifolia* after 2 years of planting. Overall, after 72 months of the treatment implementation, both plots showed high survivability which was more than 70%.

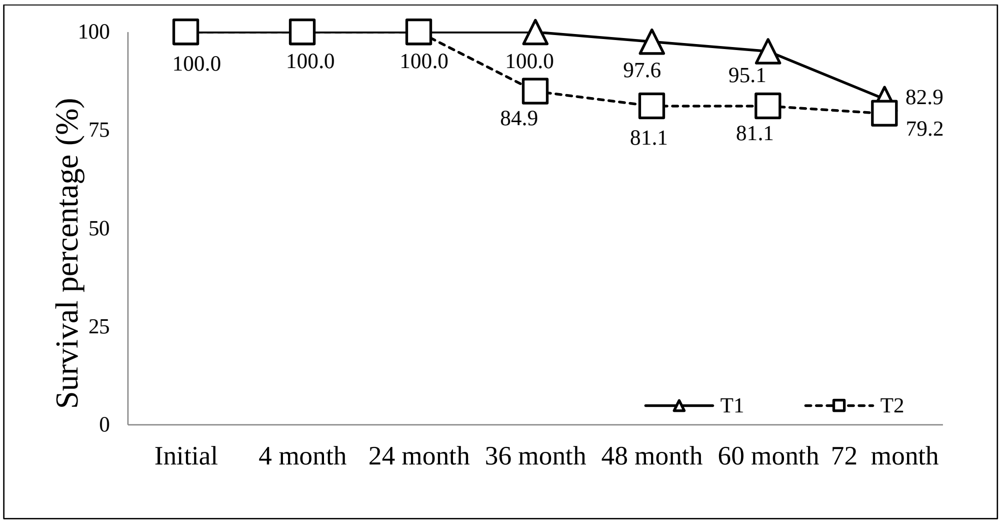

Figure 4.5: Survival of planted *D. beccarii* for both treatments

4.7 Growth Performance of *D. beccarii* in T1 and T2

Figure 4.6 shows the box plot on the distribution of the DBH and height of the planted tree from initial until 72 months period of silviculture treatment implementation. Overall, both treatments showed an increment in terms of DBH and height. There was no significant difference between both treatments in DBH at the initial stage of the experimental planting. However, the tree DBH starts to show a significant difference between T1 and T2 at 48 months. Moreover, from the quartile division of the box plot, T2 showed better growth performance than T1 in DBH where most of the DBH tabulated in quartile 3. In terms of tree height, the planted tree at both treatments shows no significant difference at the initial assessment. Then, at 24 months onward, there were significant differences in tree height for both treatments. However, both treatments show variation in quartile division for each assessment resulting in difficulties to determine which treatments contribute more to the tree height. Despite that, T2 has higher growth performance in height if compared to T1 even though there were no immediate effect on the height.

