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Survivorship and Growth Performance of *Shorea macrophylla* (de Vriese) after Enrichment Planting for Reforestation Purpose at Sarawak, Malaysia

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Abstract: Reforestation may offer one means of mitigating the processes of forest land degradation and is indispensable in an effort to conserve forest biological diversity in the tropics. Thus, a preliminary assessment was conducted in order to evaluate the survivorship and growth performance of *Shorea macrophylla* (de Vriese) after enrichment planting for reforestation purpose in Sarawak, Malaysia. This study was conducted at reforestation sites located at Sampadi Forest Reserve, Sarawak, Malaysia where indigenous Dipterocarp species, *S. macrophylla* (de Vriese) were planted by line planting system. Study sites were established at reforestation areas at different age stands; (planted in the year 1996; SM96, 1997; SM97, 1998; SM98 and 1999; SM99). The assessment on the growth performance of planted *S. macrophylla* was evaluated by measuring the trees total height, Diameter at Breast Height (DBH) and calculation of the percentage of survival. The findings indicated a positive tree growth in terms of growth performance and survival which clarified the efficacy of line planting technique adapted in the studied sites. Growth performance in terms of survivability; Mean Annual Increment of Height (MAIH) and Diameter (MAID) in SM96 revealed the highest growth rate as compared to SM97, SM98 and SM99. For the average tree height and diameter at breast height, the results showed that the tree height and diameter in SM96 were 11.8 m and 14.7 cm, respectively. Meanwhile, SM99 recorded the lowest average tree height and diameter reading with 8.8 m and 6.6 cm, respectively. Nonetheless, high survival percentage of *S. macrophylla* were depicted in this study with 89% of survival in SM96, followed by 80, 82 and 57% in SM97, SM98 and SM99, respectively. Substantial growth performance and high survival percentage of *S. macrophylla* implied that microclimate condition such as competition between planted and existing pioneer species of the study sites may have affected the tree growth performance of the planted *S. macrophylla*. Notwithstanding, further studies are essential in order to find out the plant-soil association of *S. macrophylla* where other environmental factors may affect the growth and survival of the planted species.

Keywords: Survival, Growth Performance, Enrichment Planting, Reforestation, *Shorea macrophylla*

Introduction

In the humid tropics of Malaysia, indigenous tree species from Dipterocarpaceae family are mainly chosen for reforestation and forest rehabilitation purpose. Among them, *Shorea macrophylla* (de Vriese) is commonly known in Sarawak, Malaysia as a medium to a large timber-sized tree and valued for its oil-bearing fruits (illipe nuts) but also considered as one of the selected species for forest rehabilitation purposes

(Perumal *et al*., 2015). In the Mixed Dipterocarp Forests of Sarawak and Brunei, this climax species can attain a height of 50 m tall, 4.0 m in stem girth at breast height and 2.0 m in buttress height (Ashton, 1964; 1982).

Enrichment planting is a highly effective technique for the rehabilitation or reforestation of degraded vegetation (Appanah and Weinland, 1993; Kenzo *et al*., 2008). Enrichment planting trials in tropical rainforests of Malaysia date from the year 1930's (Wyatt-Smith, 1995) and have been motivated by the need to improve regenerating forests for future timber production and by the desire to restore and thereby, protect degraded unproductive areas (Appanah and Weinland, 1993; Kollert *et al*., 1996). For developing areas of enrichment planting, a detailed understanding of the factors controlling seedling growth and survival is required. Tang and Chew (1980) reported that although there are examples of successful line-planting programmes, attempts at artificial regeneration have generally failed. Moreover, among the common problems with artificial forest regeneration were due to high maintenance costs, improper selection of planting stock, incidental damage to advance regeneration during planting operations and poor seedling survivorship (Pierront, 1995). Therefore, efforts to improve, evaluate and monitor the survivorship and growth performance of planted Dipterocarp species under enrichment planting systems continue to be important (Moura-Costa, 1994).

In Sarawak, the local authority, Forest Department of Sarawak in collaboration with the participation of international NGOs from Japan have implemented reforestation programmes under Friendships Forests Project by planting indigenous Dipterocarp species for the restoration of the tropical rainforest at degraded areas (Wasli *et al*., 2014). Such reforestation and rehabilitation efforts are especially significant in reforesting small areas deforested by shifting cultivation within the permanent forest estate and totally protected areas which would not be of an economic size for big-scale operators for plantation forest establishment. Furthermore, few researchers have stated that information on the tree growth performance and survivability of the planted indigenous tree species under reforestation effort by the local authorities in Sarawak, Malaysia is indispensable as an indicator to the successfulness of the rehabilitation efforts towards regenerating tropical forests artificially (Wasli *et al*., 2014; Perumal *et al*., 2016). Since most studies are concern with evaluation and assessment of planted trees and the changes in the surrounding ecosystem under monoculture plantation of fast-growing exotic species (Cole *et al*., 1996; Tilki and Fisher, 1998; Norisada *et al*., 2005; MacNamara *et al*., 2006; Arifin *et al*., 2008), efforts in long-term monitoring assessment on the growth performance and survivorship of planted indigenous tree species under reforestation in less diverse secondary forests is essential.

