STAND STRUCTURE OF *SHOREA* AND SPATIAL DISTRIBUTION OF *SHOREA ACUMINATA* IN A REHABILITATED AREA OF KENABOI FOREST RESERVE

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The purpose of this study is to determine the stand structure of *Shorea* species and spatial distribution of *Shorea acuminata* in a 1-hectare plot within the rehabilitated area of Kenaboi Forest Reserve (FR), Jelebu, Negeri Sembilan. An understanding of the rehabilitation that transpires the area after the plantation of *Shorea* species will enable us to devise silviculture systems for a better sustainable production as well as conservation of the environmental quality. The diameter at breast height (DBH) and coordinates of 395 trees with DBH ≥ 5 cm were recorded in this study. The tree density decreased with the increase in DBH. This observation indicated that the regenerating process of *Shorea* trees was still active but distracted within the small pole size class. The basal area and biomass of *S. acuminata* were the highest, i.e. 62% of the total basal area of *Shorea* trees and 61% of the total biomass of *Shorea* trees. These percentages were almost similar to the range of basal area and biomass of a primary forest. The spatial distribution of *S. acuminata* showed a significant aggregated distribution (p < 0.05), however, it showed a random pattern for planted *S. acuminata* trees. The rehabilitated area of Kenaboi FR was actively recovering and the silviculture practices enhanced the rehabilitation process, transforming the area to become more sustainable for production and conservation.

Keywords: Regeneration, dipterocarps, taungya system, sustainable, planted trees

INTRODUCTION

The rehabilitation of forest ecosystems is a vital strategy to tackle climate change, biodiversity loss and desertification, which are the primary current environmental problems (Jonášová et al. 2006, Jong 2009, Thomas et al. 2014). The rehabilitation of logged and poorly degraded forests in Malaysia with artificial regeneration was embarked with forest plantation, starting with rubber (*Hevea brasilienssi*) plantation in Kuala Kangsar in 1877. Following that, many trials on forest plantation was conducted for *Palaquium gutta* along with line plantation for *Neobalanocarpus heimii* (King) in the 1900s (Krisnapillay et al. 2007). However, the planting was discontinued when Commercial Regeneration Felling was introduced in 1918

(Shaharuddin 2011). Between 1929 and 1941, an experimental plantation of dipterocarps was initiated in Forest Research Institute Malaysia (FRIM), with *Shorea* being one of the main species (Shukri et al. 2008). Most of the fast-growing hardwoods, especially *Shorea*, are the most promising plants for dipterocarp plantation in Peninsular Malaysia (Kobayashi 2004, Kettel 2010, Daisuke et al. 2013, Widiyatno et al. 2014).

Dipterocarpaceae is a well-known and essential plant in Malaysia, not only for its valuable timber tree species, but also particularly for containing the genus *Shorea*. This genus is known as meranti, which is a crucial native species for forest rehabilitation as it is able to influence the

structure and function of the tropical forest. Most of the lowland forests of Southeast Asia are described as dipterocarp forests (Slik et al. 2003, Brearly et al. 2004, Ghazoul 2016). In recent decades, many of the *Shorea* species have been threatened by logging and human activities that have critically reduced the number of individuals and populations (Lee et al. 2006, Naito et al. 2008). It is expected that Malaysia will lose about 8.6% of its forest cover due to the intensification of logging activities, industrialisation and the amplification of agricultural activities to cater for local and global demands (Mustafa et al. 2012). Sist et al. (2003) reported the importance of sustainable management of the remnant dipterocarp population for sustainable use and species conservation. Therefore, narrowing the gap between forest harvesting practices and conservation requirements for dipterocarp forests is of paramount importance to their sustainability.

One of the most promising forest management and silviculture practices that enhanced sustainable production of forest timber species and rehabilitation of degraded forest area is the taungya system. Taungya is a form of agroforestry practice, which originated from Burma for temporary cultivation on hill land (Tani 2000). The main idea is to reduce the cost of rehabilitation of a degraded forest by using farmers who will conduct forest plantation together with cash crops. Farmers will receive benefits from the cash crops, while the managers or foresters will receive free labour services for forest plantation. The main objective of taungya system is to provide an inexpensive means of forest establishment with satisfactory returns to the farmers of the area (Abd Ghani & Najib 2009). In Malaysia, the taungya system was initiated with short-term cash crops (banana, tapioca, papaya, pineapple, chilli, pumpkin, maize, groundnut, sweet potato, watermelon, yam and ginger) that were planted by the participating farmers at the early years of tree plantation. After six months, the farmers will plant native tree seedlings as per the permit conditions. The tenure ranged between two to three years until the yield is no longer economic. In some cases, the tenure may even exceed four years. The rehabilitated taungya plot was later reverted to the Forestry Department (Shaharuddin et al. 1992). However, the system is no longer practical in Malaysia due to the new economic policies that prefer variety of industries

instead of plantations. Besides, the drive to generate higher income with assurance made the cash crop plantation less attractive (Krishnapillay et al. 2007, Abd Ghani & Najib 2009).

Kenaboi Forest Reserve (FR) is a lowland and hill dipterocarp forest. The rehabilitated area of Kenaboi FR was treated with the taungya system since 1969 (Cheah 1971, Shaharuddin et al. 1992). The area consisted of 250 acres of degraded forest, consisting of very few merchantable trees that were subsequently clear-felled and burnt by taungya farmers. The rehabilitated area of Kenaboi FR mainly consisted of five compartments: 103, 105, 106, 107 and 132. Compartment 107 of taungya plot area, covering 4.45 ha, was rehabilitated with planting stocks from Sungai Menyala FR. The main indigenous species planted were *Shorea leprosula* (meranti tembaga), *S. parvifolia* (meranti sarang punai) and *S. acuminata* (meranti rambai daun).

