Journal of Environmental Science and Engineering B 7 (2018) 131-140
doi:10.17265/2162-5263/2018.04.002

The Survival and Vegetative Growths of a 60 Month-Old Tropical Rainforest Tree Species Trial Established under a *Hopea odorata* Nurse Stand at an Ex-Tin Mine in Peninsular Malaysia

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Abstract: AFoCo (Asian Forest Cooperation) Project in 2011 has funded a research and development project in Malaysia for enriching a mono-species stand established in an ex-tin mine. The project covered only for a period of 12 months. A study plot of 1 ha size was established in TTAC (Tin Tailings Afforestation Centre). Twenty indigenous tropical rainforest tree species were planted and their five year-old survival count, diameter and H (top height) growths are reported in this study. Some of them are red list species of IUCN (International Union of Conservation of Nature). The survival of the 1 ha planting trial was 53%. Mortality of the tree species is mainly caused by wild boars. The tropical rainforest tree species in this planting trial had similar growth to those planted at good mineral soils. This paper also documented the tending treatments which were implemented during post-planting that have contributed to healthy growth of the mixed-species stand. The mixed-species stand is being properly tended till to-date and hence sustained growth of the stand is anticipated.

Key words: Rainforest species trial, ex-tin mine, restoration, red-list tree species.

1. Introduction

Conversion of natural forests to various land uses for developing countries is a necessary evil along the social-economic pathway leading into a developed nation. Tin mining plays an important role for the economic development of Malaysia in the past three decades. Tin mining activities completely destroy the terrestrial ecosystem and reduce once diversified tropical rainforest into denuded ex-tin mines. To-date the extent of idle ex-tin mines was estimated to be about 80,000 ha distributed mainly in Perak and Selangor [1]. Ex-tin mine is an impoverished site comprising slime and sand tailings and has adverse microclimate for plant growths [2]. In addition, ex-tin mine has heavy metal pollutants such as arsenic and cadmium which are toxicants to plant growths [3]. Natural regeneration of ex-tin mines which are isolated from the natural forest comprising mainly only pioneer species normally was found in the early successional phase of open idle land or grassland, as there is lacking of seed sources from rainforest tree species [4]. FRIM (Forest Research Institute Malaysia) has developed the rehabilitation technologies for the greening ex-tin mines [5]. An ex-tin mine covering 121.5 ha was successfully greened by FRIM in 2002 and it is known as TTAC (Tin Tailings Afforestation Centre), which is located at Bidor, Perak in Peninsular Malaysia [6]. The greened site has been a model for rehabilitation of ex-tin mines in Malaysia and the

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region comprising 20 timber tree species [7]. AKECOP (ASEAN Korea Environmental Cooperation Project) supported the rehabilitation program in TTAC since 2002 and the project completed in 2016. Authors observed poor regeneration under man-made forest stands established on sand and slime tailings comprising species such as *Acacia mangium*, *Acacia auriculifomis*, *Hopea odorata* and *Khaya ivorensis* [8]. These man-made forests established in TTAC are but an island surrounded by farmlands, housing estates and oil palm plantation. The only small fragmented logged-over lowland forest nearby is Chikus Forest Reserve, which is located 15 km away from TTAC. Hence, only some woody tree and shrub species in the logged-over lowland forest that are dispersed by avian dispersal agents were found under the man-made forest stands. The species composition of the natural regeneration is lack of main climax tree species of lowland rainforest, as their seed dispersal agents are not birds or bats but big mammals, and/or, by winds [9]. Hence, further planting of selected climax rainforest tree species which are not found in the man-made forests was carried out in TTAC in 2011. This is part of the planting activity to fulfil one of the objectives stated in the blue print of TTAC; which is turning it eventually into a plant depository of tropical rainforest [10]. From 2013 till 2016, AKECOP funded the tending of the demonstration plot established by ASEAN-Korean Forest Cooperation Project (AFoCo) in the period of 2011-2012. The demonstration plot is a mixed stand of twenty rainforest tree species established under the nurse species *Hopea odorata*. This paper aims to document the survival and vegetative growth of the mixed stand of rainforest tree species established on a greened slime tailings site at five years after planting.

