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Choosing native tree species for establishing man-made forest: A new perspective for sustainable forest management in changing world

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Abstract. *Subiakto A, Rachmat HH, Sakai C. 2016. Choosing native tree species for establishing man-made forest: A new perspective for sustainable forest management in changing world. Biodiversitas 17: 620-625.* Establishment of tree plantation on degraded lands and forest clearly favored some exotic species such as *Gmelina arborea, Acacia,* and *Eucalyptus.* High productivity, less harvesting time, and deeper silvicultural knowledge are the beneficial factor for choosing those exotics species. However, the use of a wide variety of native tree species becomes more significantly important in reforestation projects due to the greater biodiversity benefits and wider environmental services. This research was carried out as a multiyear observation and continuous experiment to value how native tree species can be prospective alternatives in providing and supporting human need. The performances of two native Indonesian *Shorea* species, *Shorea leprosula* and *Shorea selanica*, were evaluated at a dipterocarp planting trial in two different sites in Indonesia. Growth data was obtained from 15 and 17 years old plots, twelve 100 m X 100 m square plots on mineral soils (Gunung Dahu Experimental Forest/GDEF, Bogor) and eight resembled plots on frequently flooded peat land (PT. Arara Abadi/PT. AA, Riau). Survival rates were varied, ranged from 36-77%, diameter at breast height from 13.7-24.9 cm, tree height from 10.8-16.9 m, mean volume from 0.119 m^3/tree-0.567 m^3/tree, and total volume from 79.420 m^3/ha-215.412 m^3/ha. Growth rates of planted saplings were affected by species, site and spacing distance. The development of man-made dipterocarps forest in the tropic, especially in South East Asia can be as prospective as developing an exotic fast growing plantation. Eventhough *in situ* conservation would give the most benefit in conserving genetic resources of native tree species, establishing man-made dipterocarp forest still have higher environmental value than using exotic tree species such as acacia. Moreover, establishing man-made dipterocarp forest is considered more environmental friendly and possess lower to no risk of species invasion compare to those of developing exotic trees plantation.

Key words: exotic species, native tree, plantation, *Shorea leprosula*, *Shorea selanica*

Abbreviations: GDEF = Gunung Dahu Experimental Forest, PT. AA = PT. Arara Abadi, *S. leprosula* = *Shorea leprosula*, *S. selanica* = *Shorea selanica*.

INTRODUCTION

Dipterocarpaceae, a large family of dominant tree species in the tropical rain forests of Malaysia and Indonesia, is ecologically dominant and its timber is economically significant. Conservation of the dipterocarps was not an important issue in the past as the family was seen common and none were presumably threatened. However, fast dwindling natural forest resources is a general trend in Southeast Asia. Bradshaw et al. (2009) determined that Southeast Asia forests are the fastest disappearing among all other tropical region. Phat et al. (2004) is also estimated that Southeast Asia contributes 29% of the global total from deforestation. Most lowland dipterocarp forests in the area are either converted into oil palm plantations or are heavily logged in production forest of concession forest area. In such condition, it may take many decades to recover the commercial volume. Hence, there is an urgent need not to only decrease the current rate of deforestation, conserve the remaining forest cover, and restore the degraded land, but also to begin of growing new forests.

Establishment of tree plantation on degraded lands and forest initiates the recovery of native forest communities, but most of the reforestation projects favored some exotic species (e.g. *Gmelina arborea*, *Acacia*, *Eucalyptus*). There is a persisting myth for most tropical regions that exotic monocultures would significantly ease the pressure on remaining natural forests because it supplies timber needs in relatively short time. However, beyond these silvicultural aspects there are other issues in the debate on exotic vs. native tree species which deserve a deeper review. Barlow et al. (2007) reported that plantation of exotic species in the tropics have considerably lower diversity value than secondary forest and conversion of secondary forest to exotic plantation will lead to further biodiversity losses. Furthermore, reforestation is not only about restoring productive capacity of forest for future timber production but it has principal objective of recovering biodiversity and other environmental services that could be provided by forest itself. This is why the use of a wide variety of native tree species becomes more significantly important in reforestation projects. Establishment of commercial plantations of valuable dipterocarp species has been focus of research in Southeast Asia for nearly a century. The use of native tree species for plantation is likely to have greater biodiversity benefits than either exotic plantations or conversion to other land uses such as oil palm.