According to previous study by Shaharuddin et al. (1992), compartment 107 in Kenaboi FR was successfully rehabilitated with great potential as the best degraded forest rehabilitation, as well as timber production of selected *Shorea* species. The area exhibited great performance of selected indigenous and exotic species in terms of survival, growth rate, stem quality and volume production. The study considered compartment 107 of Kenaboi FR mainly as a production area and not for protection and conservation. Besides, the findings from a previous study (27 years ago) are obsolete, and the current conditions of Kenaboi FR rehabilitated areas need to be updated for a better understanding, especially in terms of protection and conservation. Furthermore, the rehabilitated area is almost 50 years of age, being one of the oldest taungya plot areas in Malaysia. Therefore, compartment 107 of Kenaboi FR was a perfect study plot to understand the process of rehabilitation that transpired from a degraded forest to a rehabilitated area. The findings can devise a better silviculture system for sustainable production and conservation of the environment.

Considering these attributes, the study aimed to provide a scientific basis for population dynamics of *Shorea* trees after the practise of taungya System in compartment 107, the rehabilitated area of Kenaboi FR. Therefore, the aim of the study was to determine the stand structure of *Shorea* species by examining the tree density for every diameter size class, basal area and biomass. The results from the stand

structures of planted *Shorea* trees will indicate the regeneration status of planted trees. The output from basal area and biomass of the *Shorea* trees will show the status of the rehabilitated area that is either recovering successfully or degrading. The second aim of the study was to elucidate the spatial distribution of *S. acuminata*, which is the most dominant *Shorea* species in rehabilitated areas. The output from spatial distribution is useful to understand the spatial relationship of the planted and regenerated trees of *S. acuminata*. Information of the stand structures of *Shorea* and spatial distribution pattern of *S. acuminata* will show comprehensive interaction that will aid in a better interpretation of the Kenaboi FR rehabilitation.

MATERIALS AND METHODS

Study site

Kenaboi FR (300–600 m a.s.l) is located in the district of Jelebu, Negeri Sembilan. The district lies between latitude 2° 57' N and longitude 102° 04' E. The research was conducted in compartment 107, Kenaboi FR. In this study, five study plots, with dimensions of 20 m × 100 m each and total area of 1-hectare, were used as the sampling area.

Data collection

An inventory on the abundance of tree species, species identification and diameter measurement of all trees ≥ 5 cm DBH was prepared. Tree identification was confirmed by a botanist from the herbarium of Universiti Kebangsaan Malaysia. Identification was directly carried out in the field for individual trees, recognised to a species level. According to silviculture practices, the *Shorea* population is categorised into four DBH size classes, i.e., 5–15 cm (small poles), 15–30 cm (poles), 30–45 cm (small tree) and above 45 cm (big tree). The DBH size classes is based on 'Manual Perhutanan' from the Forestry Department of Peninsular Malaysia (Anon. 2003).

The location of the *S. acuminata* trees was recorded using global positioning system (GPS), and the distance of each *S. acuminata* tree was measured using a digital rangefinder. Both measurements were used to plot a coordinate of each *S. acuminata* tree in the scattered chart in excel. The data in excel was imported to the R

package spatstat and calculated for the evaluation of spatial distribution patterns (e.g. clustered or random tree distribution) (Baddeley and Turner 2005). The spatial distribution pattern was calculated as: 1) for all 132 trees of *S. acuminata*, 2) for 20% of the highest DBH adult trees of 15 *S. acuminata* trees and 3) for the 17 regenerant trees of *S. acuminata*. The spatial distribution pattern was not conducted for *S. parvifolia* and *S. leprosula* due to insufficient sample size.

Statistical analysis

Based on Brower et al. (1997), the abundance parameters, such as density, stand structure and basal area, were analysed as below:

$$\text{Density (d)} = \text{number of trees (n}_i) \text{ per unit area}$$

where, n_i = total individual trees calculated for species *i*

$$\text{Basal area} = \pi r^2$$
$$= \pi \text{DBH}^2/4$$
$$= 0.00007854 \times \text{DBH (m}^2)$$

where r = radius and DBH = diameter at breast height.

The aboveground biomass (AGB) and belowground biomass (BGB) were determined using regression equations by Kato et al. (1978) and Niiyama et al. (2010), respectively. The biomass regression equation by Kato et al. (1978) is defined as follows:

$$\text{Height (m)} = (122 \times \text{DBH}) \, (2(\text{DBH}) + 61)^{-1}$$

$$\text{AGB (dry weight)} = W_s + W_b + W_l \text{ in kg}$$
$$= [(W_s + W_b + W_l) \, A^{-1}]$$
$$[1000 \text{ in t ha}^{-1}]^{-1}$$

- W_s (weight of stem) = $0.313 \, (D^2H)^{0.9733}$
- W_b (weight of branch) = $0.136 \, W_s^{1.070}$
- W_l (weight of leaves) = $(125 \times 0.124 \, W_s^{0.794}) / (0.124 \, W_s^{0.794} + 125)$

where D = diameter at the breast height, H = height and A = total area of plots.

The following equation for BGB was based on Niiyama et al. (2010):

$W_r = 0.0262 * D^{2.497}$

where D is the diameter at breast height.

From the equations of AGB and BGB, the total amount of biomass of the study plot was calculated.

Total biomass (t ha^{-1}) = AGB + BGB

The spatial distribution of *S. acuminata* in a 1-hectare plot within the rehabilitated area of Kenaboi FR was determined by Ripley's K distance function, which measures the distribution of pairwise distances among the events (Ripley 1976, Rogerson 2001, Bivand et al. 2008). The Ripley's K function was calculated using the envelope function of the package 'spatstat' (Baddeley and Turner 2005) of the R software (R Team 2014). In addition, a complete spatial randomness (CSR) point process with similar estimated intensity of the study area was simulated (999 replicates) and compared with the empirical values of Ripley's K, to determine whether the empirical function was present inside or not. The K-function or K(r) measures the distance between individuals within a population and summarises it before representing into a pattern of spatial distribution as regularity (few trees are close to each tree), independence (CSR) and clustering (all trees are close to each other).