Hence, the objective of this preliminary study was to clarify, evaluate and compare the current status of survival and growth performance of *S. macrophylla* under line planting system for reforestation and rehabilitation purposes in Sampadi Forest Reserve, Lundu, Sarawak, Malaysia.

Materials and Methods

Brief Information on Sampadi Forest Reserve Reforestation Sites

Sampadi Forest Reserve reforestation sites (N01°34'13''E109°53'12'') is located at Lundu, Sarawak which is approximately 72 km from southwest of Kuching City (Fig. 1). It covers about 5,163 hectares and has a humid tropical climate, associated with peaks of seasonal changes in rainfall and temperature. The topography at the study site was of low undulating with an average elevation of 87 m above sea level. It has a tropical seasonal climate (no dry season) with all months receiving on average more than 100 mm with a subtropical wet forest biozone (Vincent and Davies, 2003). The average annual temperature in the area ranges between 22°C (72°F) in the early hours of the morning and rises to around 31°C (88°F) during mid-afternoon with little monthly variation (Andriesse, 1972; Meteorological Department, 2010).

Based on our previous study, the soils in the study area comprised of mainly Grey-White Podzolic Soil group which is derived from the combination of sandstone, coarse-grained, humult ultisols and sandy residual parent material (Perumal *et al*., 2015). According to Sarawak Soil Classification System, the morphological properties in the study sites resemble Bako soil series as a dominant unit in association with Saratok series in which, corresponds to Typic Paleaquults of Soil Taxonomy by USDA-NRCS Classification (Teng, 2004; SSS, 2014). Soils of these features comprised of friable consistency and moderately developed soil structures with variable soil depths and do not possess densic, lithic, paralithic, or petroferric contact within 150 cm of the mineral soil surface. Such soil can be found typically on nearly flat ridges tops or dip slopes such as the topography of lowland and the low undulating hill in Sarawak, Malaysia. The general soil physicochemical properties in the study area were strongly acidic in nature with pH (H_2O) of less than (pH < 5.5) with low soil nutrient status and soil exchangeable bases. Perumal *et al*. (2015) reported that this type of soil condition in the study area could be considered as marginal for tree plantation establishment due to their low fertility and nutrient status, water retention capacity and shallow rooting depth. In fact, the presence of clay had contributed to water retention which may relate to the occurrence of the heavy flood which happened almost every year in Sampadi Forest Reserve.