However, the constraint of less economic benefit and silvicultural knowledge on most of native tree species has led the establishment of native tree plantation becomes more complicated than that of established exotic plantation species. Furthermore, past studies have also been found that the native tree species of dipterocarps showed poor survival and grow much slower than those of pioneers or exotic trees in open grasslands (Otsamo et al. 1996, 1997; Tolentino 2008).

The purpose of the study was to examine the feasibility of growing dipterocarps plantation forest in Indonesia by evaluating the performance of the species in different spacing distance and sites. This will provide how dipterocarps plantation can be potentially established in the tropics.

MATERIALS AND METHODS

Study area

There were two experimental sites chosen for establishing a dipterocarp forest plantation trial. First is Gunung Dahu Research Forest (GDRF) which is located in Bogor, and second is plots at PT. Arara Abadi (PT. AA), Riau. GDRF trial plot lies around 40 km from Bogor city. Total area of the site is about 250 ha, where around 160 ha of the area had been successfully planted with dipterocarps with different objectives. The oldest stands were planted in 1997 while the youngest were planted in 2010. At the beginning of the project, most area was abandoned farmlands or secondary forests with few residual trees. GDRF consists of red-yellow latosol (inceptisol) with hilly terrain topography (elevation: 550-700 m asl.) and represented a mineral soil type. The hilly site was surrounded by villages, farm land, and mixed gardens. While plots at GDRF represented plantation area in mineral soils, plots at PT. AA represented dipterocarps plantation in drained shallow peat swamp soils, this area is frequently flooded at certain times. PT. AA is a forest plantation concession in Riau establishing *Acacia* and *Eucalyptus* plantation. The dipterocarps experimental plots at PT AA were established in 1998 with total area of 64 Ha with remaining planted area was about 8 ha.

Planting design, data collection and analysis

Planting stocks at both sites were originated either from seed and cutting propagules. Propagation by cutting was done by applying a mass propagation technique of cutting which was developed by The Forestry Research and Development Agency-Komatsu Project (Sakai et al. 2002). The technique and facilities for producing cutting propagules of dipterocarps is known as KOFFCO system (Subiakto et al. 2005). Planting stocks were raised at KOFFCO greenhouse and nursery, Conservation and Rehabilitation Research and Development Center (CRRDC), Bogor. The average size of planting stocks at the time of planting was 0.5 cm in diameter and 60 cm in height. Prior to this study, measurement at GDFR only carried out to plots those planted by *Shorea leprosula* and *Shorea selanica* each at spacing distance of 2 x 2 m, 3 x 3 m, and 4 x 4 m with total planting system. There were 6 combinations of the treatments, each represented by one-hectare (100 m x 100 m) plot with two replicates.

Measurement on plots at PT. AA conducted to plots those planted by *S. leprosula* and *S. selanica* each at spacing distance of 3 x 2.5 m and 3 x 5 m. There were 4 combinations of the treatments, each treatment was represented by one-hectare plots with two replicate. In total there were 8-ha plots measured at PT. AA. We tabulated the available data measurement for each the plot in both sites including survival rate, tree diameter, tree height, and standing stock per ha.

Diameter at breast height (DBH) and tree height (H) were calculated for both species and sites. Volume per hectare was calculated based on formulas developed by Wahyono and Soemarna (1984). One-way analyses of variance (ANOVA) were performed on DBH and H values to test the significance of species differences and spacing distance. A Duncan test was further executed to DBH and H values to determine statistical differences between treatments. No consecutive annual data were available for each of the plot; however, data collection were carried out at the time of planting, eight years after planting and fifteen and seventeenth year after planting (in about half cutting cycle of the dipterocarps).