RESULTS AND DISCUSSION

The stand structure of *Shorea* species in the rehabilitated area of Kenaboi Forest Reserve

From the inventory, 395 trees above ≥ 5 cm DBH were found in the 1-hectare plot of compartment 107 in Kenaboi FR. The most common family was Dipterocarpaceae with 193 individual trees derived from three *Shorea* species, belonging to *Shorea acuminata* (33% of total trees), followed by *S. parvifolia* (20% of total trees) and *S. leprosula* (12% of total trees). The results indicated that the species composition of stands in the rehabilitated area of Kenaboi FR was dominated by *Shorea* species. The species richness in the rehabilitated area was lower as compared to a 1-hectare coastal lowland forest plot within Teluk Bahang permanent FR (Zakaria et al. 2011). This is because the rehabilitated area of Kenaboi FR was planted with *Shorea* trees during the taungya

system after abandonment following clear-logging (Shaharuddin et al. 1992). Teluk Bahang FR was selectively logged in the early 1930s, where the method of extraction was employing buffalos to drag out the logs from the forest. Mohd-Yunus and Mansor (2002) reported that richness of species does not only depend on the enrichment planting treatment, but also on the methods of log extraction, which determines the growth of remnant tree species, leading to species composition of stands within the selective logged area. Therefore, the damage of Teluk Bahang FR was nowhere near the clear-logged areas of Kenaboi FR, before the forestry department enhanced the method of rehabilitation. Taungya system, with plantation of native species such as *Shorea*, contributed stands of species composition in the clear-logged area, leading to rehabilitation of Kenaboi FR. The tree density, with diameter class distribution, for all 395 trees and *Shorea* trees in compartment 107, Kenaboi FR is shown in Figure 1a. This analysis illustrated the structure of a stand in the rehabilitated area of Kenaboi FR.

The distribution of diameter size classes for all trees was described by an inverse J-shaped curve. The stand structure for all the trees decreased with the increase in diameter size class. The small poles (5–15 cm DBH) of all trees had the highest tree density (30% of total trees). Following that, the tree density decreased gradually to 26% for poles (15–30 cm DBH). The density of small trees (30–45 cm DBH) continued to decrease to 22%, followed by tree density of big trees (45–60 cm DBH), 20%. The tree density for all trees above 60 cm DBH had the lowest tree density of only 3%. The biggest tree is *Artocarpus elasticus*, with diameter size class of 101 cm DBH (Fatma et al. 2016). The same pattern of tree density with diameter size classes was observed in previous studies, with or without selective cutting management, in regenerated forest areas (Okuda et al. 2003, Numata et al. 2006, Kueh et al. 2011, Pamoengkas et al. 2019). Bunyavejchewin et al. (2003) observed the diameter size classes of *Vatica cinera* at Huai Kha Khaeng Wildlife Sanctuary with the inverse J-shaped curve, indicating a continuously regenerating population. The inverse J-shaped curve, also demonstrated by UKM permanent forest reserve, indicates that the regeneration process is active even in forest logged 40 years ago (Ahmad Fitri et al. 2018). Pamoengkas et al. (2019) concluded that the inverse J-shaped curve shows that the species

composition of trees in logged-over forest is in a balanced condition, compared to recovering vegetative with silvicultural system, known as selective cutting and line planting system, and the undisturbed forest known as germplasm preservation areas in Central Kalimantan, Indonesia.

Meanwhile, the diameter distribution for *Shorea* species shown in Figure 1(b) exhibited a normal distribution curve. The tree density for *Shorea* trees increased with the increase in diameter size class. The small poles (5–15 cm DBH size class) of *Shorea* trees consist of only 15% of total small poles. The tree density for *Shorea* continued to increase gradually from poles (15–30 cm DBH size class) to big trees (above 45 cm DBH size class), which is from 47% of total poles to 73% of total big trees. The biggest *Shorea* tree in compartment 107, Kenaboi FR, was *S. parvifolia* with 80 cm DBH.

The diameter distribution for *Shorea* species was mostly contributed by S. *acuminata*, followed by *S. parvifolia* and *S. leprosula;* the tree density for *S. acuminata* was 68% of *Shorea* trees, followed by *S. parvifolia* (20%) and *S. leprosula* (12%). The most dominant tree in the rehabilitated area was *S. acuminata*. Therefore, the curve of diameter distribution for *S. acuminata* was similar to *Shorea* trees, showing normal distribution. The tree density of *S. acuminata* increased as the diameter size class increased, from 7% of 119 trees for small poles (5–15 cm DBH) to 52% of 87 trees for poles (30–45 cm DBH), and 51% of 74 trees for big trees. The biggest tree of *S. acuminata* in compartment 107, Kenaboi FR was 60 cm DBH. The DBH distribution for both *S. parvifolia* and *S. leprosula* was similar to *S. acuminata*. However, the tree densities of *S. parvifolia* was smaller, and *S. leprosula* was smallest for each DBH size class, as compared to *S. acuminata*.
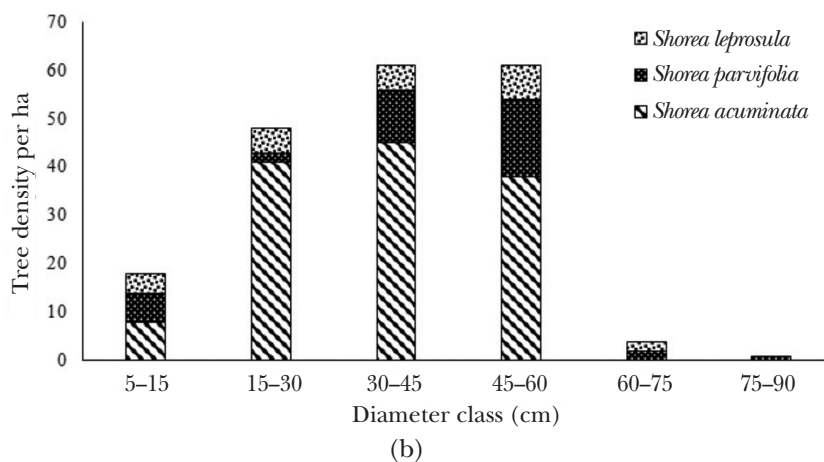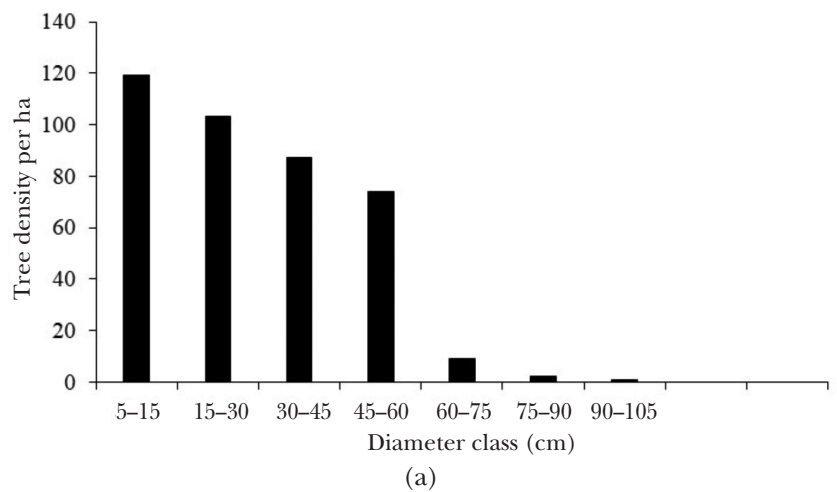