2. Material and Methods

2.1 Study Site

A study plot was divided into two subplots established under a ten-year-old *Hopea odorata* stand grown at slime tailings located in TTAC, Bidor, Perak, Peninsular Malaysia. The soil composition of the slime tailings in TTAC at 0-60 cm depth had 1.7-33.3% gravel (particle size > 2 mm), 31-38.7% sand (particle size between 0.05-2 mm), and 11.3-27.3% silt and clay (particle size < 0.05 mm). The study site has an average monthly rainfall of 283-290 mm, average daily maximum temperature of 34 to 35 °C, average mean daily minimum temperature of 22 to 24 °C, mean daily maximum irradiance of 1,600-2,500 $\mu mol \cdot m^{-2} \cdot s^{-1}$ [11]. The study plot was enriched with 20 indigenous tree species under-planting the ten year-old nurse stand of *H. odorata* with mean stand height and mean stand diameter of 13.3 ± 2.5 m and 6.7 ± 2.8 cm, respectively. The undergrowth mainly comprised of early pioneer plant species and they were cleared between the 4 × 5 m interspace of the two planting rows. The distance between two planting rows is 5 m apart. The slime tailings were then loosened to a depth of 1 m using a back-hoe machine. Planting hole of each planting point was dug manually with a specification of 30 cm radius and 50 cm depth. The planting distance was at 2 × 2 m for each planting point. The 1 ha plot is located between two forest roads namely Jalan Biodiversiti and Jalan Pasir in TTAC, it is further divided into two subplots of each 0.5 ha size. Subplot A is located adjacent to Jalan Biodiversiti and it was treated with burnt-rice husk and Subplot B which is located adjacent to Jalan Pasir acted as a control or without the treatment (Fig. 1).

For subplot treated with burnt-rice husk, the planting hole was then applied with ashes of burnt-rice husk of 1 kg per planting point mixed with the slime and refilled back to 20 cm. Another 1 kg burnt-rice husk was applied to each planting point at six months after planting. Burnt-rice husk treatment was found to be an insignificant effect on the survival and growth of the rainforest tree species grown under the nurse stand [12].

