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ASSESSMENT OF FOREST REGENERATION FOLLOWING A SERIES OF DISTURBANCES IN TWO TYPES OF PRIMARY FOREST AT BUNGO RANGE, BAU, SARAWAK

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The forest regeneration study was conducted in a mixed dipterocarp forest and a heath forest at Bungo Range, Sarawak to determine the natural regeneration status after a series of forest disturbances. The research objectives were (i) to estimate the tree diversity in mixed dipterocarp forest and heath forest and (ii) to determine the natural regeneration status of dominant tree species with potentials for reforestation. The systematic sampling method using nested plots was conducted, in which three plots were placed at mixed dipterocarp forest and four at heath forest. The species diversity in the mixed dipterocarp forest was H' = 3.7 and heath forest is H' = 3.8. *Neolamarckia cadamba* was found to be the dominant timber-producing species in mixed dipterocarp forest with good regeneration. Likewise, *Litsea lancifolia* and *Calophyllum inophyllum* were the dominant timber-producing species with good regeneration in the heath forest. There was only one non-timber producing species with good regeneration, i.e. *Goniothalamus uvarioides*, from the mixed dipterocarp forest.

Keywords: Reforestation, natural regeneration, diversity index, dominant species, forest disturbance

INTRODUCTION

Forest acts as a multi-player in maintaining the ecosystem and biodiversity balances (Chazdon & Guariguata 2016). However, extensive deforestation either by natural phenomena such as forest fire and typhoon or human activities such as extensive logging and land clearing have disrupted forest functions (Egbe et al. 2012, Zafirah et al. 2017). The largest forest destruction due to forest fire, which happened back in 1997–1998, destroyed approximately 2.4 Mha of forests in Borneo, Indonesia and Southeast Asia (Dohong et al. 2017). The forest fire incident does not always happen naturally as shown by the 1997–1998 forest fire. The fire started from open burning activities to clear lands by plantation companies in Indonesia (Dohong et al. 2017). It did not only destroy the forest but also created pollution, damaged the ecology, contributed to global warming and soil erosion (Aini et al. 2000). Besides, logging and oil palm plantation are the biggest contributors to the declining forested areas of Sarawak. As of 2009, only 20% of 122,019 km^2 total land area in Sarawak were still intact forests and 58% were degraded (Bryan et al. 2013).

Several initiatives such as large-scale forest plantation, Payments for Ecosystem Services (PES) and reforestation have been carried out worldwide to mitigate deforestation (Scheidel & Work 2016, Jayachandran et al. 2017). Among the listed alternatives, reforestation has proved to be the most efficient alternative to mitigate deforestation (Hashim et al. 2015). Reforestation is proved to be an effective tool in mitigating and slowing climate change, as shown in Brazil (Ciccarese et al. 2012). It also contributes to forest biodiversity protection and biomass production in Malaysia (Raihana et al. 2018). In addition, it provides many social and economic benefits such as extra income and job opportunities for the local community, and to supply timber for the wood industries, as in Brazil (World Bank 2017).

Reforestation can be categorised into two, namely, the natural regeneration and artificial regeneration (USDA 1999, Schuck et al. 2002, Chazdon & Guariguata 2016). Natural regeneration is the forest regrowth or reestablishment process after disturbance, and the success of natural regeneration is usually influenced by natural pollinators such as insects and vertebrates (Chazdon & Guariguata 2016). On the other hand, artificial regeneration is the process of planting or seeding on lands which have been cleared (USDA 1999, Schuck et al. 2002). Studies on natural regeneration are important to portray forest health, to illustrate environmental, natural and human factors affecting vegetation and to show the potential of forest restoration (Kuma & Shibru 2015, Nur et al. 2016, Saha et al. 2016). FAO (2015) also highlighted that the protection and management of natural regeneration is an important element in any forest restoration decision on dryland.

Natural regeneration poses several advantages in forest restoration including preservation of the local population, genetic variability and lowering cost (Minore & Laacke 1992, Lindner et al. 2008). Besides, natural regeneration has a higher success rate compared to other methods of reforestation, as natural seedling has a naturally strong root system with less damage, unlike transplantation of planted seedlings (Duryea 2000). Since natural regeneration of degraded forest can take a long time, assisted natural regeneration method can be applied to accelerate the process (Duryea 2000, Shono et al. 2007). The application of technologies such as drone and new imaging devices for monitoring, maintenance and seeding works poses a bright future for this method (Elliott 2016).