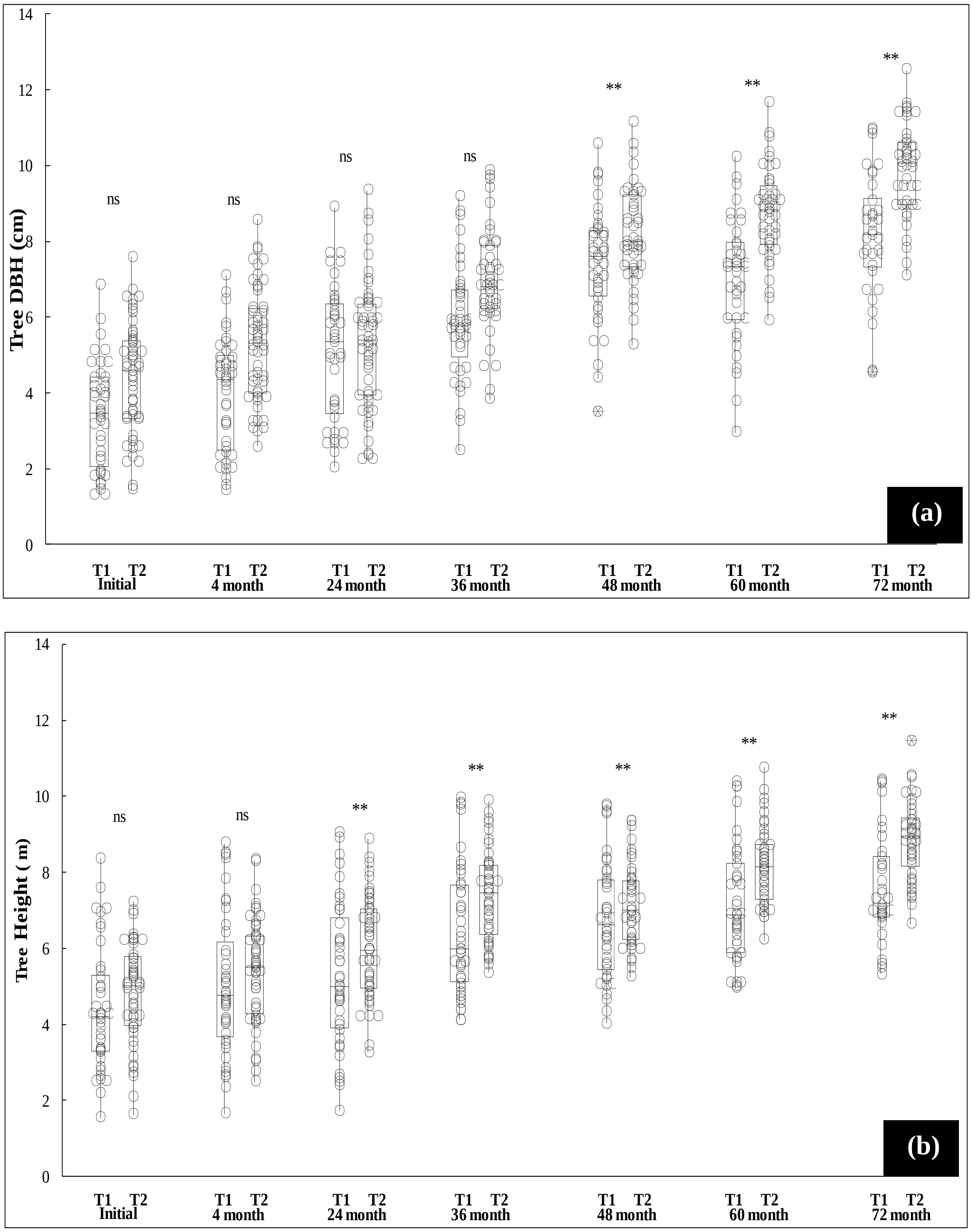

Figure 4.6: Boxplot distribution on the growth performance of planted *D. beccarii* in DBH (a) and height (b) for both treatments. ** mean significantly different between both treatments using independent student t-test at 5%. ns: not significant.

On the other hand, the mean annual increment in DBH and height of the planted *D. beccarii* under treatment T1 and T2 were shown in Table 4.4 and expressed in cm year $^{-1}$ and m year $^{-1}$ for DBH and height respectively. At initial, the growth rate in DBH for T1 and T2 were 0.43 and 0.53 cm year^{-1} respectively, and statistical analysis using the t-test showed no significant difference among the treatments at initial. Besides, in terms of growth rate in height, there was no significant difference between T1 and T2 were 0.55 and 0.64 m year $^{-1}$, respectively. Then, at 24 months T2 started to show a higher growth rate in height if compare to T1. Overall, the growth rate still higher if compare to naturally growth seedling where Widiyanto et al. (2013) reported that in natural tropical rainforest, the total growth rate for all species was about 0.22 cm year^{-1} while for dipterocarp species is within the range of 0.34 – 0.40 cm year^{-1}. Next, Table 4.4 also showed the comparative statistic between T1 and T2 by using the Mann-Whitney U test. The findings indicated that there are significant differences between treatment T1 and T2 for each particular assessment either in terms of height or diameter. From the P-value, T2 shows significantly higher growth performance in diameter than T1 where the P-value <0.001. Meanwhile, for the height parameter, the findings showed a variation on P-value where the value range $0.01< \text{P-value} < 0.1$. Thus, suggesting that the T2 where the implementation of selective girdling accompanied with undergrown slashing contributes more to planted *D. beccarii* growth performance than T1 which without girdling practices. The girdling practices provide a competitive advantage for shade-tolerant species over pioneer forest floor vegetation thus allowed the planted seedlings to gradually gain control of growth resources liberated in the gap and prolong the girdling effect (Romell et al., 2008). In addition, planting gaps created by girdling and slashing favored shade-tolerant dipterocarp species over light-demanding species (e.g. *Macaranga* sp.) due to low level of irradiance in the sub-canopy layer (Sovu et al., 2010).