(a)

(b)

Figure 1   The diameter distribution of (a) all 395 trees and (b) *Shorea* species in compartment 107, the rehabilitated area in Kenaboi Forest Reserve

The rehabilitated area of Kenaboi FR was regenerating. In addition, compartment 107 of Kenaboi FR exhibited many seedlings of *Shorea* species on the forest floor. However, the study showed that the density of small poles of *Shorea* trees was the smallest, whereas the density of all high poles was the highest. The silviculturally important plants, the red meranti, including *S. acuminata*, *S. leprosula* and *S. parvifolia*, are characterised by a high demand for light and a rapid early growth (Pamoengkas 2010, Widiyatno et al. 2014, Ghazoul 2016). However, another study showed that the different DBH size classes of *Shorea* trees have different light acquisition. Extra amount of light can damage the photosynthetic apparatus of dipterocarp seedlings and saplings, therefore, the seedlings and saplings of *Shorea* species are well adapted to understory shade conditions. Since seedlings and saplings require partial shade from germination to the pole stages, they need increasing amount of light as they approach the canopy (Ghazoul 2016). Different dipterocarp species grow optimally in the gaps of different sizes based on their responses towards light and microclimate (Bebber et al. 2002, Kenzo et al. 2008). In this study, the *Shorea* seedlings adapted well to shade conditions due to close canopies, and grew rapidly within the rehabilitated area. However, the small poles of *Shorea* species in compartment 107, Kenaboi FR was likely to receive insufficient light for growth because the high density big trees only allowed light through close canopies. Small poles of *Shorea* need more light for growth as compared to the seedlings of *Shorea* trees. Thus small poles of *Shorea* trees faced high mortality and was unable to survive in compartment 107, Kenaboi FR. This could be the reason why the density of small poles of *Shorea* was smaller as compared to non-dipterocarp species. About 85% of the small poles regenerated in the rehabilitated area of Kenaboi FR belonged to non-dipterocarp species.

According to Numata et al. (2006), the difference of light availability on the forest floor between primary forest and regenerating forest is due to the rich stratification of canopy in the primary forest, as compared to the regenerating forest that has lesser stratification of canopy layers. Inada et al. (2017) suggested strip cutting and slashing non-commercial understory species and lianas for increasing the growth of light demanding species such as *Shorea*. Pamoengkas (2010) recommended some silvicultural treatment, such as liberation, to provide better growing space for dipterocarp species by reducing competition. The early mortality of planted trees in the rehabilitated area of Kenaboi FR is also caused by termites, insect attacks, diseases, fire and prolonged seasonal dryness at rain shadow (Mohd-Ramli & Ong 1972, Shaharuddin et al. 1992).

Basal area is an important parameter for stand density. In addition, basal area also provides valuable information on the degree of forest stand recovery. The basal area for *Shorea* species in the rehabilitated area of Kenaboi FR was 23.42 $m^2 ha^{-1}$. The species *S. acuminata* demonstrated highest basal area of 14.58 $m^2 ha^{-1}$ (42%), followed by *S. parvifolia* with 5.85 $m^2 ha^{-1}$ (17%) (Table 1). Pamoengkas et al. (2018) reported that the basal area of planted forest surpassed primary forest, which are 19.79 $m^2 ha^{-1}$ and 19.64 $m^2 ha^{-1}$, respectively. This is due to the rapid regeneration of non-dipterocarps after selective cutting of forest. However, the rehabilitated area of Kenaboi FR was once a clear-logged are which was planted with stocks of *Shorea* trees. Gilman et al. (2016) showed similar findings, concluding that the

Table 1   Basal area and biomass of *Shorea* species in 1-hectare compartment 107, Kenaboi Forest Reserve

Species	Basal area ($m^2 ha^{-1}$)	AGB ($t ha^{-1}$)	BGB ($t ha^{-1}$)	Total biomass ($t ha^{-1}$)
Shorea acuminata	14.58 (42)	194.75	135.70	330.45 (46.80)
Shorea parvifolia	5.85 (17)	83.32	59.40	142.72 (20.21)
Shorea leprosula	2.99 (9)	42.05	29.92	71.97 (10.19)
Non-dipterocarps	11.62 (32)	144.30	103.14	160.98 (22.80)
Total	35.04	464.41	328.17	706.12

AGB is aboveground biomass and BGB is belowground biomass; values provided in parentheses represent the percentage

factor contributing towards rapid increase in basal area in actively regenerating plots was the use of planted species that enhanced rapid and early growth rates. For example, in Malaysia, the species *Shorea* is suitable to be planted in the rehabilitated areas of Kenaboi FR for recovery of forest (Krishnapillay 2007, Ghazoul 2016). In addition, this species is also a sustainable timber supply of the forest.