This study was conducted to determine the natural regeneration status after a series of forest disturbance in two different forest types i.e. the mixed dipterocarp forest (MDF) and heath forest (HF) in Bungo Range. The MDF covers the biggest areas among other forest types in Sarawak (Sarawak Forestry Department 2020). The forest is characterised by its tall canopy (40–60 m), very high proportion of Dipterocarp family and a great diversity of species (Sarawak Forestry Department 2020). The HF, on the other hand, is characterised by its locality on poor, acidic and podsolic soils, usually derived from sand or sandstone (Soepadmo et al. 1996, Davies & Becker 1996). The HF species can be differentiated from the MDF species through its leaves. The HF species has thicker leaves and is low in nitrogen and ash concentration, than the MDF species (Turner et al. 2000).

Bungo Range has suffered from a series of disturbances due to both natural phenomena and human activities. In the past 10 years, approximately in the year 2009, Bau district suffered from a severe storm, which caused incidents of landslides and hurricane in several areas (Tay & Selaman 2011). According to the local representative, a part of the west side of Bungo Range also suffered from strong winds, which caused falling of big trees and destruction of ground cover plants. In addition, the lower part of the Bungo Range also experienced major forest clearing due to shifting cultivation and logging activities, around the same time as the hurricane incident.

The study area comprises of forests located at the periphery of Bungo Range National Park, where native communities have access via the native customary rights. It is the interest of the local Tringgus Bidayuh community to manage the area as their communal reserve. Furthermore, recognising the importance of forest preservation and conservation, the Kampung Tringgus community also initiated proper forest management i.e. community-based initiative to manage their forest. This communal forest area is crucial to the welfare of the community as it provides key environmental services such as water, timber for domestic use and collection of other non-timber forest resources.

The regeneration study is important to identify forest diversity, important species and their regeneration status in order to provide a cause for conservation. Additionally, the community is interested in regeneration of timber-producing species, which produce good quality timber and were preferred for their fast growth rate and production of wood with good workability properties. This study is the first natural regeneration study in this area, and it will serve as a good reference for future endeavours.

Hence, the main objectives of the study were (i) to estimate the tree diversity in mixed dipterocarp forest and heath forest and (ii) to determine the natural regeneration status of dominant tree species with potentials for reforestation. It is hypothesised that both MDF and KF have high species diversity, and that the dominant tree species has good regeneration status.

MATERIALS AND METHODS

Study area

The regeneration study was carried out at the south-west corner of Bungo Range national park, from March to April 2018. Bungo Range is located at N 1° 16′ latitude and E 110° 9′ longitude, of about 500 meters above sea level. The Bungo Range is covered by primary and secondary forests. The primary forest has an approximate area of 8,096 ha and has been gazetted as the national park. The park is under the management of the Forest Department of Sarawak. However, the study area is located in the primary forests along the national park boundary. Figure 1 shows the location of the Bungo Range national park and the study area. The estimated time from Bau Town to Kampung Tringgus, which was used as the access to the study area, is approximately 30 minutes. The study area has an approximate area of not more than 250 hectares and is covered by MDF and HF (UNIMAS 2017).

The on-site forest-floor temperature and humidity was measured using a pocket hygro-thermo-anemometer. The mean forest-floor temperature of both study areas is 27 °C and the mean humidity is 85.2%. The annual rainfall in Sarawak is between 3,300–4,600 ml (Sarawak Government 2020). Data collection is conducted at the end of the monsoon season, which explains the high percentage of humidity.

Sampling design

A systematic sampling method using nested plot has been carried out at all study areas (Asrat & Tesfaye 2013). A total of seven nested plots were placed systematically of about 20 meters apart, in which three at MDF and four at HF. The total sampling area was 0.35 ha. The