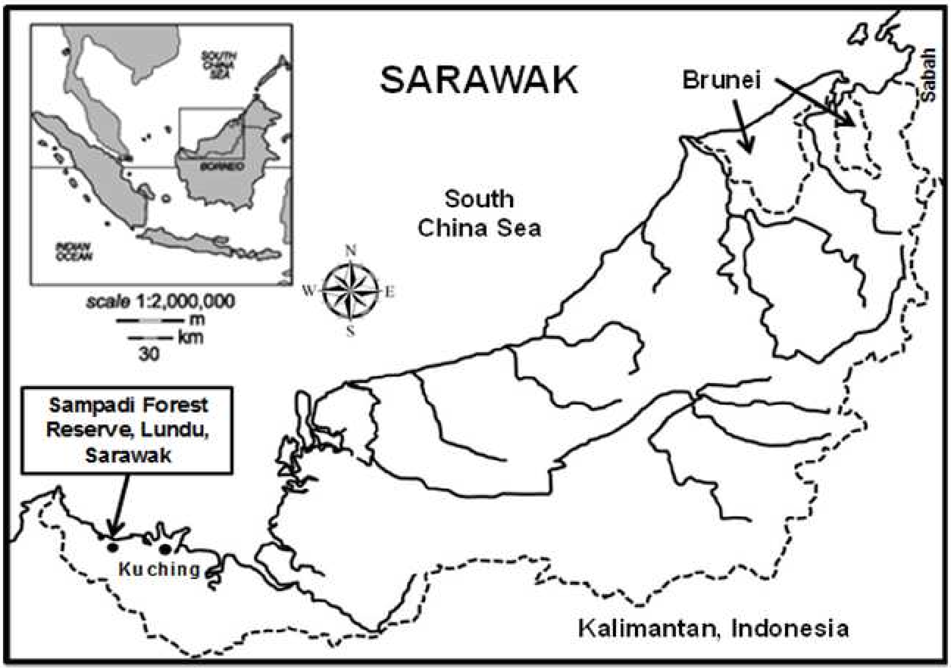

Fig. 1. Location of the study area: Sampadi Forest Reserve, Lundu, Sarawak

Prior to the plantation establishment, this area has been under different kinds of land use activities which, in one way or another, affected the edaphic condition of the area. Since the year 1995, joint tree planting activities involving the participation of Japanese citizens and the local people of Sarawak was initiated through the establishment of the Friendship Forests as part of the continuous efforts by the Forest Department, Sarawak in restoring the abandoned shifting cultivation areas in Sarawak. In the year 1996, the local goverment from Forest Department of Sarawak together with various international agencies had initiated a community reforestation programme for the purpose of restoring the degraded land areas by planting various types of indigenous tree species (mainly of Dipterocarpaceae family). Among the planted species in the study area were *Engkabang jantong* (*Shorea macrophylla*), *Kapur bukit* (*Dryobalanops beccarii*), *Selangan batu* (*Shorea falcifera*), *Meranti sarang punai* (*Shorea parvifolia*) and *Bintangor bukit* (*Calophyllum alboramulum*).

The reforestation sites were established under the secondary forests which developed from the previous history of slash and burn activities. It should be noted that all the tree seedlings were raised and cultivated for a year in the nursery and were transplanted during the community reforestation project held in the year of 1996, 1997, 1998 and 1999, respectively. All the tree seedings were planted under line planting technique with lines cut 5 m apart and at 5 m interval along the lines. Preparation and maintenance of planting lines were conducted by the manual slashing of the undergrowth with a bush knife along the planting line. Weeding activity in the reforestation area was conducted once annually where all herbaceous species and seedlings of pioneer species were slashed with a bush knife. For larger pioneer tree species, they were left uncut when preparing the planting lines.

Methods for Assessing Tree Growth Performance and Survival of Shorea macrophylla

In terms of tree evaluation on the growth performance and survival, study plots with the size of 75×50 m were constructed within the compartment planted with *S. macrophylla* at four different age tree stands (planted in the year 1996, 1997, 1998 and 1999). It should be noted that abbreviation was coded as to represent each study plots; SM96 (*S. macrophylla* planted in the year 1996), SM97 (*S. macrophylla* planted in the year 1997), SM98 (*S. macrophylla* planted in the year 1998) and SM99 (*S. macrophylla* planted in the year 1999).

The growth assessment of the planted trees under such forest cover was conducted in the year 2013 since no initial information and data was available and recorded on the condition of the seedlings at the time of planting. The assessment involved measurements such as trees total height and Diameter at Breast Height (DBH) of 1.3 m above ground level. The planted trees were measured individually in each plot using diameter tape and Suunto clinometer, respectively followed by the calculation of survival (Arifin *et al*., 2009). As for tree saplings, the diameter of the trees were taken 0.3 m from the ground level if their height did not reach 1.3 m. The electronic caliper was used to measure the diameter for younger seedlings (Perumal *et al*., 2014; Wasli *et al*., 2014). Trigonometry principles were applied for taller trees where the height was taken from ground level to the point where top diameter was the minimum size for the trees (Philip, 1994). The following formula was used to calculate the survival percentage of the planted *S. macrophylla* within the study plots:

$$Survival,\ X = \frac{Z}{Y} \times 100\%$$

Where:

X = Survival of planted *S. macrophylla*
Y = Total planted *S. macrophylla*
Z = Total number of *S. macrophylla* standing trees

As for the Mean Annual Increment (MAI) in terms of tree Total Height (MAIH) and Diameter at Breast Height (MAID), both values were estimated based on the average values of the tree height and diameter of assessed trees with the age stand of the study plot.

Statistical Analyses

In order to compare and determine significant differences between different age stands of the planted *S. macrophylla*, all data of the mean annual increment in height and diameter were statistically analyzed by using a one-way Analysis of Variance (ANOVA). Tukey's HSD was chosen as post hoc tests to compare the species mean annual increments under various age stands. All the statistical tests were performed using IBM SPSS version 21.0 for windows. Descriptive statistics (boxplots) and histogram were performed using MINITAB version 14.0 for windows.

Results and Discussion

Survivability of Shorea macrophylla under Various Age Stands in Sampadi Forest Reserve

The assessment on the survival of species after rehabilitation or plantation programmes especially Dipterocarp trees when planted under various age stands in a degraded forest is vital and required towards better recommendation of species selection in the future. The percentage of survival and mortality for planted *S. macrophylla* under various age stands in all the study plots of SM96, SM97, SM98 and SM99 are shown in Fig. 2.