The basal area estimates of *S. acuminata* was higher as compared to non-dipterocarps, and the highest basal area was displayed at a certain diameter size class, from small to big tree size classes (30 cm to 80 cm DBH) (Figure 2). The highest basal area was also characterised in a plantation forest of Gutianshan National Nature Reserve, Southeast China. This reflected that most of the trees in the plantation belong to the same cohort (Lin et al. 2015). Okuda et al. (2003) obtained a basal area of 34 m^2 ha^{-1} from a regenerating forest, and most of the trees that arose after logging belong to the medium size class. This study concluded that the trees were from the same cohorts after logging activities. Therefore, *Shorea* trees (30–80 cm DBH) in the rehabilitated area of Kenaboi FR was assumed to belong to the same cohort that consisted of planted *Shorea* trees taken from Sungai Menyala FR, in the taungya system in 1968. However, the *Shorea* trees below 30 cm DBH might be young trees, subsequently regenerating from the planted *Shorea* trees. Further studies are

needed to assess the paternity analysis of *Shorea* trees in the rehabilitated area of Kenaboi FR. The information is important for a better understanding of genetic relatedness and quality of the *Shorea* trees in the rehabilitated area of Kenaboi FR.

The biomass estimate of *Shorea* species in the study plot was 545.14 t ha^{-1}. The AGB contributed 320.11 t ha^{-1} (58.72%), whereas BGB was 225.03 t ha^{-1} (41.28%). The results indicated that the AGB of *Shorea* species, in the rehabilitated area of Kenaboi FR, was within the range of Southeast Asia primary rainforest, approximately 300 t ha^{-1} to 500 t ha^{-1} (Laumonier et al. 2010, Niiyama et al. 2010). At the species level, *S. acuminata* contributed the highest biomass estimate of 330.45 t ha^{-1} (46.80%), whereas AGB and BGB were 194.75 t ha^{-1} and 135.70 t ha^{-1}, respectively. The second highest biomass estimate was contributed by *S. parvifolia* of 142.72 t ha^{-1} or 20.21% (AGB = 83.32 t ha^{-1} and BGB = 59.40 t ha^{-1}). The *S. leprosula* was recorded as the third highest biomass with 71.97 t ha^{-1} (10.19%), whereas both AGB and BGB contributed biomass estimates of 42.05 t ha^{-1} and 29.92 t ha^{-1}, respectively (Table 1). The AGB of six years stand of *S. roxburghii* in Forest Research Institute Malaysia (FRIM) Research Station in Segamat, Johor was 168.31 t ha^{-1} (Mun et al. 2018). The total biomass is a very essential parameter that can be used to elucidate productivity and carbon balance assessment of
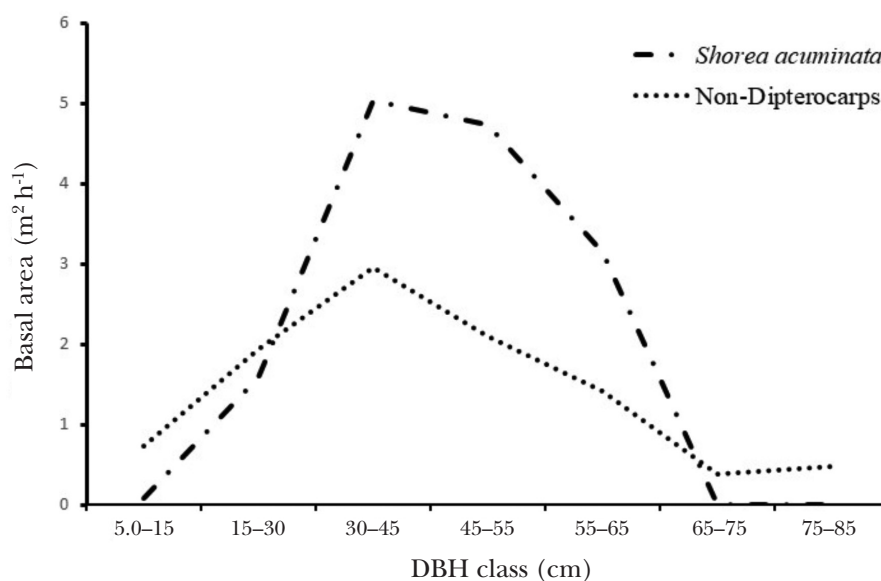

Figure 2   Basal area by the diameter class distribution for *Shorea acuminata* and non-dipterocarps species in 1-hectare, plot of compartment 107, Kenaboi Forest Reserve

the forest (Nie et al. 2017). The rehabilitated area of Kenaboi showed an increment of basal area and biomass. A previous study suggests that such increments indicate a notable ability for the rehabilitated area to accumulate and store carbon (Lin et al. 2015).

Spatial distribution of *S. acuminata* in the rehabilitated area of Kenaboi Forest Reserve

Ripley's K indicated that all 132 individual trees of *S. acuminata* were consistently, significantly and spatially aggregated (Figures 3a and 3b). The majority of tropical tree species show significant spatial aggregation at various diameter classes (Condit et al. 2000, Seidler & Plotkin 2006). The possible mechanism of aggregating would be from the aspect of seed dispersal (Seidler & Plotkin 2006, Smith et al. 2015). The significant spatial aggregation was also found for 17 regenerating trees, which indicates that seed dispersal for *S. acuminata* was short distance, as the seeds were collected