Table 4.4: Result of t-test and non-parametric test (Mann Whitney U test) for Mean annual increment in diameter (MaiD) and high (MaiH) of planted *D. beccarii* at T1 and T2. Different letter indicates significant different at 5% using independent student t-test and ns= no significance/ *p<0.05, **p<0.01 and ***p<0.001

Parameters		Treatment			Mann-Whitney test
		Age stand (year)	T1	T2	P-value
Mean annual increment in Diameter	Initial	8	0.43 ± 0.21ns	0.53 ± 0.22ns	0.026*
	4 months	9	0.44 ± 0.20ns	0.52 ± 0.20ns	0.096
	24 months	11	0.42 ± 0.20ns	0.52 ± 0.19ns	0.021*
	36 months	12	0.48 ± 0.15a	0.62 ± 0.14a	0.000***
	48 months	13	0.51 ± 0.14a	0.66 ± 0.11b	0.000***
	60 months	14	0.50 ± 0.14a	0.64 ± 0.11b	0.000***
	72 months	15	0.50 ± 0.13a	0.63 ± 0.10b	0.000***
Mean annual increment in Height	Initial	8	0.55 ± 0.25ns	0.64 ± 0.20ns	0.034*
	4 months	9	0.59 ± 0.26ns	0.65 ± 0.19ns	0.095
	24 months	11	0.54 ± 0.22a	0.61 ± 0.15b	0.074
	36 months	12	0.55 ± 0.18a	0.63 ± 0.12b	0.024*
	48 months	13	0.56 ± 0.15a	0.63 ± 0.10b	0.014*
	60 months	14	0.55 ± 0.14a	0.62 ± 0.09b	0.004**
	72 months	15	0.55 ± 0.12a	0.61 ± 0.09b	0.009**

4.8 Influence of Silviculture to the Relative Light Intensity

Figure 4.7 shows the relative light intensity (RLI) for each particular assessment. At initial, the RLI at T2 plot much lower than the T1 plot, but there was no significant difference between treatment until 60 months mark. Then, the RLI gradually increase as the girded tree started to fall as there was a huge gap of RLI between both treatments 60 months onward. Hence, we assumed that the 15 girded trees which mention earlier in the discussion have fully dead and fall in the interval of 48 to 60 months. The girdling practices have been shown a positive effect on the light availability on the forest floor. Even the effect quite weak in which only effective after 60 months of implementation in terms of increasing the light availability, but the girdling practice was more persistent over time than other canopy opening treatments (Romell, 2007). Besides, increasing the light intensity in the forest floor will lead to the better growth performance of the planted tree as Brown (1993) and Hattori et al. (2013) stated that that sunlight exposure in a secondary forest can enhance the growth performance of Dipterocarp species.