2.2 Planting Stock

The planting stock of the twenty selected indigenous

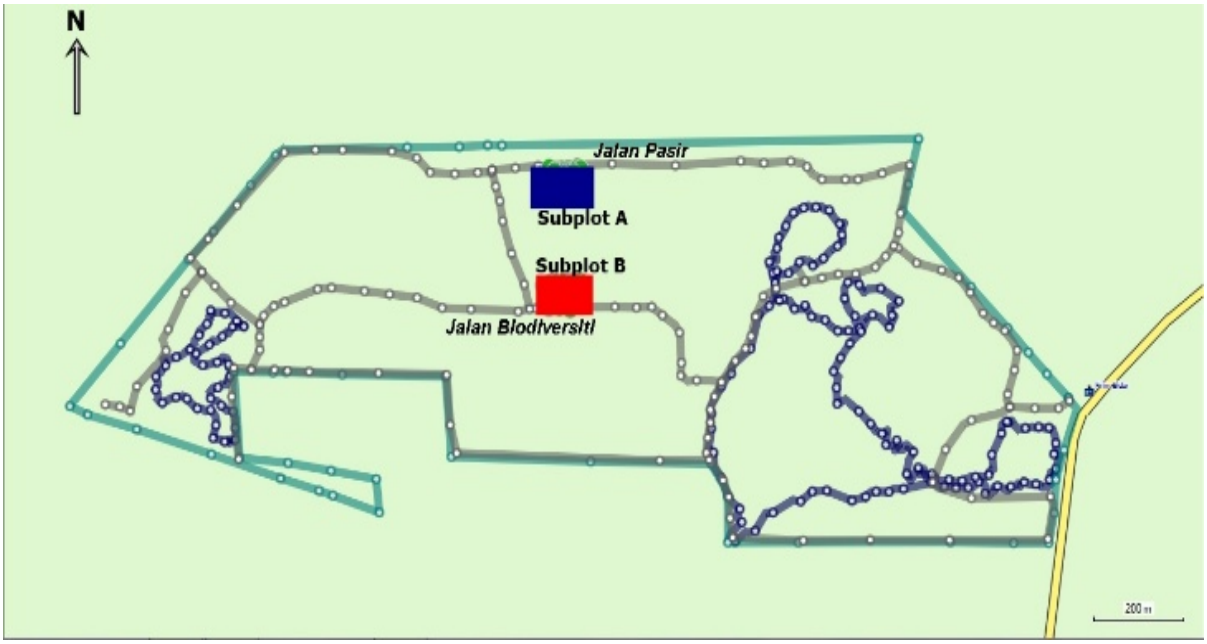

Fig. 1 The location of the two subplots (not to scale) in TTAC.

Table 1 Tree species list for the planting trial.

Non-dipterocarps	Dipterocarps
Garcinia hombroniana (NE)	**Shorea assamica* (CR)
Melaleuca cajuputi (NE)	*Shorea parvifolia* (NE)
Sindora coriacea (NE)	**Shorea acuminata* (CR)
Careya arborea (NE)	*Shorea curtisii* (LC/LR)
Cananga odorata (NE)	*Dryobalanops aromatica* (NE)
**Agathis borneensis* (EN)	**Hopea ferruginea* (CR)
Palaquium gutta (NE)	**Neobalanocarpus heimii* (VU)
**Aquilaria malaccensis* (VU)	**Shorea roxburghii* (EN)
Pentaspadon motleyi (DD)	**Shorea platyclados* (EN)
	Shorea ovalis (NE)
	Shorea macroptera (NE)

* denotes species listed in IUCN Red List Categories and Criteria Version 2.3 as threatened taxa include EN (Endangered), CR (Critically Endangered) and VU (Vulnerable). The other species are classified as NT (Near Threatened), LC (Least Concern)/LR (Lower Risk), DD (Data Deficient) and NE (Not Evaluated) [13, 14].

rainforest species were acclimatized in the TTAC for a period of three months prior to planting and they were distributed randomly in the two subplots. They have an average height of 45-50 cm and collar diameter of < 1 cm. They were planted during the wet season in December 2011. These species planted in the enrichment program are listed in Table 1. Eight of the twenty rainforest tree species is referred to as threatened species according to IUCN (International Union of Conservation of Nature) Red List version 2.3 (Table 1), of which two are non-dipterocarps and six dipterocarps.

2.3 Tending Regime

Tending practices including weeding together with loosening of soils and fertilizer application were carried out at two-month and three-month intervals, respectively. Weeding includes blanket weeding using environmentally safe weedicide sprayed at 50 cm away from each planting point, then followed by

circle weeding manually within the 50 cm radius of the planting point. Loosening of soils within 50 cm radius was carried out together with the circle weeding. The planting point was further enriched with additional nutrients from the application of a mixture of organic fertilizer comprising 80% chicken manure with 10 g NPK (15:15:15) at three-month intervals. Watering was carried out during the first year after planting during the dry periods of April, June and July 2012, with an average monthly rainfall of 80 ±10 mm. The mean daily evapotranspiration is at 4 mm·day^{-1} [5]. No more watering after the second year but weeding and loosening of soils were carried out till to-date.

2.4 Survival and Growth Parameters

Each species was planted with 36 seedlings in each subplot. Hence, total seedlings of 20 rainforest tree species are 720 seedlings per subplot. The survival of each species was computed accordingly as number of survived seedlings × 100%/36. Each planting point of the surviving species was ground positioned using a ground positioning satellite receptor, Garmin Rino 650. The diameter at breast height (dbh) was measured at 1.4 m above ground level using a Richter fiber-glass diameter measuring tape with diameter graduation readable to mm. The top height (H) of saplings and trees was measured using a telescopic height measuring stick (Fig. 2). Mean diameter or height annual increment is calculated by mean diameter or height divided by five years (Mean dbh/5 or H/5). Initial height range of the seedlings for all the species was from 30 to 50 cm.