RESULTS AND DISCUSSION

Establishment of man-made dipterocarp forest in GDRF

Dipterocarp plantation at GDRF was established for various purposes. The initial objective of planting dipterocarps in this area were as follow: (i) to test the adaptability of various dipterocarp to be planted outside their natural habitat; (ii) to determine the growth rate increment; (iii) to reveal its silvicultural technique both in nursery and field; and (iv) to conduct ex-situ conservation strategies of the species in a reliable and secure location (Subiakto et al. 2001). However, this study focused only to those block planting system plots of the two *Shorea* species with different spacing distance. Direct planting of dipterocarps and other primary forest species especially on *Imperata* grasslands have largely been unsuccessful because of slow growth and high mortality arising from their shade and moisture requirements (Otsamo et al. 2001).

At seventeenth year after planting, the survival rates were varied between 30.5%-77% depends on species and spacing distance. Survival rate within the same species showed that *S. leprosula* and *S. selanica* had their highest survival rate at 3 x 3 m spacing distance and the value went down when planted at more spacious distance of 4 x 4 m (Table 1). Hai et al. (1996) studied that shade together with terrain were the factor that significantly affect the survival rate. At the early stage of dipterocarps growth, denser population in semi-open area would create more shade environment and support higher survival rate compare to those planted on more spacious distance. In addition, Widiyatno et al. (2013) reported that *S. leprosula* were more resistant on availability of sunlight and hence they could be easily established in open planting that has high heat and temperature stress in the early plantation establishment.

Diameter at breast height varied among species and spacing distance (Table 1). In contrast to survival rate, both species showed similar tendency that they gained their highest DBH at more spacious distance (4 x 4 m > 3 x 3 m > 2 x 2 m). In further developmental stages, denser population would increase competition among individual and hence limit the availability of nutrient, light, and water for each tree. Comparison among two studied species showed that *S. leprosula* had higher DBH compare to *S. selanica* except for 2 x 2 m spacing distance when both species has no significant differences (Table 1). Similar to those DBH, height growth also increased along with more spacious distance except for *S. selanica* at 3 x 3 m spacing distance that resulted in shorter height compare to its 2 x 2 m spacing distance. Comparison between two studied species also showed that *S. leprosula* gave better height performance compare to *S. selanica* (Table 1). The estimation of standing stock per hectare based on numbers of tree survived indicated that *S. leprosula* gave the highest result at 3 x 3 m spacing distance, whereas for *S. selanica* the highest was 2 x 2 m. Both species showed similar result that more spacious distance would yield in highest DBH and height growth but lowest volume per hectare related to less number of trees per hectare.

In the primary forest at tropical rain forest the wood volume was estimated 211.75 m^3/ha where dipterocarps was 86,9% of total volume (Bischoff et al. 2005). The current dipterocarps standing stock potency of logged over area (LOA) in Indonesia range between 35 to 40 m^3/ha (Van Gardingen et al. 2003). This value is not economically profitable and attractive for the forest companies and thus many forest companies converted the area to exotic monoculture plantation. Therefore, several silviculture managements are needed to establish more economically attractive native tree plantation with the stressing on improving the yield. Standing stock value in GDRF showed that *S. leprosula* (2 x 2 and 3 x 3 m), could reach 195.855 m^3, 215.412 m^3 respectively, whereas *S. selanica* (2 x 2) could reach 181.395 m^3at around their half rotation cycle. These values are prospective considering that GDRF is not an optimum habitat for lowland dipterocarps and hence contain several major growth limitations.