within 18 m from beneath the trunk of each mother tree (Naito et al. 2008). Lee et al. (2016) suggested that the aggregation dispersion is probably due to seed dispersal, gap recruitment, distance-dependent recruitment, as well as topography. However, the spatial distribution pattern for 15 adult trees of *S. acuminata* was significantly and randomly dispersed (Figure 3c). A previous study disclosed that *S. acuminata* is planted in line planting during the implementation of taungya system. When the system was no longer practised, the rehabilitated areas lacked proper silviculture treatment. Therefore, some of the planted *Shorea* trees could have died due to inter- or intraspecific competition. Furthermore, the early mortality of planted trees in the rehabilitated areas of Kenaboi FR is also caused by termites, insect attacks, diseases, fire and prolonged seasonal dryness at rain shadow (Mohd Ramli & Ong 1972, Shaharuddin et al. 1992). As a result, the line planting of *Shorea* trees showed a random dispersion.
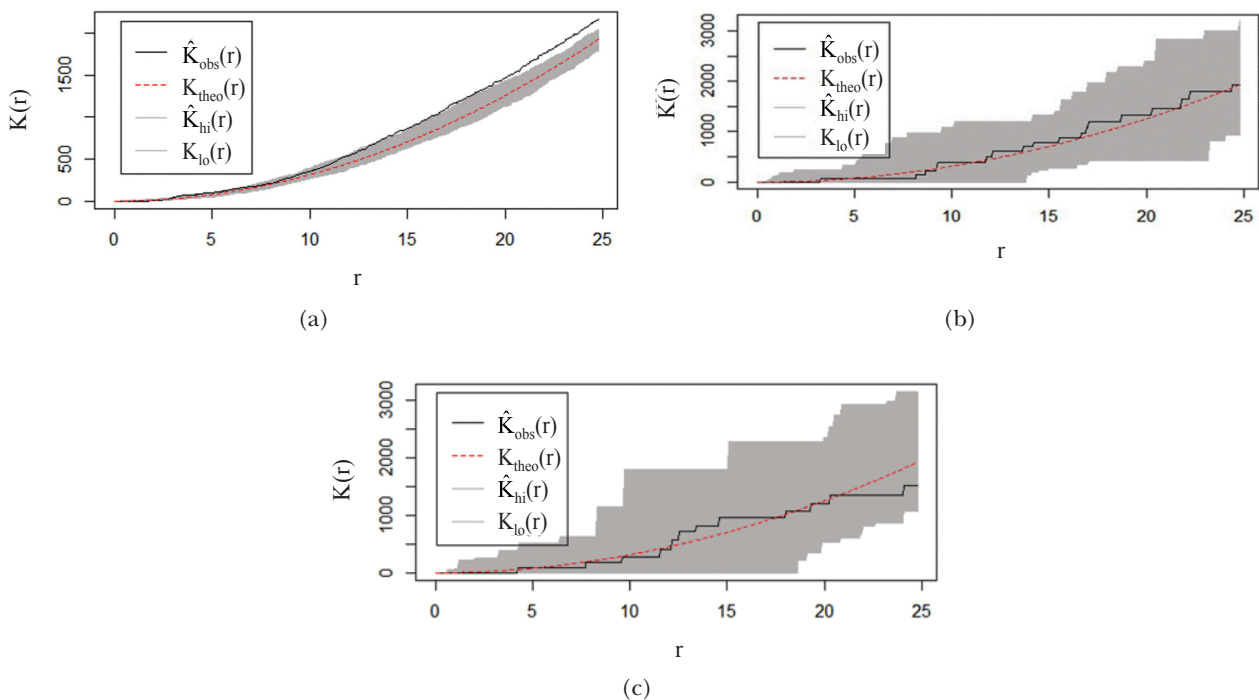

(a)

(b)

(c)

Figure 3   Ripley's K plots of spatial distribution for (a) all 132 individuals of *Shorea acuminata* trees (including the planted and regenerated trees of *S. acuminata*), (b) the 17 regenerated trees of *S. acuminata* and (c) the 15 planted trees of *S. acuminata* in compartment 107, Kenaboi FR; the continuous line ($_{obs}$) is the observed function of the individual records, the dashed line (K_{theo}) is the theoretical function of a CSR point process, and the grey shading is the lower and higher limits of the CSR point process after 999 replications; if the observed function is above the CSR limits, then the point process is considered as aggregated, if it is below the limits, then it is considered as regular, and if it is between the limits, it is considered as random

CONCLUSION

Compartment 107 of Kenaboi FR was regenerated after clear-logging, which then turned into an abandoned farmland. Later, it was designated into a rehabilitated forest. Unfortunately, the growing process of *Shorea* trees was distracted within the small pole size class. Silviculture treatment and thinning should be able to enhance light acquisition for better recruitment of small pole *Shorea* species. The increment of basal area and total biomass of *S. acuminata* showed that the rehabilitated area of Kenaboi FR was in a recovery process, and at the same time able to efficiently accumulate carbon. The spatial distribution of *S. acuminata* trees was almost similar to the majority tropical trees of the primary forest, which was significantly aggregate. However, planted *S. acuminata* trees indicated a significantly random distribution, even though the trees were systematically planted using line planting during the taungya system. This might be due to inter- and intraspecific competition and early mortality of the planted *S. acuminata* trees. The planting stocks of *Shorea* species can be used to rehabilitate a poorly degraded forest area. Together with the enforcement of silviculture practices, the rehabilitated area can serve as a sustainable production area, as well as conserve the environmental quality of natural forest.

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REFERENCES

Abd Ghani AR & Najib LA. 2009. Agroforestry approach of planting timber and non-timber species in Malaysia. Pp 125–135 in Gotoh T & Yakota Y (eds) *Development of Agroforestry Technology for the Rehabilitation of Tropical Forests, JIRCAS Working Paper No 60.* Japan International Research Centre for Agricultural Sciences (JIRCAS), Tsukuba.

Ahmad-Fitri Z, Mohd-Azman K, Wan-Norilani et al. 2018. Species composition, community structure and biomass estimation of Anacardiaceae. Pp 34–43 in Kader-Maideen HM et al. (eds) *A Natural Heritage: The Flora and Fauna of Universiti Kebangsaan Malaysia.* Universiti Kebangsaan Malaysia, Bangi.

Anon. 2003. *Manual Perhutanan Jilid 3.* Jabatan Perhutanan Semenanjung Malaysia, Kuala Lumpur.

Baddeley A & Turner R. 2005. Spatstat: an R package for analyzing spatial point patterns. *Journal of Statistical Software* 12: 1–42. doi: 10.18637/jss.v012.i06.

Bebber D, Brown N, Speight M et al. 2002. Spatial structure of light and dipterocarp seedling growth in a tropical secondary forest. *Forest Ecology and Management* 157: 65–75. doi: 10.1016/S0378-1127(00)00659-9.

Bivand RS, Pebesma EJ & Gòmez-Rubio V. 2008. *Applied Spatial Data Analysis with R.* Springer, New York. doi: 10.1007/978-1-4614-7618-4.