In addition, Figure 4.8 shows the overall growth performance, relative light intensity and condition of the neighboring pioneer trees at initial treatment implementation until a period of 72 months of silviculture implementation. For both plots, the initial relative light intensity was low where most parts of the plot were less than 5% of relative light intensity. In the T2 plot wherein the compartment, the selective girdling has been conducted controlled the emergent of big pioneer species as well as provide a better light environment where most part of the plot the relative light intensity was more than 20%. Moreover, in terms of a planted tree, T2 shows better growth rate performance if compare to T1 where most of the planted tree highest recorded with DBH more than 8 cm and height more than 8 m. The main possible explanation was the T2 which compromised bush slashing in line planting manner and selective girdling on the big neighboring *Macaranga gigantea* has provided a better light environment and reduce competition for nutrition and space for the planted *Dryobalanops beccarii*.

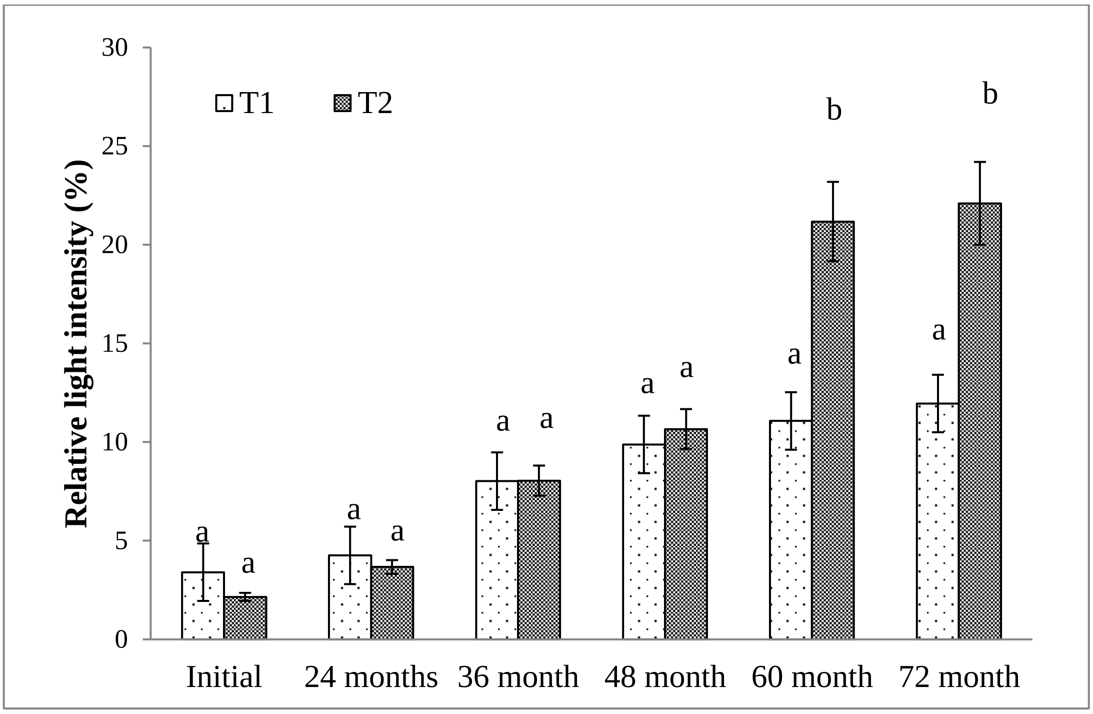

Figure 4.7: Relative light intensity trend over 72 months of silviculture implementation. Different letter indicate significance different between both treatments. Ns: not significance