3 Results and Discussion

3.1 Survival

Survival counts were carried out in June 2012, May 2013, July 2015 and June 2017. The survival of the enrichment species is reduced from an average of 91.8% to 53% from 2012 to 2017, respectively (Table 2). The distribution of each species in Subplots A & B is recorded in GPS map (Fig. 3). Mortality of the planting is mainly due to destruction of seedlings by wild boars which contributed to 80% of the total mortality of the mixed stand (Fig. 4), the other remaining 3% was due to root diseases and 17% due to adaptability of the species. Wild boars uprooted the seedlings in the first two years, and later debark them and eventually they were killed during the drought seasons. Similar problem is also recorded for a planting of indigenous timber species in logged-over forest in Peninsular Malaysia, 60% of the mortality was due to wild boars [15].

Generally, dipterocarp species had higher survival count than non-dipterocarps grown on the greened slime tailings (Table 3). *Shorea roxburghii* had survival more than 80%, this species is known to be suitable for adapting in open conditions especially in open planting but lower than the planting on good mineral soils under *Acacia mangium* as a nurse stand [15, 16], followed by *Neobalanocarpus heimii* and *Dryobalanops aromatica*. *Shorea platyclados* in this study had the lowest survival of 54.2%, as it severely suffered from wild boar attacks. However, despite

Fig. 2 Height measurement of the rainforest trees grown under the *Hopea odorata* stand.

Table 2 Survival (%) of tropical rainforest species grown on greened slime tailings.

	Quantity	7/11/11	12/6/12	13/5/13	14/7/14	15/7/15	17/6/16
Subplot A	720	100%	98.3%	75.1%	62.2%	54%	50%
Subplot B	720	100%	91.8%	76.1%	64.7%	59%	56%
Mean		100%	95.1%	75.6%	63.5%	56.5%	53%

* Seedlings were planted in Nov. 2011 & refilling was done in May 2012.