The results show that the survival percentage of planted *S. macrophylla* in SM96, SM97, SM98 and SM99 plots were 88, 80, 82 and 57%, respectively. The highest survival was with 88% from the SM96 plot and the lowest survival was from the SM99 plot with the percentage of survival, 57%. A total of 23% (139 trees out of 600 trees) of *S. macrophylla* did not survive among all the study plots from SM96, SM97, SM98 and SM99. In terms of the percentage of mortality, plot SM99 depicted the highest percentage value as compared to other studied plots.

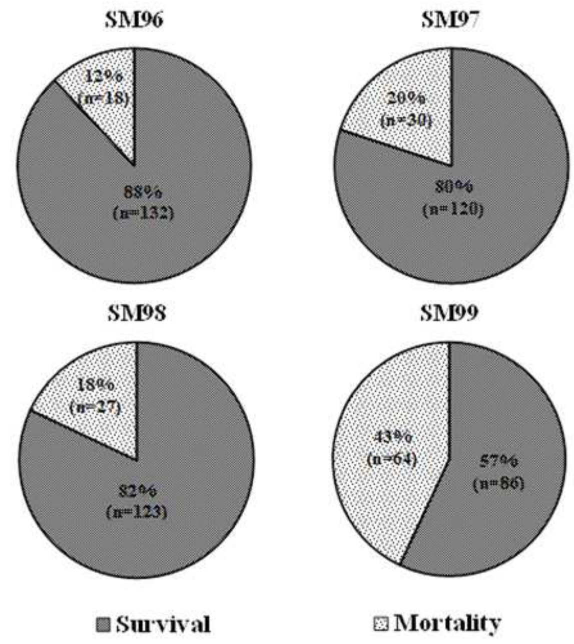

Fig. 2. Percentage of survival and mortality of planted *S. macrophylla* at different age stands

High light irradiance could be one of the possible factors which may reduce the survivability of the planted species in plot SM99 (data not shown). Light intensity factor had a particularly large influence on the SM99 plot due to the wide gap of canopy openness which enabled the sunlight to penetrate downward through the canopy of the *S. macrophylla* trees. Based on the previous study by Hattori *et al*. (2013), it was reported that high light intensity reduced the seedling survivability of both over 0-24 months and 24-81 months planted Dipterocarp forest species. On the contrary, Ådjers *et al*. (1995) reported that planted *Shorea parvifolia* and *Shorea leprosula* for a period of 26 months exhibited better height and basal diameter in the 2 and 3 m line planting widths compared to 1, reflecting sufficient amount of overhead light. Thus, the opening of the vegetation canopy plays a vital role with the species-specific light requirement to promote higher survival and growth rates of the planted *S. macrophylla*.

The percentage of survival and mortality are crucial in order to understand the mechanisms that affect the dynamics of the tree population and vital to effectively manage that population and its habitat. Previous reports on enrichment planting of various Dipterocarp species in Southeast Asia also showed higher interspecific differences in seedling mortality ranging from only a few percent to almost 100% (Appanah and Weinland, 1993; Ang and Maruyama, 1995; Ådjers *et al*., 1996). Vincent and Davies (2003) stated that in general, planting Dipterocarps in logged and degraded forests have reported substantially higher mortality in most studies.

Suhaili *et al*. (1998) reported that the percentage of seedling mortality was 22% for *Shorea parvifolia* over the first 6 months after planting on a degraded logged-over forest in Negeri Sembilan, Peninsular Malaysia. Ådjers *et al*. (1996) showed seedling mortality of 30 to 62.5% in a degraded secondary forest in South Kalimantan, Indonesia. In contrast, Vincent and Davies (2003) reported significantly lower seedling mortality of less than 6% over 22 months in a degraded secondary forest of Sarawak. In their study, high monthly rainfall throughout the first year of the experiment may have enhanced seedling survival (Vincent and Davies, 2003). Nevertheless, the percentage of mortality have been 20 to 50% in the first few years and sometimes even higher in several other Dipterocarp plantation studies in South-East Asia (Ådjers *et al*., 1995; Ang and Maruyama, 1995; Ådjers *et al*., 1996).

Environmental factors may also have a great influence on the survival and growth performance of the tree species such as light intensity, soil fertility, mineral nutrients and water holding capacity. According to Evans (1992), environmental factors such as drought season, diseases, planting technique and weed competition influence the growth performance and survival of planted species. In addition, among the two major factors that usually influence the seedlings survival is light intensity and the amount of available moisture especially during the initial stage of stand establishment.