Blanford HR. 1958. Highlights of one hundred years of forestry in Burma. *Empire Forestry Review* 37: 33–42. https://www.jstor.org/stable/42600438.

Brearley FQ, Prajadinata S, Kidd PS et al. 2004. Structure and floristics of an old secondary rain forest in Central Kalimantan, Indonesia, and a comparison with adjacent primary forest. *Forest Ecology and Management* 195: 385–397. doi: 10.1016/j.foreco.2004.02.048.

Brower JE, Jerold HZ & Van Ende C. 1997. *Field and Laboratory Methods for General Ecology. Fourth edition.* Mc-Hill Companies Inc., New York.

Bunyavejchewin S, Lafrankie JV, Baker PJ et al. 2003. Spatial distribution patterns of the dominant canopy dipterocarp species in a seasonal dry evergreen forest in Western Thailand. *Forest Ecology and Management* 175: 87–101. https://doi.org/10.1016/S0378-1127(02)00126-3.

Cheah LC. 1971. A note on taungya in Negeri Sembilan with particulars reference to the incidence of damage by oviposition of insects in plantation in Kenaboi Forest Reserve. *The Malayan Forester* 34: 133–153.

Condit R. 2000. Spatial patterns in the distribution of tropical tree species. *Science* 288: 1414–1418. doi: 10.1126/science.288.5470.1414.

Daisuke H, Kenzo T, Kendawang JJ et al. 2013. Rehabilitation of degraded tropical rainforest using dipterocarp trees in Sarawak, Malaysia. *International of Forestry Research*: 683017. http://dx.doi.org/10.1155/2013/683017.

Fatma NAH, Wan Juliana WA, Shaharuddin MI & Wickneswari R. 2016. Community stand structure of rehabilitated forest at Kenaboi Forest Reserve, Negeri Sembilan, Malaysia. Pp 1–7 in Che-Radziah CMZ et al. (eds) *Proceedings of The 2016 UKM FST Postgraduate Colloquium.* 13–14 April 2016, Bangi. doi: 10.1063/1.4966851.

Ghazoul J. 2016. *Dipterocarp Biology, Ecology and Conservation.* Oxford University Press, Oxford.

Gilman AC, Susan GL, Rita MF et al. 2016. Recovery of floristic diversity and basal area in natural forest

regeneration and planted plots in a Costa Rican wet forest. *Biotropica* 48: 798–808 2016. doi: 10.1111/btp.12361.

INADA T, WIDIYATNO, HARDIWITONO S ET AL. 2017. Dynamics of forest regeneration following logging management in a Bornean lowland dipterocarp forest. *Journal of Tropical Forest Science* 29: 185–197. https://www.jstor.org/stable/44160936.

JONG WD. 2009. Forest rehabilitation and its implication for forest transition theory. *Biotropica* 42: 3–9. https://doi.org/10.1111/j.1744-7429.2009.00568.x.

JONÁŠOVÁ M, HEES AV & PRACH K. 2006. Rehabilitation of monotonous exotic coniferous plantations: a case study of spontaneous establishment of different tree species. *Ecological Engineering* 28: 141–148. doi: 10.1016/j.ecoleng.2006.05.008.

KATO R, TADAKI Y & OGAWA H. 1978. Plant biomass and growth increment studies in Pasoh Forest. *Malayan Nature Journal* 30: 211–224.

KENZO T, YONEDA R, MATSUMOTO Y ET AL. 2008. Leaf photosynthetic and growth responses on four tropical tree species to different light conditions in degraded tropical secondary forest, Peninsular Malaysia. *JARQ-Japan Agricultural Research Quarterly* 42: 299–306. doi: 10.6090/jarq.42.299.

KETTLE JC. 2010. Ecological considerations for using dipterocarps for restoration of lowland rainforest in Southeast Asia. *Biodiversity and Conservation* 19: 1137–1151. doi: 0.1007/s10531-009-9772-6.

KOBAYASHI S. 2004. Landscape rehabilitation of degraded tropical forest ecosystems case study of the CIFOR/Japan project in Indonesia and Peru. *Forest Ecology and Management* 201: 13–22. https://doi.org/10.1016/j.foreco.2004.06.009.

KRISHNAPILLAY DB, RAZAK MAA & APPANAH S. 2007. Forest rehabilitation—the Malaysian experience. Pp 85–123 in Don KL (ed) *Proceeding of Keep Asia Green. Volume 1.* 17–18 February 2007, Bangkok.

KUEH JHR, ABD. MAJID NM, GANDASECA S ET AL. 2011. Forest structure assessment of a rehabilitated forest. *American Journal of Agricultural and Biological Sciences* 6: 256–260.

LAUMONIER Y, EDIN A, KANNINEN M ET AL. 2010. Landscape-scale variation in the structure and biomass of the hill dipterocarp forest of Sumatra: implications for carbon stock assessments. *Forest Ecology and Management* 259: 505–513. https://doi.org/10.1016/j.foreco.2009.11.007.

LEE SL, NG KKS, SAW LG ET AL. 2006. Linking the gaps between conservation research and conservation management of rare dipterocarps: a case study of *Shorea lumutensis*. *Biological Conservation* 131: 72–92. ttps://doi.org/10.1016/j.biocon.2006.02.005.

LEE SL, NG KKS, NG CH ET AL. 2016. Spatial studies of *Shorea parvifolia* spp. *parvifolia* (Dipterocarpaceae) in a lowland and hill dipterocarp forest. *Journal of Tropical Forest Science* 28: 309–317.

LIN D, LAI J, YANG B ET AL. 2015. Forest biomass recovery after different anthropogenic disturbance: relative importance of changes in stand structure and wood density. *Europian Journal of Forest Research* 134: 769–780. doi: 10.1007/s10342-015-0888-9.

MOHD-RAMLI M & ONG KB. 1972 Taungya in Negeri Sembilan. *The Malayan Forester* 35: 309–316.