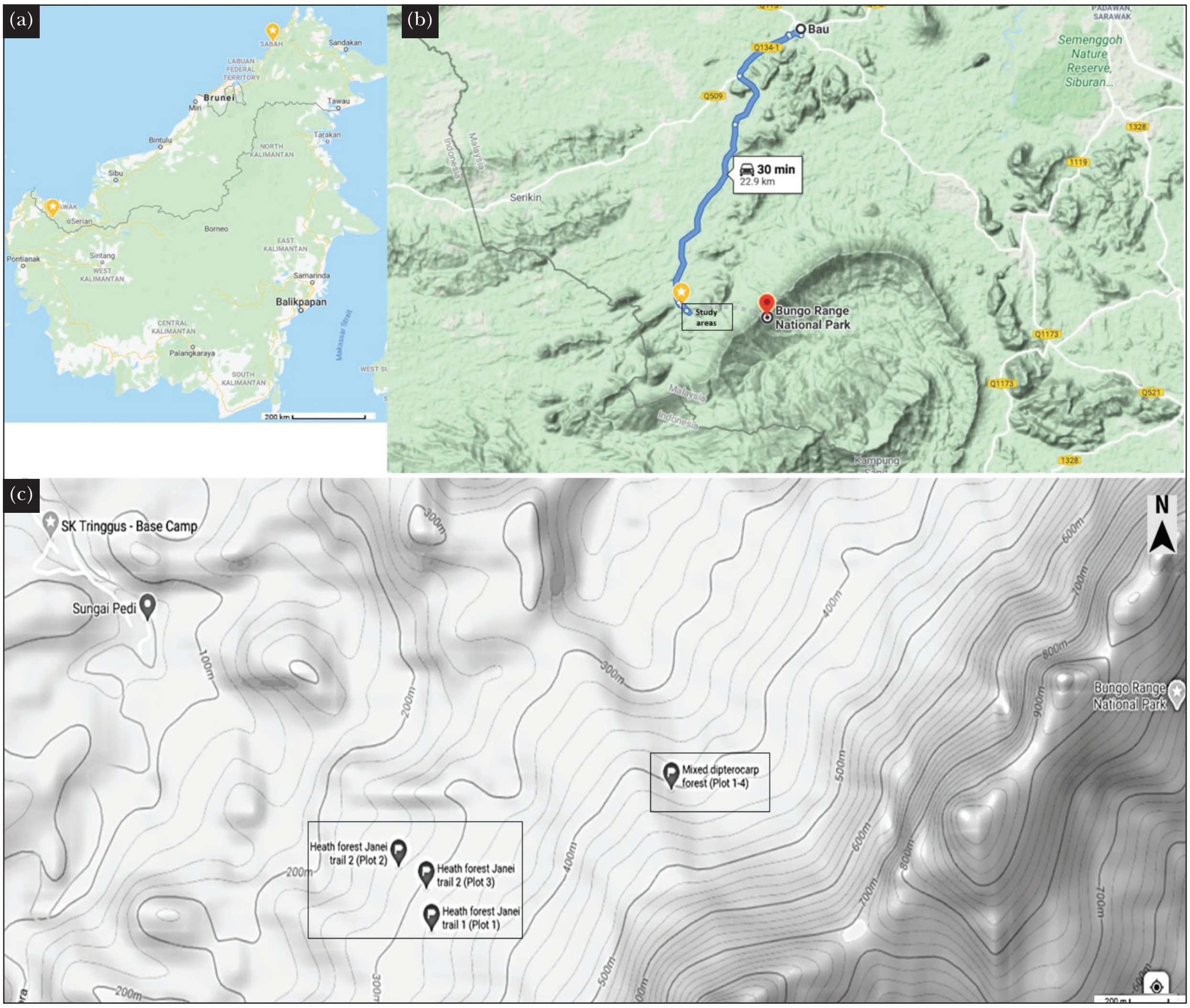

Figure 1 Map showing the location of the study areas: (a) the location of Bungo Range in the Borneo Island, (b) the direction to the Bungo Range from the nearest town, which is the Bau Town, (c) the distribution of plots during the forest regeneration survey in Bungo Range

calculation of the sample size for nested plot was (100 m^2 + 25 m^2 + 1 m^2) * 4 * 7 = 3528 m^2 / 0.35 ha. According to the sampling design, there were four subplots of 100 m^2 in each 400 m^2 main plots, and then multiplied by total of seven plots. Although there were only seven nested plots used, the sampling intensity yielded almost the same results of species richness as of 1-hectare plot. This was also shown in a study by Barnett & Stohlgren (2003). A similar study with a small number of sampling plots was carried out by Din et al. (2015) to quantify tree diversity and community composition in Brunei heath forest. Figure 2 shows the nested plot design used during sampling.