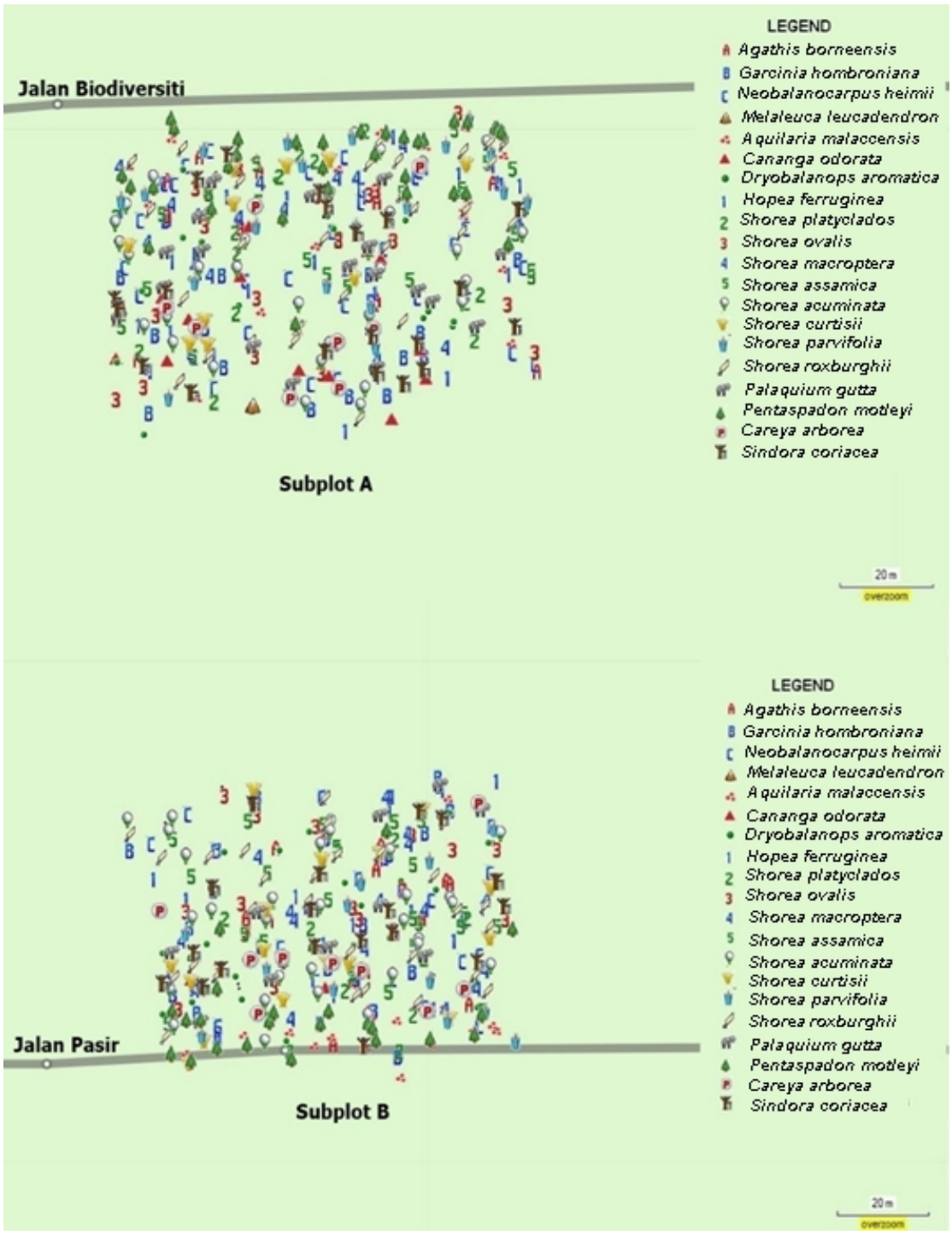

Fig. 3 Distribution of the surviving species in Subplot A at Jalan Biodiveristi and Subplot B at Jalan Pasir.

Fig. 4 Debarking of trees by the wild boars which eventually killed the five year-old *Dryobalanops aromatica*.

Table 3 Survival of rainforest species grown on the greened slime tailings at five years after planting.

No.	Species	Survival (%)		
		Subplot A	Subplot B	Mean
	Dipterocarps			
1	*Shorea roxburghii*	86.1	86.1	86.1
2	*Neobalanocarpus heimii*	80.5	63.9	72.2
3	*Dryobalanops aromatica*	75	66.7	70.8
4	*Shorea parvifolia*	72.2	55.6	63.9
5	*Shorea acuminate*	63.9	63.9	63.9
6	*Shorea curtisii*	55.6	55.6	55.6
7	*Shorea macroptera*	55.6	55.6	55.6
8	*Shorea assamica*	47.2	63.9	55.6
9	*Shorea ovalis*	52.7	55.6	54.2
10	*Hopea ferruginea*	55.6	47	51.3
11	*Shorea platyclados*	33.3	50	41.6
	Non-dipterocarps			
12	*Pentaspadon motleyi*	80.5	80.6	80.6
13	*Sindora coriacea*	50	50	50
14	*Agathis borneensis*	41.7	50	45.8
15	*Aquilaria malaccensis*	36.1	55.6	45.8
16	*Garcinia hombroniana*	52.8	25	38.9
17	*Palaquium gutta*	47.2	27.8	37.5
18	*Cananga odorata*	11.1	11.1	11.1
19	*Careya arborea*	13.8	8.3	11
20	*Melaleuca cajuputi*	0	2.7	1.35

growing in an impoverished slime tailings site, it has the same range of survival as it was planted in a good mineral soils of a logged-over forest. A study showing that *Shorea platyclados*, *S. parvifolia* and *S. assamica* were line planted in a logged-over forest at Tapah Forest Reserve had survival of 48.2%, 67% and 89.9%, respectively at 60 months after planting [15]. Similarly, *Neobalanocarpus heimii* grown in slime tailings had better survival than those planting under the nurse stand of *Acacia mangium* established on good mineral soils which had only 9 to 13% survival at 76 months after planting [15].