Growth Performance of Shorea macrophylla under Different Age Stands at Reforestation Sites

The number of occurrences or encountered trees and total height distribution of planted *S. macrophylla* at various age stands in Sampadi Forest Reserve is shown in Fig. 3. Based on the histogram obtained, the frequency of encountered trees with the height class of 5.01 to 10.00 m shows the highest with a total frequency of 211 trees among all the four study plots surveyed; SM96, SM97, SM98 and SM99. This followed by the height class of 10.01 to 15.00 m with a total of 143 trees, ≤ 5.00 m class with 64 trees and 15.01 to 20.00 m class with 34 trees. Less than 10 trees with the size exceeding the height of more than 20.00 m were observed.

Figure 4 shows the mean average total height of *S. macrophylla* in all study sites. The results show that the average total height of *S. macrophylla* in SM96, SM97, SM98 and SM99 were 11.77, 8.59, 8.27 and 8.75 m, respectively. The average total height of planted *S. macrophylla* in the SM96 was higher as compared to SM97, SM98 and SM99 plots. SM98 recorded the lowest average in mean value among all study plots.

The number of occurrence of encountered trees and Diameter at Breast Height (DBH) distribution of planted *S. macrophylla* at various age stands in Sampadi Forest Reserve is shown in Fig. 5. Based on the histogram obtained, the frequency of encountered trees with the diameter class of 5.1 to 10.0 cm showed the highest with a total frequency of 197 trees among all the four study plots surveyed; SM96, SM97, SM98 and SM99. This followed by the diameter class of 10.1 to 15.0 cm with a total of 115 trees, ≤ 5.0 cm class with 77 trees and 15.1 to 20.0 cm class with 57 trees. There was only a total of 12 trees in diameter class 20.1 to 25.0 cm. Less than 5 trees with the size exceeding the diameter at breast height of more than 25.1 cm were observed.

Figure 6 shows the average diameter at breast height of *S. macrophylla* in all study sites. The results show that the average diameter at breast height of *S. macrophylla* in SM96, SM97, SM98 and SM99 were 14.7, 9.3, 7.0 and 6.6 cm, respectively. It was observed that the mean average size of the trees decreases and was directly proportional to the increasing planting age of *S. macrophylla*. The average diameter at breast height in SM96 was higher as compared to SM97, SM98 and SM99 plots. SM99 depicted the lowest average in mean value among all study plots.

In addition, in plot SM99, competition between *S. macrophylla* and pioneer tree species for sunlight significantly affected the mortality rates in which, had a large impact on the growth performance of *S. macrophylla*. A total of 64 trees out of 150 trees (approximately 43%) of planted *S. macrophylla* did not survive in the SM99 plot.

According to Perumal *et al*. (2012), high density of pioneer species in plot SM99 could be assumed as another reason why most of the growth of *S. macrophylla* in SM99 was poor. On the other hand, the growth performance in terms of mean annual increment in height and diameter in SM96 and SM97 were better as compared to plot SM98 and SM99. Good height and diameter growth of the species could be due to the good adaptability of planted *S. macrophylla* to the locality or species-site matching and ability to tolerate water stress and other unfavorable site conditions (Perumal *et al*., 2012). Azani *et al*. (2003) described that the variation in growth of planted species is due to the specific reaction of the species to environmental conditions such as climate, soil and topography. Furthermore, growth in terms of height and diameter increment is also influenced by the availability of space between trees (Mohd Zaki *et al*., 2003).

The results for mean annual increments in height (MAIH) and diameter at breast height (MAID) among species after 18, 17, 16 and 15 years of planting are shown in Table 1. In similarity to survival percentage, generally, there were significant differences ($p<0.05$) of the mean annual increments in height and diameter among *S. macrophylla* being planted in the study plots, especially in plot SM96. The average value of the Mean Annual Increment of Height (MAIH) of *S.*

macrophylla planted in SM96 (0.65 m year^{-1}) recorded the highest MAIH of planted trees among the plots surveyed, followed by SM99 with MAIH 0.58 m year^{-1}, SM98 (0.52 m year^{-1}) and the lowest SM97 (0.51 m year^{-1}). In addition, the average value of the Mean Annual Increment of Diameter (MAID) of planted trees in SM96 (0.82 cm year^{-1}) attained significantly higher MAID than SM97 (0.55 cm year^{-1}), SM 98 (0.44 cm year^{-1}) and SM99 (0.44 cm year^{-1}), respectively.

Generally, in terms of mean annual increments of height and diameter, the growth performance of planted *S. macrophylla* was relatively poor. Even though these Mean Annual Increments (MAI) were relatively slow after 18 years of planting, *S. macrophylla* still can adapt well and survive under harsh conditions such as annual flooding (Fig. 7).