Data collection and analysis

Data collection process involved the determination of the tree species, mensuration of the diameter/diameter at breast height (DBH), height and environmental parameter i.e. light intensity, relative humidity and temperature. The height and stem diameter of seedlings (height < 0.9 m), saplings (height 0.91–3 m tall) and trees (height > 3 m tall, DBH ≥ 5 cm) were determined according to University of Kentucky (date unknown). Determination of static size class to measure regeneration has been applied by several studies (Aliyi et al. 2015, Kuma & Shibru 2015). Data analysis was then conducted, involving four types of analysis i.e. Shannon diversity index, importance value (IV), regeneration status and Kruskal Wallis H-test.

Firstly, the woody tree species were categorised into timber producing and non-timber producing species. The classification of tree species into timber/non-timber was based on their potential utilisation as defined from their properties (Sosef et al. 1998, Wong 2002).

Tree species composition and diversity is important to provide information on the forest structure and function (Singh et al. 2016). Hence, the Shannon diversity index and richness were calculated to further determine and present detailed information on tree diversity in the study areas. Shannon diversity index is usually used to describe the species diversity in a community accounting both the abundance and evenness of the species present (Magurran 2004). The value of Shannon diversity usually ranges between 1.5 and 3.5 (Khan SA 2013). The formula for the diversity of a species (H') is,

$$\text{Diversity of a species } (H') = -\text{SUM } [(pi) \times \ln (pi)]$$

where SUM = summation and pi = relative abundance of i^{th} species (n_i / N).

Species richness is defined as the number of different species within a community. Unlike the

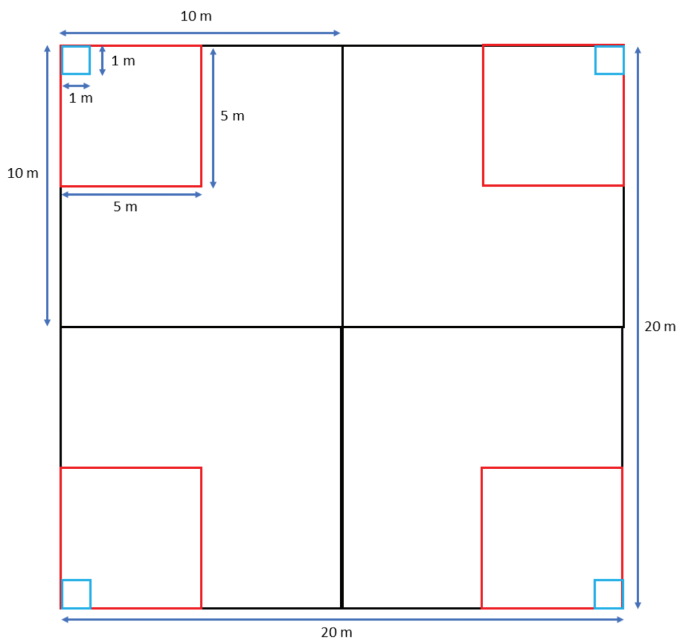

Figure 2 Nested plot design in which the 20 m × 20 m plot is used to measure trees, 5 m × 5 m plot for saplings and 1 m × 1 m for seedlings (Knight 1978)

diversity index, species richness does not consider species abundance and distribution within the community, but is affected by the number of individuals and heterogeneity of the sample. The species richness (S) is calculated using the formula:

$$\text{Species richness } (S) = \frac{\text{No. of species}}{\sqrt{\text{Total individual}}}$$

Next, the IV was calculated for all tree species in all sites to determine the dominant tree species. The quantitative analysis of the IV for all tree species in the study sites may provide information on potential tree species for reforestation in Sarawak. High IV indicates the dominance of the tree species in the area, and the dominant species affects the balance and sustainability of the area (Wiryani et al. 2018). The IV index has not only been used to calculate the dominant species from mature trees exeeding 5 cm DBH but also for regeneration studies (Al-Amin & Alamgir 2003, Rahman et al. 2011, Kueh et al. 2013, Bogale et al. 2017). The formula for IV as per Saha et al. (2016) is:

Relative frequency + Relative density + Relative dominance = Importance value (IV)

where Relative frequency = (frequency of a species/total frequency) × 100, Relative density = (density of a species/total density) × 100 and Relative dominance = (dominance of a species/ total dominance) × 100.