For survival of the selected non-dipterocarps planted under the *Hopea odorata* stand, *Pentaspadon motleyi* had the highest survival followed by *Sindora coriacea*, and the lowest survival group of species comprising of *Cananga odorata, Careya arborea* and *Melaleuca cajuputi.* No survival was recorded for *Melaleuca cajuputi* in Subplot A, one of the reasons other than being destroyed by wild boars through uprooting it during the seedling phase, is due to its low adaptability in growing under shade. *Melaleuca cajuputi* is a strong light demander grown gregariously and dominantly in open and acidic conditions of coastal swales-sand dunes in Malaysia [17]. Lower survival of *Cananga odorata* under shade is anticipated as it is also a strong light demander and grows as plantation crop in open condition for essential oil production and is highly sought in the fragrance industry. *Careya arborea* is also another species more susceptible to the wild boar attack thus has lower survival.

3.2 Mean dbh and MAID (Mean dbh Annual Increment)

The mean dbh and MAID are tabulated in Table 4. Based on the growth assessment, twenty species of rainforest tree species could be grouped into four groups. The first group comprises of *Shorea acuminata, S. parvifolia*, and *S. platylados* are relatively fast growers and have their range of dbh from 6.2 to 6.9 cm (Table 4). The second group of rainforest species had mean range of dbh from 4.8 to 5.1 cm including *Shorea ovalis*, *S. macroptera, S. curtisii*, *Hopea ferruginea* and *Pentaspadon motleyi*. The third group of tree species namely *Shorea assamica, Neobalanocarpus heimii*, *S. roxburghii*, *Cananga odorata*, *Palaquium gutta*, *Agathis borneensis*, *Sindora coriacea* and *Garcinia homobroniana* had a mean dbh range from 3.6 to 4.8 cm. Lastly, *Careya arborea* was identified as the slowest grower due to its low drought tolerant morphological properties and also easily attracts wild boar attacks. Their MAID follows the same trend of mean diameter growth (Table 4).

Shorea parvifolia in this study has similar MAID with other finding when it was grown in a good mineral soil through similar type of planting method. Periodic mean diameter annual increment of *S.*

Table 4 Mean dbh and periodic MAID of the tree species at five years after planting.