In many cases exotics have been favored for plantation and reforestation projects due to the assumption that they grow faster. In contrast to widely believed that dipterocarps and others native trees perform poorly when planted in open and degraded lands (Suzuki and Jacalne 1986; Otsamo et al. 1996, 1997; Tolentino 2008), our results revealed that dipterocarps can be a promising alternative to those of exotic species to be used for reforestation projects and establishing tropical plantation. Considering both experimental sites have their major limitation for the suitability of optimum growth, our study showed that *S. leprosula* and *S. selanica* still grow well under their peripheral site condition. For GDRF, altitude seems to be the major limitation, since both species are the lowland dipterocarps components. The elevation of GDRF is about 700 m a.s.l. may haltered the optimum growth and performance of the species. While plots in PT. AA did not meet its criteria for optimum growth because once in a time it still has frequent flooded because the sites were originated from drained peat swamp forest. Hence, the growth of the two dipterocarps still performed well in this location. Other critical factor for growth of dipterocarps is precipitation. The average rainfall of GDRF and PT AA were 2500 mm/year and 2700 mm/year respectively, which are considered suitable for both tested species. The good growth performance of those species on both less suitable sites may be due to intensive maintenance of the weeding activity once every three months considered as reducing competition against weeds during early growth stage.

Our result further support those of Shono et al. (2007) and Santos Martin et al. (2010) who determined that native trees, including some Dipterocarpaceae, can survive and perform well even in open degraded sites. The very important native dipterocarps merit further research into developed for commercial plantation when all silvicultural management and site-species matching are determined so that survival rate and growth performance are increased (Langenberger 2006; Wishnie et al. 2007; Millet et al. 2013) to similar or nearly similar of that exotics species. In fact, our result supported previous study that *S. leprosula* showed faster growth and are potential to be established into commercial plantation especially in well-drained sites (Soekotjo 2009; Adjers et al. 1995).

The growth rates provided by this study help improve understanding of the potential prospect of the dipterocarps for establishing commercial plantation in the tropics. For most of dipterocarps, most of the studies focus on recently established plantings. The growth and performance review only to those of early stage and there are very few data points for plantations of more than 10 years, or for smallholder-managed sites. Thus, this study helps build knowledge about dipterocarps species management, and provides a comparison point for relative species and site performance. However, several important factors that influence tree performance such as site management and frequency and intensity of weeding around planted trees does not take into detailed consideration in this study.

Accordingly, site care and maintenance varied among two of experimental sites and so did for the spacing distance. Our study indicated that even the very frequent weeding activity conducted to every tree in PT. AA sites, the result for survival rates does not show extreme differences to those of GDRF. However, intensive weeding in PT. AA might give a positive impact to maintain the survival rate value. Similar to that of survival rate, even though diameter showed more consistent value among treatment in PT. AA, its increment also did not show an extreme difference to that of GDRF. In spite of intensive and frequent maintenances, the result seemed to indicate that several species do better in certain soil types and site conditions (Shono et al. 2007; Yamada et al. 2012; Scheneider et al. 2013; Dong et al. 2014); however swampy area might need more intensive nurturing than those of mineral soil for a dipterocarp lowland dry species to reach the similar growth performance and so as the vice versa.

More recent research in Singapore has also shown that native species, including certain dipterocarps such as *S. leprosula, S. acuminata, H. nutans* and *D. caudatus*, can successfully be planted in open lands (Shono et al. 2007), while other studies demonstrate that native dipterocarps in Sri Lankan such as *D. zeylanicus, S. disticha, S. migisttophylla* and *S. trapezifolia*need for nurse trees (Ashton et al. 1997, 1998), and others showed that dipterocarps performed well in enrichment plantings in semi-open selectively logged plantations (Millet et al. 2013).

This study demonstrated that in similar environment of hilly semi-open area, *S. leprosula* and *S. selanica* vary in their tolerance during their growth stages. However, *S. leprosula* showed higher growth both for diameter and height compare to those of *S. selanica* those resulted in higher mean volume/tree and total volume/ha. *S. leprosula* is known to be capable of fast initial growth and benefit from full open conditions (Appanah and Weinland 1990; Symington 2004; Shono et al. 2007). *S. leprosula* has also been shown to be the most suitable *Shorea* species for reforestation in several studies (Adjers et al. 1996; Howlet and Davidson 1996; Otsamo et al. 1996). Among four species of twelve years old dipterocarps studied by Hai et al. (1996), *S. leprosula* gave the best result in height and diameter for both locations of terrain and hill tops. Its better performance compare to *S. selanica* in this study somehow was not surprising and hence support the previous studies.