The regeneration status of the selected species was then carried out based on the densities of the seedling, sapling and tree per hectare and are classified into five ratings (modified from Sarkar & Devi 2014) viz.

(1) Good regeneration : seedlings > or < saplings > tree
(2) Fair regeneration : seedlings > or < saplings < tree
(3) Poor regeneration : a species survives only in the sapling stage, but no seedlings
(4) No regeneration : only tree is present and
(5) New species : only saplings and/or seedlings are present

Finally, the top ten timber-producing species and non-timber producing species with the highest IV value were determined. All non-timber producing species from both forest types were selected as there were only ten species from MDF and three species from HF.

RESULTS

Tree diversity in two forest types

A total of 79 woody species, from 41 families were found in MDF. Euphorbiaceae had the highest number of species (seven species), followed by Annonaceae and Lauraceae (both six species). From the total number of species found, 64 were timber-producing species and 14 were non-timber producing species. On the other hand, from a total of 92 species, 34 families were found in HF. Dipterocarpaceae was abundant in HF (15 species), followed by Euphorbiaceae (11 species) and Myrtaceae (eight species). A total of 80 species were timber-producing species and 12 were non-timber producing species. The MDF (S = 4.6) had higher species richness than HF (S = 4.3), and this indicated that there were more species found in MDF than HF. Although MDF showed higher species richness, HF had a higher species diversity (H = 3.8).

The regeneration status of dominant tree species with potentials for reforestation

The top ten timber-producing species with the highest IV were selected from both forest types. Figure 3(a) shows that the total number of dominant species regenerating is higher than the number of species, with no regeneration for both forests. There was only one species (*Neolamarckia cadamba*) and two species (*Litsea lancifolia* and *Calophyllum inophyllum*) with good regeneration status, in which seedlings > or < saplings > tree, in MDF and HF. This indicated the potential for these species to be planted for reforestation due to their high availability of wildings.

There were four species (viz. *Syzygium* sp., *Elaeocarpus* sp., *Artocarpus odoratissimus* and *Knema latifolia*) not regenerating in HF. However, there was none in MDF. There were also two new dominant species found in both forests, namely, *Koompassia excelsa* and *Dryobalanops beccarii.*

On the other hand, there were only ten and three non-timber producing species in MDF and HF. From the total of ten species in MDF, there was only one species with good regeneration (*Goniothalamus uvarioides*).

Table 1 Tree diversity in MDF and HF of Bungo Range

Forest types	Total trees	No. of species	Timber producing species	Non-timber producing species	Species richness (S)	Shannon diversity index (H)
MDF	262	79	64	14	4.6	3.7
HF	445	92	80	12	4.3	3.8

MDF = mixed dipterocarp forest, HF = heath forest; the full species composition table can be found in the appendix