MOHD-YUNUS Z. & MANSOR MY. 2002. *Teluk Bahang Forest Trail: An Oldest Tropical Rainforest in the Vicinity of the City Penang Malaysia.* Penang Forestry Department, Penang.

MUN HW, FARIDAH AA, AMIR SK & ANG LH. 2018. Assessment of growth and biomass of *Shorea Roxburghii* G. Don in selected areas of Peninsular Malaysia. *International Journal of Agriculture, Forestry and Plantation* 7: 46–52.

MUSTAFA MFJ, SURATMAN MN & ISA NNM. 2012. Dipterocarpaceae: survival amidst degradation: a brief compilation for conservation prescription. Pp 158–162 in Zuhabri I & Mustafar KH (eds.) *IEEE Symposium on Business, Engineering and Industrial Application* (ISBEIA). 23–26 September 2012, Bandung. doi: 0.1109/ISBEIA.2012.6422858

NAITO Y, KANZAKI M, IWATA H ET AL. 2008. Density-dependent selfing and its effects on seed performance in a tropical canopy tree species, *Shorea acuminata* (Dipterocarpaceae). *Forest Ecology and Management* 256: 375–383. https://doi.org/10.1016/j.foreco.2008.04.031.

NIIYAMA K, KAJIMOTO T, MATSUURA Y ET AL. 2010. Estimation of root biomass based on excavation of individual root systems in a primary dipterocarp forest in Pasoh Forest Reserve, Peninsular Malaysia. *Journal of Tropical Ecology* 26: 271–284. doi: 10.1017/S0266467410000040.

NIE S, WANG C, ZENG H ET AL. 2017. Above-ground biomass estimation using airborne discrete-return and full-waveform LiDAR data in a coniferous forest. Ecological Indicators 78: 221–228. https://doi.org/10.1016/j.ecolind.2017.02.045.

NUMATA S, YASUDA M, OKUDA T ET AL. 2006. Canopy gap dynamics of two different forest stands in a Malaysian lowland rain forest. *Journal of Tropical Forest Science* 18: 109–116.

OKUDA T, SUZUKI M, ADACHI N ET AL. 2003. Effect of selective on canopy and stand structure and tree species composition in lowland dipterocarp forest in Peninsular Malaysia. *Forest Ecology and Management* 175: 297–320. https://doi.org/10.1016/S0378-1127(02)00137-8.

PAMOENGKAS P. 2010. Potentialities of line planting technique in rehabilitation of logged over area referred to species diversity, growth and soil quality. *Biodiversitas* 11: 34–39. doi: 10.13057/biodiv/d110108.

PAMOENGKAS P, SIREGAR IZ & DWISUTONO AN. 2018. Stand structure and species composition of merbau in logged-over forest in Papua, Indonesia. *Biodiversitas* 19: 163–171. doi: 10.13057/biodiv/d190123.

PAMOENGKAS P, ZAMZAM A & DWISUTONO AN. 2019. Vegetation recovery of logged-over dipterocarp forests in Central Kalimantan, Indonesia. *Floresta e Ambiente* 26: e20171239. http://dx.doi.org/10.1590/2179-8087.123917.

RIPLEY B. 1976. The Second-Order Analysis of Stationary Point Process. *Journal of Applied Probability.* 13: 255–266.

R CORE TEAM. 2014. R: *A Language and Environment for Statistical Computing.* R Foundation for Statistical Computing, Vienna. http://www.R-project.org/.

Rogerson P. 2001. *Statistical Methods for Geography*. Sage Publications, London.

Seidler TG & Plotkin JB. 2006. Seed dispersal and spatial pattern in tropical trees. *PLoS Biology* 4: e344. https://doi.org/10.1371/journal.pbio.0040344.

Shaharuddin MI, Mohd Basri H & Samsudin S. 1992. An evaluation of a 19-year old taungya planting in Negeri Sembilan Darul Khusus. *The Malaysian Forester* 55: 1–12.

Shaharuddin MI. 2011. Forest management systems in Southeast Asia. Pp 1–20 in Wickneswari R & Cannon C (eds) *Managing the future of Southeast Asia's Valuable Tropical Rainforests. A Practitioner's Guide To Forest Genetics*. Springer Heidelberg, New York, Dordrecht, London.

Shukri WA, Shamsudin I, Samsudin M et al. 2008. Concept of enrichment planting in tropical forest. Pp 9–28 in Chan HT et al. (eds) *An In-Depth Look At Enrichment Planting. Malayan Forest Record No. 47*. Forest Research Institute Malaysia, Kepong.

Sist P, Fimbel R, Sheil D et al. 2003. Towards sustainable management of mixed dipterocarp forests of Southeast Asia: moving beyond minimum diameter cutting limits. *Environmental Conservation* 30: 364–374. ttps://doi.org/10.1017/S0376892903000389.

Slik JWF, Poulsen AD, Ashton PS et al. 2003. A floristic analysis of the lowland dipterocarp forests of Borneo. *Journal of Biogeography* 30: 1517–1531. https://doi.org/10.1046/j.1365-2699.2003.00967.x.

Smith JR, Bagchi R, Ellens J et al. 2015. Predicting dispersal of auto-gyrating fruit in tropical trees: a case study from the Dipterocarpaceae. *Ecology and Evolution* 5: 1794–1801. doi: 10.1002/ece3.1469.

Tani Y. 2000. Ecological factors affecting taungya farmers behavior in teak plantation projects: a case study in Bago range, Union of Myanmar. *Tropics* 10: 273–286. https://doi.org/10.3759/tropics.10.273.

Thomas E, Jalonen R, Loo J et al. 2014. Genetic considerations in ecosystem restoration using native tree species. *Forest Ecology and Management* 333: 66–75. https://doi.org/10.1016/j.foreco.2014.07.015.

Widiyatno, Soekotjo, Naiem M et al. 2014. Early performance of 23 dipterocarp species planted in logged-over rainforest. *Journal of Tropical Forest Science* 26: 256–266.

Zakaria R, Mansor A & Mansor M. 2011. Tree diversity of a lowland coastal forest, teluk bahang permanent forest reserve, Pulau Pinang, Malaysia. *Malayan Nature Journal* 63: 601–612.