	Species	Subplot A	Subplot B	Mean dbh (cm)	MAID (cm/y)
1	*Shorea acuminata*	7.9 (2.5)	5.9 (1.4)	6.9 (1.9)a	1.38 (0.39)
2	*Shorea parvifolia*	7.2 (2.4)	6.4 (3.2)	6.8 (2.8)a	1.36 (0.56)
3	*Shorea platyclados*	6.7 (2.4)	5.8 (2.5)	6.2 (2.4)a	1.25 (0.49)
4	*Dryobalanops aromatica*	5.1 (2.1)	5 (1.7)	5.0 (1.8)b	1.01 (0.37)
5	*Shorea assamica*	5.7 (2)	4.4 (1.1)	5.0 (1.6)b	1.01 (0.31)
6	*Shorea ovalis*	5.4 (1.4)	4.5 (2.2)	5.0 (1.8)b	0.99 (0.36)
7	*Shorea macroptera*	4.9 (1.8)	4.8 (1.5)	4.8 (1.6)b	0.97 (0.33)
8	*Shorea roxburghii*	3.8 (2.1)	4.5 (1.7)	4.2 (1.9)c	0.83 (0.38)
9	*Shorea curtisii*	4.8 (2)	3.5 (1.2)	4.2 (1.6)c	0.83 (0.32)
10	*Cananga odorata*	3.5 (1.1)	4.7 (1.9)	4.1 (1.5)c	0.82 (0.3)
11	*Hopea ferruginea*	4.4 (1.4)	3.5 (0.9)	4.0 (1.2)c	0.79 (0.23)
12	*Palaquium gutta*	2.2 (1.1)	4.4 (1.2)	3.3 (1.15)cd	0.66 (0.23)
13	*Garcinia hombroniana*	3.1 (1.1)	3.2 (1.1)	3.2 (1.1)cd	0.63 (0.22)
14	*Neobalanocarpus heimii*	2.8 (1.1)	3 (1.2)	2.9 (2)d	0.58 (0.23)
15	*Agathis borneensis*	2.7 (1.1)	3 (0.8)	2.8 (0.95)cd	0.57 (0.19)
16	*Aquilaria malaccensis*	2.2 (1.1)	2.8 (1.1)	2.5 (1.1)d	0.5 (0.22)
17	*Pentaspadon motleyi*	2.2 (0.8)	2.8 (1)	2.5 (0.9)d	0.5 (0.18)
18	*Careya arborea*	1.6 (0.57)	1.6 (0.7)	1.6 (0.63)de	0.32 (0.12)
19	*Sindora coriacea*	2.9 (1.2)	2.97 (1.3)	1.2 (1.2)e	0.24 (0.25)
20	*Melaleuca cajuputi*	-	3.4	-	0.68

() denotes standard deviation and different alphabetical letters denote significant differences by *t*-test at 0.05 level.

Table 5 Mean H and MAIH (Mean Top Height Annual Increment) of the tree species.

No.	Species	Subplot A	Subplot B	Mean H (m)	MAIH (m/y)
1	*Shorea parvifolia*	8.7 (3.2)	7.5 (2.5)	8.1 (2.8)a	1.6 (0.6)
2	*Shorea platyclados*	7.9 (2.3)	6.6 (2.2)	7.2 (2.2)a	1.45 (0.45)
3	*Aquilaria malaccensis*	7.2 (1.9)	6.9 (1.8)	7.0 (1.8)a	1.41 (0.37)
4	*Dryobalanops aromatica*	7.4 (1.9)	7.1 (2.1)	7.2 (2)a	1.4 (0.4)
5	*Shorea acuminata*	7.9 (2.5)	5.9 (1.4)	6.9 (1.9)ab	1.38 (0.45)
6	*Shorea ovalis*	7 (1.6)	5.8 (1.9)	6.4 (1.8)b	1.28 (0.35)
7	*Shorea macroptera*	6.4 (1.9)	6.2 (2.2)	6.3 (2.0)b	1.26 (0.41)
8	*Shorea curtisii*	6.8 (2.6)	5.4 (1.7)	6.1 (2.2)b	1.22 (0.43)
9	*Pentaspadon motleyi*	4.4 (2.3)	7.2 (2.8)	5.8 (2.6)bc	1.16 (0.51)
10	*Hopea ferruginea*	6.5 (1.1)	5 (1.4)	5.8 (1.6)bc	1.15 (0.25)
11	*Cananga odorata*	4.1 (1.8)	5.6 (1.6)	4.8 (1.7)c	0.97 (0.34)
12	*Shorea assamica*	3.6 (1.9)	6 (1.4)	4.8 (1.6)c	0.96 (0.33)
13	*Shorea roxburghii*	3.8 (2.1)	5.7 (2.3)	4.8 (2.2)c	0.95 (0.44)
14	*Palaquium gutta*	4.3 (1.1)	4.4 (1.2)	4.4 (1.2)c	0.87 (0.23)
15	*Agathis borneensis*	3.4 (1.5)	4.4 (0.9)	3.9 (1.2)c	0.78 (0.24)
16	*Neobalanocarpus heimii*	3.7 (1.8)	3.8 (1.4)	3.8 (1.6)c	0.75 (0.32)
17	*Sindora coriacea*	3.6 (1.2)	3.9 (1.3)	3.8 (1.2)c	0.75 (0.25)
18	*Garcinia hombroniana*	3.5 (1)	3.8 (1.3)	3.6 (1.12)c	0.73 (0.23)
19	*Careya arborea*	1.9 (1.2)	1.4 (1.2)	1.6 (1.2)d	0.33 (0.24)
20	*Melaleuca cajuputi*	-	6.6	6.6	1.32