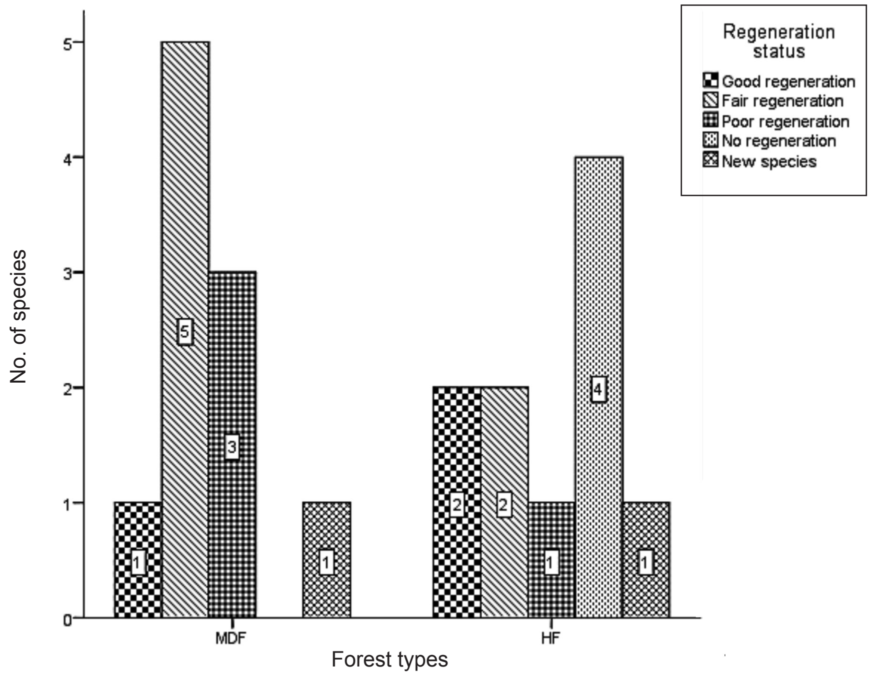

Figure 3(a) Regeneration status of timber-producing species in the MDF and HF

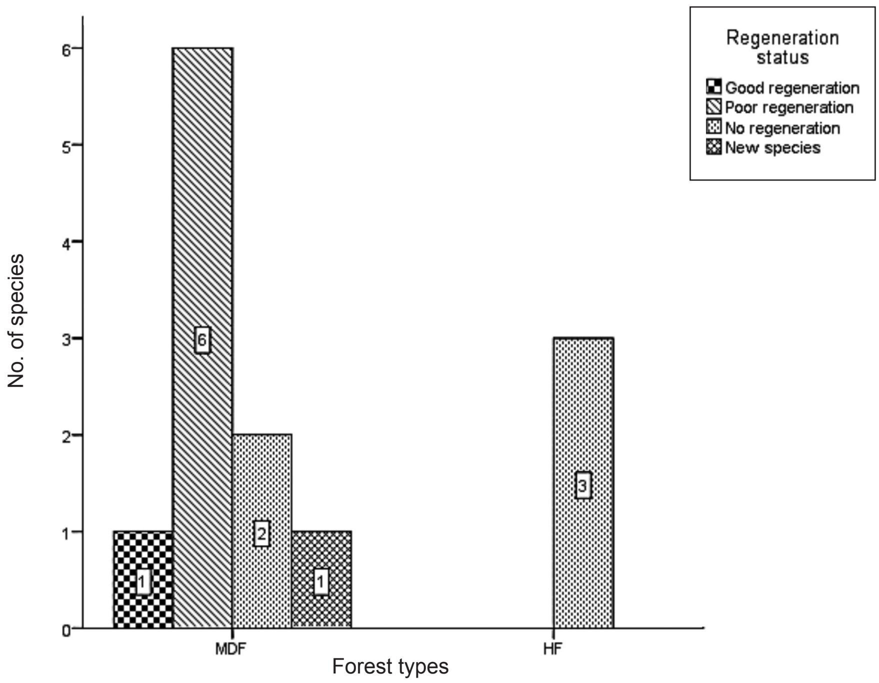

Figure 3(b) Regeneration status of non-timber producing species in the MDF and HF

Although the number of species with poor regeneration in MDF was higher than other regeneration status, there were two tree species not regenerating (*Litsea suboppositifolia* and *Tabernaemontana macrocarpa*). A new tree species was also found in MDF, i.e. *Acranthera* sp. Contrarily, all three tree species in HF showed no regeneration particularly, only mature trees were present, with the absence of the seedling and sapling.

DISCUSSION

Species richness and diversity

The results showed that MDF had higher species richness than HF. A comparison study between MDF and HF in Brunei Darussalam showed similar findings where MDF plots had richer species composition than heath plots (Davies & Becker 1996). However, it was also found that MDF had a lower species diversity than HF. The lower species diversity value in MDF than HF may also be contributed by the dominance of some species in both forest types, as shown in Davies & Becker (1996). It was found that, although MDF had higher species richness than HF, the MDF had less tendencies towards species dominance due to extremely high species richness. The high percentage of understory species in heath forest may also contribute to the difference in species diversity between MDF and HF (Becker et al. 1999). The difference in species richness and diversity may also be affected by total soil nitrogen concentration and canopy openness (Din et al. 2015). Although the study was carried out in one forest type (HF), the tree species compositions in each plot differed due to the abovementioned reasons (Din et al. 2015). The difference in canopy openness also affected the herbs diversity and abundance in both MDF and HF (Nurul & Rahayu 2014). Another study by Nishimua et al. (2007) found that HF had low stand basal area and high stand density as compared to peat-swamp forest, following a severe drought. This was due to the richness of small diameter species found in HF.