The performance of man-made dipterocarps forest in peat swamp areas of PT. AA

Similar to those in GDRF, establishment of initial man-mad forest in swampy areas showed a potential prospect. Survival rate for both *S. leprosula* and *S. selanica* showed higher value at denser population and that *S. leprosula* gave higher vol/ha to those of *S. selanica* (Table 2). Tables 2 also showed that DBH at denser population had lower value compare to those at more spacious distance, however tree height did not show similar tendency.

Mean volume per tree showed higher value at more spacious distance (Table 2). However, total volume/ha has not showed similar tendency, those depend on numbers of survived trees/ha. Both species showed prospective standing stock at their half rotation cycle when planted with 3 x 2.5 m spacing distance, with the wood volume per/ha were 208.448m^3 and 183.688 m^3 for *S. leprosula* and *S. selanica*, respectively. Considering the target volume for dipterocarp plantation in their optimum habitat considered to yield 174-400 m^3 at 30 years (Appanah and Weinland 1993; Soekotjo 2009), our study plots in PT. AA showed a prospective result for further development of dipterocarp plantation even in swampy peat land.

Table 1. Data measurement for a 17-years old dipterocarp plantation forest in Gunung Dahu Research Forest, Bogor

Species	Spacing (m x m)	DBH		Height		Survival rate		∑ trees survived/ha (ind)	Mean volume/tree		Vol/ha (m3)
		(cm)	sd	(m)	sd	(%)	sd		(m^3)	sd	
S. leprosula	2 x 2	13.7^c	2.35	12.5^d	1.65	66^{ba}	0.13	1650	0.119^c	0.05	195.855
	3 x 3	19.7^b	2.47	14.9^{cb}	1.77	69^{ba}	0.12	767	0.281^{cb}	0.08	215.412
	4 x 4	24.9^a	2.44	16.9^a	1.23	36^c	0.17	225	0.567^a	0.13	127.602
S. selanica	2 x 2	13.9^c	2.06	13.3^{dc}	0.48	58^b	0.17	1450	0.125^c	0.04	181.395
	3 x 3	15.2^c	2.22	10.8^e	1.12	77^a	0.11	855	0.124^c	0.05	105.993
	4 x 4	19.6^b	2.45	16.2^{ba}	1.85	45^c	0.17	281	0.306^b	0.13	85.992

Note: Numbers followed with one or more similar letter in the same column showed that the result not significantly different based on Duncan test; DBH = diameter at breast height; sd = standard deviation

Table 2. Data measurement for a 15-year old dipterocarp plantation forest in swampy area of PT. AA, Kampar, Riau

Species	Spacing (m x m)	DBH		Height		Survival rate		∑ trees survived/ha	Mean volume/tree		Vol/ha (m^3)
		(cm)	sd	(m)	sd	(%)	sd	(ind)	(m3)	sd	
S. leprosula	3 x 2.5	18.53^c	2.46	13.30a	2.22	69.5^a	0.13	926	0.225^c	0.08	208.448
	3 x 5	22.96^a	2.49	14.49a	2.29	59.5^b	0.17	397	0.367^a	0.10	145.650
S. selanica	3 x 2.5	19.34^c	1.79	14.33a	2.61	52.0^b	0.15	693	0.265^{cb}	0.11	183.688
	3 x 5	21.09^b	1.31	13.44a	2.92	40.5^c	0.12	270	0.294^b	0.10	79.420

Note: Numbers followed with one or more similar letter in the same column showed that the result not significantly different based on Duncan test; sd = standard deviation

Shorea leprosula maintained higher volume/ha at more spacious distance, but *S. selanica* decreased almost 40% of its volume when the species planted at 3 x 5 m spacing distance (Table 2). This condition indicates the possibility of different tolerance to exposure during their growth development with *S. selanica* is more sensitive to exposure than *S. leprosula*.