There were no similar characteristics observed and found in terms of growth as compared to the early establishment of the plantation was done. Nevertheless, *in-situ* observation suggested that factors such as competition between the existing pioneer species as well as topographical features in all the study sites may have contributed to differences in terms of MAIH and MAID in SM96, SM97, SM98 and SM99. Similar findings on the factors influencing the growth performance and survival of *Dryobalanops beccarii* were reported and highlighted by Wasli *et al*. (2014) in Gunung Apeng Forest Reserve, Sarawak. In addition, Itoh *et al*. (2003) stressed that soil properties such as soil texture and topographical features had largely affected the spatial distribution of Dipterocarp species under natural tropical rainforests.

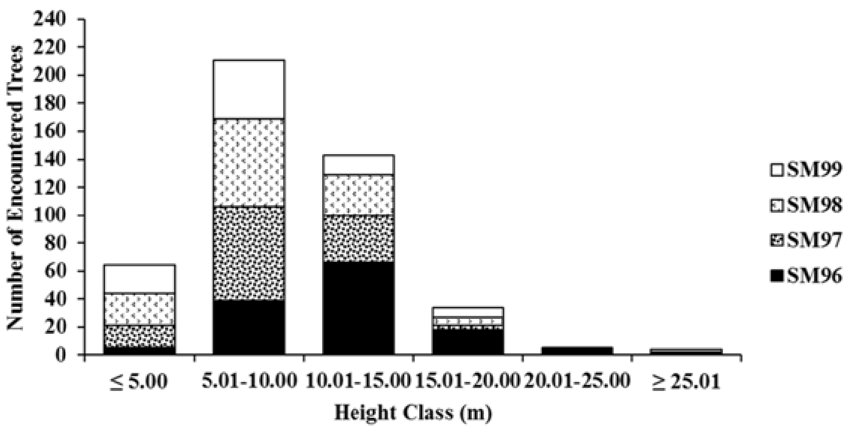

Fig. 3. Total tree height (m) distribution of planted *S. macrophylla* in SM96, SM97, SM98 and SM99

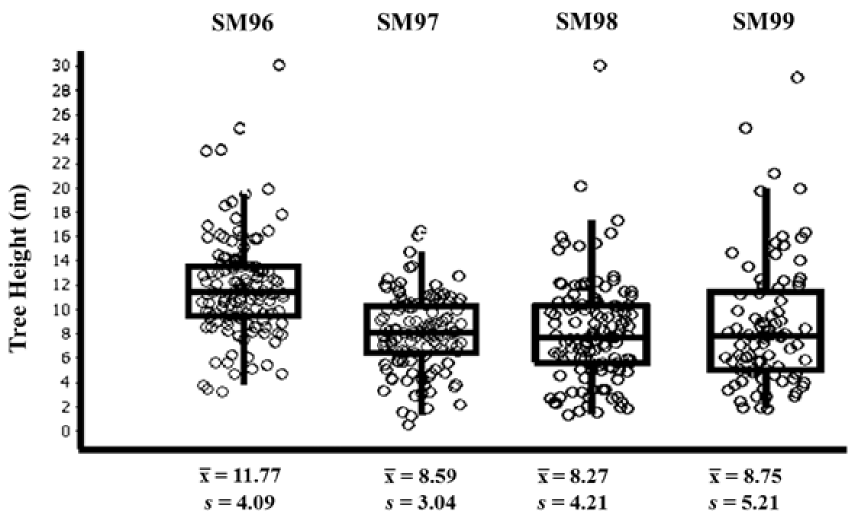

Fig. 4. Mean average total height (m) of planted *S. macrophylla* at different age stands. x̄ and s refer to mean and standard deviation, respectively

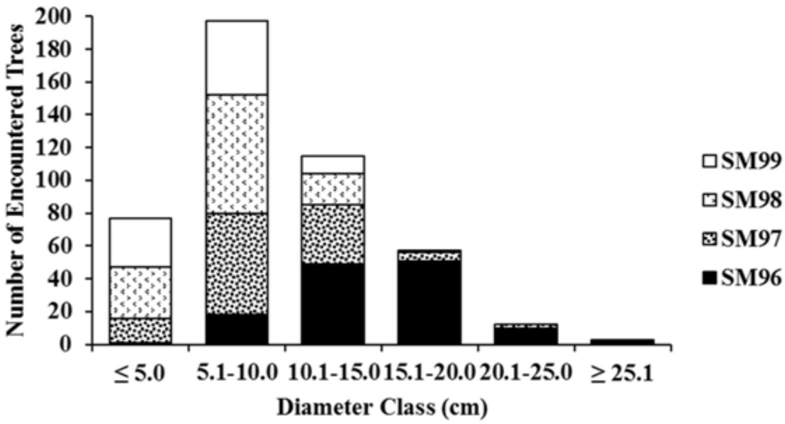

Fig. 5. Diameter at breast height (cm) distribution of planted *S. macrophylla* in SM96, SM97, SM98 and SM99