Dominant tree species with potentials for reforestation

The results showed that there were three valuable timber-producing species with high importance value and good regeneration, with potential for reforestation. The high number of species and regenerating individuals present a potential of highly diverse seed banks for reforestation (Viani & Rodrigues 2009). *Neolamarckia cadamba* has high importance value and good regeneration in MDF, and the abundance of regeneration helps the reforested stand to develop into a natural forest over time (Bosire et al. 2006). *Neolamarckia cadamba* is a typical pioneer species in the secondary forest (Jøker 2000, Nilus & Sugau 2015). Due to its fast growth and light-demanding characteristic, it is suitable for reforestation (Jøker 2000). *Neolamarckia cadamba* were planted in forest plantation and as an intercropping tree (Lee et al. 2005, Abd Latif et al. 2018). Although the timber is weak (strength group D), it still produces quality wood for general purposes such as plywood, packing cases and canoes, if properly seasoned (Wong 2002).

Litsea lancifolia also had good regeneration in HF, and it was found to be one of the pioneer species of a deforested peat swamp forest which showed relatively fast growth rates and opportunistic characteristic, and it can survive in both under shade or open area (Freund 2012, Siti-Hamidah et al. 2018). Besides, *Litsea* sp. is also incuded in enrichment planting in Indonesia's rubber smallholdings alongside other dipterocarps species, due to its high natural regeneration rate (Tata et al. 2014). Plants from the genus *Litsea* has been used in traditional medicine worldwide due to the pharmacological properties such as antifungal, anti-inflammatory, anti-asthmatic and antioxidant (Alimah 2016). The timber of this genus has a fair strength (strength group C) and is suitable for medium construction under cover such as plywood, furniture and panelling (Wong 2002).

Calophyllum inophyllum was also found to have good regeneration in HF. It is generally a slow-growing tree with tolerance to full sun and drought, and mass regeneration make it suitable to be planted in a forested area (Orwa et al. 2009). *Calophyllum alboramulum,* for example, has been planted among others in the restoration of shifting cultivation areas at multiple forest reserves around Sarawak in 2005 (Wasli et al. 2014). *Calophyllum* sp. also produces a moderately strong timber (strength group C) and suitable for light construction such as flooring, furniture and plywood (Wong 2002).

Despite the potential species mentioned hereabove, it is also important to take note of the species without regeneration and other new species found in the area. Poor germination rate is one of the main reasons of slow natural regeneration such as *Elaeocarpus* sp. (Kumari et al. 2018). The lack of regeneration may predict the risk of extinction of these valuable species. *Syzygium* sp., for example, does not only provide good wood but also helps in stabilising river banks, thanks to its rooting system (Mudiana 2016). *Syzygium* sp. and *Artocarpus odoratissimus* also produce food and beneficial chemical constituents for medicinal purposes (Whistler & Elevitch 2006, Khandaker & Boyce 2016, Noorfarahzilah et al. 2017).

Goniothalamus uvarioides was found to have a good regeneration status in MDF. This species has been used traditionally, not only in Malaysia but also in Indonesia, the Philippines and Taiwan (Wiart 2007, Muhammad Shahzad et al. 2016).

CONCLUSION

The study provided valuable information on the potential tree species for reforestation initiatives. The results rejected the null hypothesis (both MDF and KF have high species diversity) and showed that HF had higher diversity than MDF. There was also a difference in IV of tree species between the study sites, which indicated the value of each species. The null hypothesis (dominant tree species has good regeneration status) was also rejected. There were four native tree species with the potential to be included in reforestation efforts, namely, *Neolamarckia cadamba, Litsea lancifolia, Calophyllum inophyllum* and *Goniothalamus uvarioides*. To use these potential native species for reforestation, however, will require serious silvicultural research to ascertain their ability to perform in degraded forest environments.