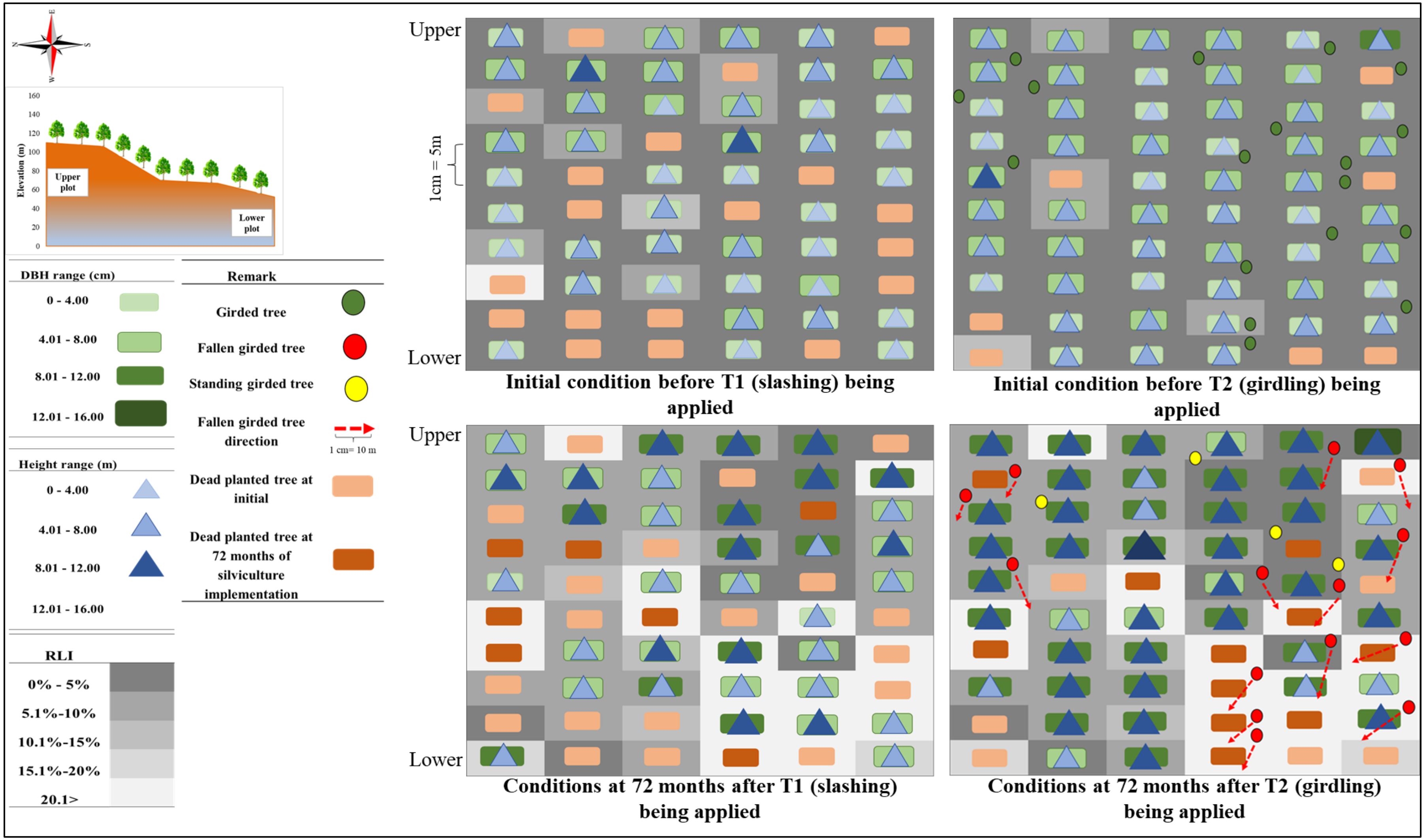

Figure 4.8: Overall light condition and planted *D. beccarii* growth trend at initial and 72 months of silviculture treatment implementation.