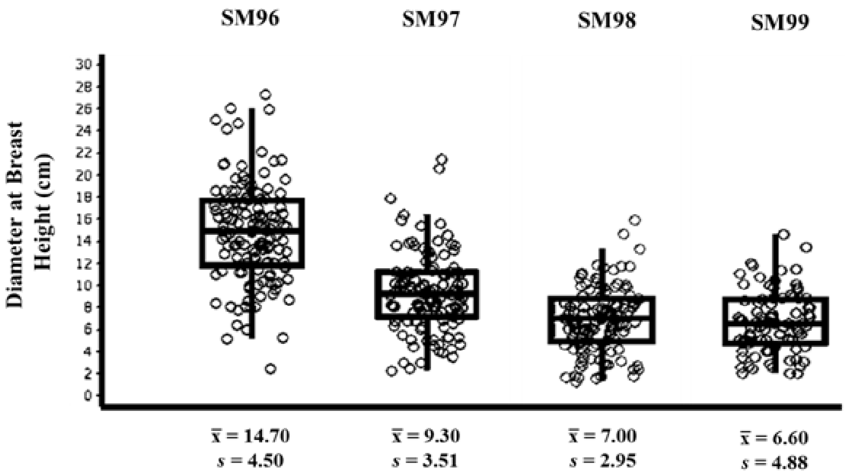

Fig. 6. Mean average diameter at breast height (cm) of planted *S. macrophylla* at different age stands. x̄ and s refer to mean and standard deviation, respectively

Fig. 7. Periodic inundation at Sampadi Forest Reserve reforestation sites

Table 1. Mean Annual Increment in Height (MAIH) and Mean Annual Increment in Diameter (MAID) of planted *S. macrophylla* at different age stands in this study and other previous studies on reforestation in Malaysia

Studied species	Stand age (years)	MAIH (m yr^{-1})	MAID (cm yr^{-1})	Planting technique	Source
Shorea macrophylla	18	0.65b	0.82c	Line planting	Present study
Shorea macrophylla	17	0.51a	0.55b	Line planting	Present study
Shorea macrophylla	16	0.52a	0.44a	Line planting	Present study
Shorea macrophylla	15	0.58ab	0.44a	Line planting	Present study
Shorea leprosula	6	1.08	1.10	Open planting	Hamzah *et al*. (2009)
Shorea parvifolia	6	1.00	1.01	Open planting	Hamzah *et al*. (2009)
Shorea leprosula	12	1.24	1.44	Multi-storied forest planting	Arifin *et al*. (2008)
Shorea parvifolia	12	1.01	1.20	Multi-storied forest planting	Arifin *et al*. (2008)
Shorea pauciflora	11	0.67	0.74	Line planting	Arifin *et al*. (2008)
Shorea macroptera	11	0.61	0.67	Line planting	Arifin *et al*. (2008)
Shorea pauciflora	11	0.77	1.08	Gap planting	Arifin *et al*. (2008)
Shorea macroptera	11	0.74	0.86	Gap planting	Arifin *et al*. (2008)

Note: Different letters within same column of studies species, *S. macrophylla* indicate significant differences at $p<0.05$ using Tukey HSD test

Suitability, Adaptability and Growth Performance of Shorea macrophylla at Sampadi Forest Reserve and other Previous Studies on Forest Rehabilitation in Malaysia

In order to clarify the fundamental information on the suitability of *Shorea macrophylla* as one of the suitable species selected for future reforestation and rehabilitation purposes in Sarawak, Table 1 shows the findings in this study with previous studies in Malaysia on experimental reforestation efforts to rehabilitate degraded lands by using indigenous Dipterocarp tree species under various forms of enrichment planting techniques. Even though the performance of planted tree species and edaphic factors in previous studies varied from this study and may influence over speculation when comparing, it should be noted that the tree species used in these studies are of the same family (family Dipterocarpaceae) and the discussion from this study is principally to obtain information on whether *S. macrophylla* is well-suited tree species for future reforestation and rehabilitation purposes.

In the present study, regardless of the difference in stand age after planting, planting techniques and types of planted tree species, the Mean Annual Increment in Height (MAIH) and Diameter (MAID) of *S. macrophylla* planted in SM96, SM97, SM98 and SM99 were lesser as compared to the results reported by (Hamzah *et al*., 2009; Arifin *et al*., 2008). Nonetheless, the Mean Annual Increment in Height (MAIH) and Diameter (MAID) of *S. macrophylla* were lower as compared to planted *S. pauciflora* and *S. macroptera* under both line and gap planting techniques.