() denotes standard deviation and different alphabetical letters denote significant differences by *t*-test at 0.05 level.

assamica and *S. platyclados* planted under a logged-over forest is reported to be 1.0 and 0.6 $cm \cdot y^{-1}$, respectively, at 60 months after planting [18]. Both the species in this study had greater MAID than those grown in a good mineral soils at a logged-over forest. Similarly, *Shorea macroptera* and *Neobalanocrpus heimii* had greater MAID than those planted in good mineral soils [15-17, 19].

3.3 Mean H and Mean Annual Top Height Increment

The mean H and periodic mean height annual increment of twenty species of rainforest tree species could be grouped into four groups. The first group comprises of *Aquilaria malacensis*, *Shorea parvifolia*, *S. platyclados*, *Dryobalanops aromatica* and *S. accuminata*, which are relatively fast growers and have their range of H from 6.9 to 8.1 m (Table 5). The second group of rainforest species had mean H of 5.8 to 6.4 m including *Shorea ovalis*, *S. macroptera*, *S. curtisii*, *Hopea ferruginea* and *Pentaspadon motleyi*. The third group of tree species namely *Shorea assamica*, *Neobalanocarpus heimii*, *S. roxburghii*, *Cananga odorata*, *Palaquium gutta*, *Agathis borneensis*, *Sindora coriacea* and *Garcinia hombroniana* had a range of H from 3.65 to 4.85 m. Lastly, *Careya arborea* was identified as the slowest grower due to its low drought tolerant morphological properties and also easily attracts wild boar attacks. A single remaining tree of *Melaleuca cajuputi* was excluded from the ranking.

Similarly, mean height annual increment follows the same trend as the mean H. Interesting to note that *Shorea platyclados*, *Neobalanocarpus heimii*, *S. parvifolia*, *S. curtissi*, *Agathis borneensis* and *Pentaspadon motleyi*, *S. accuminata*, *S. macroptera*, *Sindora coriacea* and *S. curtisii* are species used for enriching the timber stock in logged-over forests which have good mineral soils [15, 16, 18, 19]. They are now proven to survive and grow healthily in a greened slime tailings site under the nurse stand of *Hopea odorata*. The single tree of *Melaleuca cajuputi* left in the planting trial is growing at the edge of the plot which is

at open condition hence it has high diameter and height growths.

4. Conclusion

Based on the results of survival and vegetative growth parameters of the mixed-species stand grown on slime tailings, most of selected tropical rainforest tree species are suitable for growing on the improved slime tailings through under-planting the nurse stand except strong light demander such as *Melaleuca cajuputi*. It is important to highlight the good growth for most of the species in the five year-old mixed stand is largely contributed by the proper tending practices being implemented. To reduce further mortality caused by wild boars to the mixed stand, a research on how to prevent the wild boar attacks may need to be conducted. The tending practices of the mixed-species stand developed in this study provide a plantation know-how to further enrich a successful rehabilitation phase of ex-tin mine from a mono-species stand to a mixed-species stand which will eventually lead to restoration success of turning barren ex-tin mine into a man-made tropical forest.

Acknowledgements

The authors would like to thank the funding agencies namely AKECOP (ASEAN Korea Environmental Cooperation Project) and AFoCo (ASEAN-Korean Forest Cooperation Project) for financing the establishment of the plot in the first five years, and presently the demonstration plot is being supported by the management fund of FRIM from the Government of Malaysia.

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