4.9 Overall Overview on Girdling Effect on the Growth Performance *D. beccarii* in Gunung Apeng National Park

The result obtained from the multiple assessments in both plots treated with different silviculture treatments, the girdling practices contributes a positive effect on the growth performance of the planted *D. beccarii* for reforestation purpose in Gunung Apeng NP. The practice of girdling shows a slower effect in which the girded pioneer tree does not die immediately as compare to felling practices due to the girdling practices that do not lead to immediate death and defoliation to the girded tree. Even though the girdling effect difficult to assessed than other practices like thinning and felling where the intended tree fell immediately, however, the girdling effect was more persistent over time and less damage induce to the planted trees. This can be seen in Table 4.4 where the girdling plot (T2) starts to show better growth in diameter and height on 36 months and 24 months, respectively. Thus, suggesting that the practices of selective girdling on the pioneer species start to take effect minimum on 24 months above where the girded tree started to fall and provide a favorable light condition for the planted tree to grow. Romell (2007) reported that selective girdling impact needs at least 2 years after implementation to see its effect on canopy opening by improving the light environment on the forest floor. The possible explanation for the better growth rate in height for T2 was the girded tree have been fallen and provide a lighter favorable condition for the planted tree to grow more in height. The slower growth performance in T1 may due to low light conditions release shade tolerance pioneer vegetation and obstruct the establishment of slow-growing tree seedling (Romell et al., 2008). Next, the Mann-Whitney test showed that the trees planted under T2 practice showed better growth performance where the mean annual increment in diameter and height were significantly higher than the T1 plot at 36 months onwards. P-value in table 4.4 showed that the MAI in diameter was strongly significance at $p < 0.001$ was an important indicator as the increment in diameter indicated that the planted tree started to vigorously increase in size. Although the effect only can be seen after 36 months which were slower if compare 6 -12 months as reported by some researchers, the variability in the ecosystem is diverse as various edaphic factors can obstruct the slow growth of the planted indigenous tree species.

Besides that, for rehabilitation purposes, not only how fast the planted indigenous tree growth was crucial, but how well the tree survive after anthropogenic activities were one of the main considerations. As observed in the survival rate, T2 shows a better growth pattern than T1 where the survival rate was almost stable with no sudden increase in mortality rate as in T1 where sudden mortality increased was observed on 60 months after silviculture implementation. Overall, both treatments T1 and T2 were practicable in managing the planted *D. beccarii* tree in Gunung Apeng NP where it can increase the probability for the tree to grow and adapt well in the ecosystem. However, T2 practice was preferable as it has the tendency to give a better environment for the planted indigenous tree to grow well. In addition, T2 show slightly fast growth performance than T1 with an average 0.63 cm $year^{-1}$ and 0.61 m $year^{-1}$ if compared to T1 with an average 0.50 cm $year^{-1}$ and 0.55 m $year^{-1}$. Canopy opening by girdling and the gap created by slashing in T2 have provided optimum grow condition for the *D. beccarii*. In addition, light availability plays an important role in regenerating tropical tree seedlings (Agyeman 1994; Poorter 1989) and creating gaps by slashing under-storey seemed to be an efficient treatment for forest floor shade reduction in the secondary tropical forests (Romell et al., 2009). Mauricio (1987) also reported that dipterocarp seedlings or stands with DBH ranging from 5-20 cm will triple their growth when competing secondary growth was cleared. As in this study, the girdling was only applied when the age stands at eight (8) years old since mostly dipterocarps seedling demand shelter from sunlight during their establishment phase (Nicholson, 1960; Weidelt & Banaag, 1982; Mauricio, 1987). Moreover, young trees (less than 30 cm in DBH) react better to liberation and subsequent increase in light intensity (Weidelt & Banaag, 1982). Aside from canopy treatment (girdling), weeding or slashing practices also essential where at a young age dipterocarp trees need intensive tending (Adjers et al., 1995). The frequency of slashing application also has to be adjusted by considering the main climatic conditions in the area (Carandang et al., 2007). As the study plot located at a tropical rainforest where the emergent of weeds at rapid phase due to availability of rainfall throughout the years, the frequency of slashing should be increase and conducted at constant interval since if weeding is carried out late, dipterocarps are easily damaged (Priasukmana, 1991). Although in some forest plantation management systems, mostly practice felling rather than frequent slashing due to the cost of maintenance, Weidelt (1976) also pointed out the importance of maintenance as insufficient tending is the most common reason for failure.