According to Arifin *et al*. (2008; Hamzah *et al*., 2009), the effect of extreme heat, strong winds and overexposure of light to the planted seedlings under open planting could be the major reason behind the low survival of planted *S. leprosula* and *S. parvifolia* in their study. In addition, Suhaili *et al*. (1998) reported that the full sunlight received by the seedlings has caused scorching of leaves hence resulting in a low percentage of survival. Based on the current study, although the survival of the planted *S. macrophylla* in Sampadi Forest Reserve was substantially higher, it is expected that in the future, the percentage of survival of *S. macrophylla* will decline when the planted trees reached its maximum maturity due to competition for space, available nutrients in soil and light requirement for the planted trees. In the case of planted dipterocarp species like *Shorea* spp., several researchers have also reported a similar trend of low survival when involving planting dipterocarp species on the degraded secondary forest. For example, Azman *et al*. (1990) reported that *S. leprosula* and *S. parvifolia* survival of 30 and 20%, respectively at 15 years after planting. In addition, Ådjers *et al*. (1996) reported that the survival of planted ten dipterocarp species varied widely from 5.9 to 77.8% after three years of planting in degraded secondary forest subjected to shifting cultivation in Kalimantan, Indonesia. Dipterocarp species shows relatively slow growth rate but it is adapting well to sufficient amount of sunlight when planted on a land with poor soil properties (Appanah and Weinland, 1993; Ådjers *et al*., 1996; Vincent and Davies, 2003).

Environmental factors such as weather condition in terms of sunlight intensity, pest attack (termites), animal distribution, planting technique, weed competition and poor soil condition are the factors possibly could lead to variation in growth performances and survival of Dipterocarp species (Evans, 1992). A study by Hattori *et al*. (2006) has been reported that *S. macrophylla* is susceptible to termite attack. The sap-sucking insect, *Helopeltis clarifer* has been recorded to kill seedlings in the nursery. Moreover, growing space also may contribute to the growth performance (Mohd Zaki *et al*., 2003).

One of the advantages adapting enrichment planting such as line planting technique is that it enables the local vegetation such as some kind of undisturbed pioneer species which has grown naturally before the establishment of reforestation site to provide optimal shade condition for the planted dipterocarp seedlings.

Nevertheless, silvicultural activities can be conducted easily as the spaces between the planted seedlings are uniform. Notwithstanding, good silvicultural activities under this form of planting technique in the reforestation area at Sampadi Forest Reserve should be considered as tree species like *Dillenia suffructicosa* and *Macaranga* spp. in SM96, SM97, SM98 and SM99 would generate a competition for light and space with the planted *S. macrophylla*. As described by Arifin *et al*. (2008), the percentage survival of planted *Shorea* spp. was significantly higher under narrow than the wider opening of both line and gap planting techniques in Peninsular Malaysia. Generally, dipterocarp seedlings have been found to survive better in shaded sites as compared to open sites (Ådjers *et al*., 1996; Romell *et al*., 2007). Therefore, selection of the suitable seedlings is essential for future reforestation and rehabilitation programmes in the humid tropics of Malaysia.

Conclusion and Recommendations

In conclusion, the preliminary assessment on the survivorship and growth performance of *S. macrophylla* after enrichment planting under various age stands indicated a positive tree growth which clarified the efficacy of line planting system used in Sampadi Forest Reserve. The findings implied that *S. macrophylla* is suitable for forest rehabilitation purpose in the study area and the positive outcome could be achieved from this reforestation effort on a long run. Nonetheless, high survival percentage associated with substantial growth rate in terms of diameter and height of *S. macrophylla* could be due to the good adaptability and survivability of this species which can grow under certain soil condition or competition for light between planted trees and naturally grown vegetation which was undisturbed with the planting line. It is recommended that *S. macrophylla* can be considered as one of the choices of planting species for current and future reforestation purpose since it was able to survive periodic inundation as reported in this study. Thus, further detailed studies are required in order to find out other environmental factors which could affect the survivorship and growth performance of *S. macrophylla* under line planting system in the humid tropics of Sarawak.

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Author's Contributions

Mugunthan Perumal: Involved in all experiments, field work, coordinated data analyses and contributed to the scientific writing of the manuscript.

Mohd Effendi Wasli: Project leader, involved in the supervision of the research, field work, data analyses, editing and proofreading of the manuscript.

Ho Soo Ying: Involved in field work and provide technical help during the field survey.

Jonathan Lat: Involved as field assistance and provide technical help during the field survey.

Hamsawi Sani: Involved in the supervision of the research.

Ethics

The authors declare no conflicts of interest and this article is original and contains unpublished material in accordance with the ethical standards specified by the OnLine Journal of Biological Sciences.

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