Both *S. leprosula* and *S. selanica* are naturally grown at mineral soil. However, this study demonstrates that establishing man-made dipterocarp forest in swampy area is surely possible. Yet, some notes are needed to be considered. Species and spacing distance were determined to affect DBH, survival rate, and mean volume/tree, thus resulting in different gain for total volume/ha. Site-species matching is a factor that needs to be considered properly through trial and experiments. Hence, it is needed to screen and select the most appropriate species growing in lowland swampy area and establish native tree plantation as an alternative to those of most exotic species planted in Indonesia (e.g. *Acacia, Eucalyptus*). While *S. leprosula* and *S. parvifolia* actually will reach their optimum grow in well drained sites, other species such as *S. macrophylla* was shown the best choices to be planted in frequently flooded sites (Mohd Nawar 2012).

The significant difference between plots on hilly mineral soils and lowland swampy area descriptively could be seen in their generative ability in which a 15-years old dipterocarp forest in PT. AA have been reported for three times fruiting but not for a 17-years old dipterocarps in GDRF. Monsoon climate as characterized by distinct separation between wet and dry months is widely proposed as one of cues for triggering generative reproductive of the many dipterocarps. Most area in Java Island are affected by monsoon, however Bogor is among the few areas that has tropical wet climate without any influence by monsoon. Having similar Koppen *Af* (tropical rainforest climate) climatic group as those of PT. AA in Perawang Riau, monsoon climate seems not to be the plausible factors for determining why GDRF has not experienced flowering season like those in PT. AA-Riau. Another environmental factor that is possible in determining the flowering pattern is precipitation. However, both GDRF and PT. AA are characterized by showing almost similar data of precipitation with total annual rainfall > 2500 mm/year and total rainy days >160 days/year (Meteorology and Geophysics Bureau; www.bmkg.go.id). Altitude is remaining as the only one that showed rather extreme differences in which PT. AA is located in < 100 m a s l, while GDRF is located at nearly 700 m asl. In this case, we proposed that the differences for flowering phenology of *S. leprosula* and S. *selanica* in two sites mainly caused by the altitude. This is also supported by the fact that *S. platyclados*, a hill dipterocarps species, have been experiencing flowering events several times in GDRF. Since this is the phenomena that we found along the establishment of the plot, it will need further observation and more comprehensive analysis in determining the most possible factor responsible for the differences of the generative reproduction of the two studied *Shorea*.

It is generally believed that the limitation of domestication efforts of the native trees still exists probably due to problems with germplasm multiplication, distribution, and availability. However, as the series of research on the prospect of the native tree species recently increased progressively, the important findings began to shed a light. As the germplasm multiplication generatively is a problem in dipterocarps due to its irregular fruiting and their recalcitrant seed characteristics, a mass vegetative propagation by means of cutting and known as KOFFCO technique showed a significant progress.

Considering changing wood processing technology, producing timber of lower dimension may be currently acceptable. Depending on site and management intensity, rotation cycles of 30 years or less with a target diameter of 30-50 cm seem to be feasible for some of the faster growing dipterocarps. Based on our result, it is determined that planting dipterocarps in more spacious distance would be suitable to fulfill demand of timber for the purpose of construction and furniture (yield in bigger DBH), while planting dipterocarps in denser population would result in higher volume/ha with smaller DBH in which will be suitable for carbon stock and pulp industry.

In the long term, the need for the establishment of man-made native tree plantation will increase. Timber product will not be available to be supplied only from natural forest due to their rapid loss. Future forest products must be fulfilled from commercial forest plantation. Considering the environmental issues emerge along with the development of the exotic species in the tropics, the development and establishment native tree commercial forest plantation will be the only choice left to ease pressure of the remaining natural forest. Native tree plantation, especially dipterocarps in SE Asian tropical forest, would gain several benefit started from carbon sinks, gene pools, source for biologically active compound/medicinal benefit, water regime and maintaining biodiversity. The need to establish dipterocarp plantation with proper silvicultural management technique however is a must.

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