As has been recommended by Wasli et al. (2014) in the preliminary assessment, suitable silvicultural practices should be implemented to ensure the successfulness of the reforestation program. Whereby in this study, selective girdling was recommended to be applied and should be accompanied by continuous slashing practices. Besides, as the forest continues to regenerate, given time and disturbance, the pioneer species in the forest will decline and are replaced by climax species, converting the secondary forest to a community that is similar to primary forest (Osborne, 2012). Hence, the girding practice implementation is crucial to fasten the process of forest rejuvenation since naturally form primary forest take years to complete. In order to ensure successful enrichment planting, the necessary condition must be provided, which include the provision of adequate light conditions, proper supervision and follow up maintenance (especially canopy opening treatment) (Akindale & Onyekwelu, 2011). Meanwhile, the location of the pioneer tree that will be girded should be taken into consideration to fully utilized the gap created when the girded tree fell as well as the intensity of the girdling should be more emphasized to ensure the effectiveness of its application. Slashing the undergrowth still recommended despite the cos of operation in order to keep the planting line accessible for future supervision and tending activities (Adjer, 1995). A further comprehensive study in the future should be more focus on broader views such as look onto the pioneer species competition with the planted tree, soil-plant relationship, and canopy opening by the treatment applied. Meanwhile, the existing natural pioneer species inside the study plot that interact and compete with the planted tree for light, space, and nutrients should be identified clearly in the future study.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In conclusion, the soil physicochemical in the study plot also has been assessed. The soil in the study area was nearly identical in terms of its physical properties and chemical properties. This may due to the soil at both study plots were determined as “grey white podzolic soil”. Only in some aspects such as the amount of the soil organic material and texture has a significant impact on the available cations exchange capacity (CEC) in the soil as these two parameters are the main contributor to the CEC in the soil. The higher CEC in the soil is better as it is indicating that more readily available nutrients in the soil for the plant uptake. The topographical especially may play the main factor in influencing the soil physicochemical properties. Soil at high slope hill probably more tendency exposes to leeching problem especially during the rainfall. Hence, for future study, it is important to incorporate this parameter.

On the other hand, the growth performance and survival rate of planted *Dryobalanops beccarii* planted in 2005 at reforestation were successfully being assessed. From this study, the implementation of silviculture treatments which were bush slashing and selective girdling have significantly growth effects on the planted tree. The percentage of survival in both silviculture plot T1 (bush slashing) and T2 (bush slashing + selective girdling) were considered high which both mortality rate below 30%. This indicates that the successfulness of the reforestation effort in which more than half of the planted trees succeed to thrive and grow well despite the environment condition in the secondary forest.

Next, the plot treated with selective girdling as an additional silviculture treatment shown much better growth performance than when only bush slashing being applied as in T1. As shown earlier, the implementation of the selective girdling also has a positive effect in controlling the emergent sapling of *Macaranga* tree species thus allowed not only the planted tree but as well as other important species to grow well thus this ultimately will fasten the succession stages to achieve stable forest ecosystem faster than self-rejuvenate forest.

In additions, *Macaranga* patches can affect the performance of dipterocarp seedlings through the forest floor condition due to the nutrient accumulation rate beneath the litter layers was slow in which resulted to the slow recovery of the nutrient availability of the forest floor. Thus, by eliminating the *Macaranga* sp. by girdling will minimise the possibility of slow nutrient recovery problems in the study plot. The elimination of the *Macaranga* tree in the study plot also contribute better growth performance of the *Dryobalanops beccarii* neither in diameter nor height in the study plot. The planted tree supported by girdling on the selected pioneer species and under-growth slashing has a much better mean annual increment in diameter and height. Even though the rate per year was not 1 cm diameter or 1 m height per year, but in terms of reforestation, this considered a fast generation where the silviculture only being applied annually (bush slashing) as well as one-time implementation during the initial stage (selective girdling).

5.2 Recommendations

In addition, future studies are suggested to further explain the effects of silvicultural treatments mainly the selective girdling treatment on the pioneer species. Incorporating the crown study, gap opening effect and the fallen impact of the girded tree should be given more intentions in future research. Aside from that, there is also a gap in how frequent the silviculture treatment should be imposed annually and its effect on the growth performance and survival of *Dryobalanops beccarii* as well as its ecological impact on the forest biodiversity in the reforestation area. Meanwhile, the present study also suggested that the implementation of selective girdling and constant bush slashing practices is recommended as it had shown the positive effects on the planted tree. Moreover, other silvicultural practices such as pruning, and thinning can be considered to be applied in future research in order to faster the growth rate of planted trees and ultimately fasten the forest rejuvenation processes.

On the other hand, the role of soil in supporting the growth of the planted tree also should not be taken lightly. Even though in term of physical and chemical properties of the soil condition in the study area were almost the same, there are other aspects such as biological properties, nutrient cycling rate as well as forest litter study should be assessed in future research. In addition, other soil indices such as Soil Fertility Index (SFI) and Soil Evaluation Factor (SEF) in other rehabilitation sites with different environmental conditions and soil types should be taken into consideration.

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APPENDICES

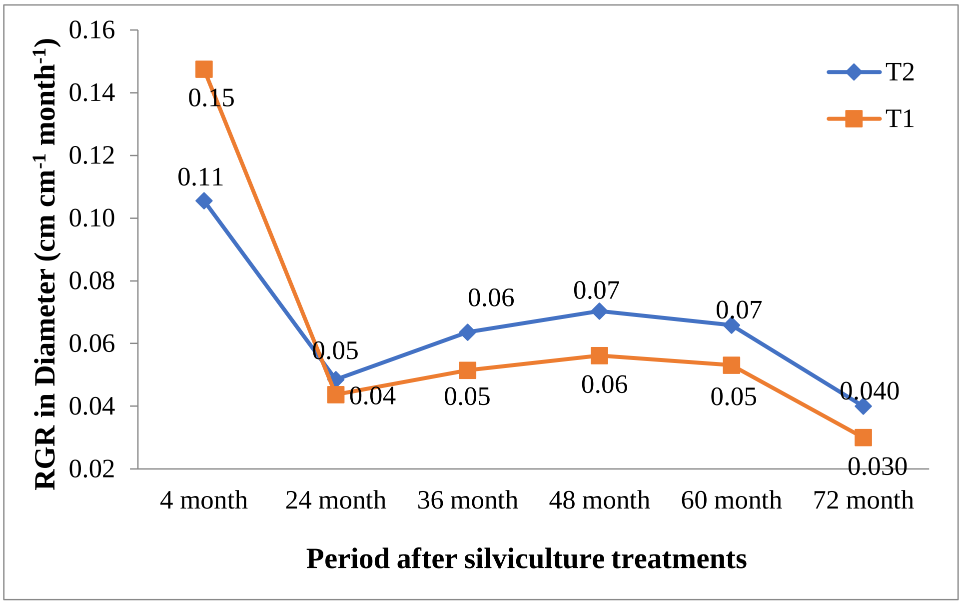
Appendix 1: Publication

1. Wasli, M. E., **Ambun D. B**., Kalu, M., Sidi, M., Nahrawi, H., Elias, H. (2020). Assessment on the growth performance of planted Dryobalanops beccarii at reforestation sites after implementation of selective girdling. *Biodiversitas*, *21*(5), 1880-1889. https://doi.org/10.13057/biodiv/d210514

2. **Douglas, B.,** Wasli, M. E., Perumal, M., Anarrin, N. J., Sani, H., Oscar, J. N., Lat, J., Hidir, M., & Arip, S. (2017). Soils properties at reforestation sites after different silviculture treatment at Gunung Apeng Forest Reserve, Sarawak. *Proceeding of International Conference on Sustainable Soil Management* (SOILS2017). 2017 Sarawak, Malaysia.

3. Anarrin, N. J., Wasli, M. E., **Douglas, B.,** Perumal, M., Sani, H., Oscar, J. N., Lat, J., Hidir, M., & Arip, S. (2017). Soil morphological properties of planted mono and mixed tree species at Gunung Apeng Forest National Park, Sarawak. *Proceeding of International Conference on Sustainable Soil Management* (SOILS2017). 2017 Sarawak, Malaysia.

Appendix 2: Relative growth rate in diameter after silviculture treatments.



Appendix 3: Relative growth rate in height after silviculture treatments.