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Appendix 1 List of ten dominant species in Bungo Range

Forest types	Family	Scientific name	Local name	Timber/Non-timber	Regeneration status	Relative dominance	Relative frequency	Relative density	Importance value
MDF	Annonaceae	*Polyalthia* sp.	Semukau (Ib)	Timber	Fair	10.83	1.96	13.64	26.43
	Lauraceae	*Litsea lancifolia*	Medang (Ib/Mal)		Poor	10.23	1.96	5.68	17.87
	Ebenaceae	*Diospyros* sp.	Kayu malam (Ib/Mal)		Fair	8.92	1.96	6.82	17.7
	Dipterocarpaceae	*Koompassia excelsa*	Do'oh (Bid)		New species	11.19	1.96	1.89	15.05
	Rubiaceae	*Neolamarckia cadamba*	Kelampayan (Mal)		Good	11.36	1.96	1.14	14.46
	Dipterocarpaceae	*Shorea* sp.	Meranti (Mal)		Fair	8.57	0.98	3.79	13.34
	Meliaceae	*Aglaia* sp.	Segera (Ib)		Fair	3.13	1.96	7.2	12.29
	Tiliaceae	*Pentace* sp.	Baru bukit (Mal)		Fair	5.86	0.98	1.14	7.98
	Euphorbiaceae	*Croton* sp.	Entupak (Ib)		Poor	3.09	1.96	2.65	7.7
	Polygalaceae	*Xanthophyllum ellipticum*	Nyalin (Mal)		Poor	3.6	1.96	1.52	7.08
	Actinidiaceae	*Saurauia* sp.	Mata ikan (Mal)	Non-timber	Poor	0.03	1.96	3.41	5.4
	Annonaceae	*Goniothalamus uvarioides*	Kinamai (Bid)		Good	0.03	1.96	2.65	4.65
	Apocynaceae	*Kopsia* sp.	Tengang (Ked)		Poor	2.71	0.98	0.38	4.07
	Flacourtiaceae	*Flacourtia rukam*	Rukam (Ib)		Poor	2.43	0.98	0.38	3.79
	Moraceae	*Ficus* sp.	Ara (Mal)		Poor	0.48	0.98	2.27	3.73
	Lauraceae	*Litsea subopposititfolia*	Medang pangit mit (Ib)		No regeneration	0.01	1.96	1.52	3.49
	Rubiaceae	*Acranthera* sp.	Sabar bubu (Ib)		New species	0	0.98	0.76	1.74
	Myrsinaceae	*Ardisia javanica*	Merjemah (Ib)		Poor	0.12	0.98	0.38	1.48
	Moraceae	*Ficus eumorpha*	Tempan bulu (Ib)		Poor	0	0.98	0.38	1.36
	Apocynaceae	*Tabernaemontana macrocarpa*	Pelir kambing (Ib)		No regeneration	0	0.98	0.38	1.36
HF	Myrtaceae	*Syzygium* sp.	Bah (Bid)	Timber	No regeneration	7.7	2.67	11.49	21.85
	Elaeocarpaceae	*Elaeocarpus* sp.	Emperdu (Ib)		No regeneration	11.34	2.67	6.31	20.31
	Dipterocarpaceae	*Hopea heathensis*	Luis kerangas (Ib/Mal)		Poor	3.06	2	8.78	13.85
	Lauraceae	*Litsea lancifolia*	Medang (Ib/Mal)		Good	8.18	2.67	2.93	13.77
	Dipterocarpaceae	*Shorea* sp.	Meranti (Mal)		Fair	6.14	2.67	3.83	12.64
	Moraceae	*Artocarpus odoratissimus*	Terap (Mal)		No regeneration	6.98	1.33	4.28	12.59
	Myristicaceae	*Knema latifolia*	Kumpang (Ib/Mal)		No regeneration	6.6	2.67	2.48	11.75
	Anacardiaceae	*Mangifera* sp.	Asuom (Bid)		Fair	8.13	2.67	0.9	11.69
	Dipterocarpaceae	*Dryobalanops beccarii*	Kapur (Mal)		New species	2.02	0.67	6.08	8.77
	Clusiaceae	*Calophyllum inophyllum*	Bintangor (Mal)		Good	5.19	1.33	1.8	8.33
	Elaeocarpaceae	*Elaeocarpus floribundus*	Emperdu pensi mit (Ib)	Non-timber	No regeneration	0.55	0.67	0.68	1.89
	Lauraceae	*Endiandra* sp.	Medang bejubai (Ib)		No regeneration	0.01	1.33	0.45	1.79
	Euphorbiaceae	*Elateriospermum tapos*	Perah/Rapi (Mal)		No regeneration	0.2	0.67	0.23	1.1

MDF = mixed dipterocarp forest, HF = heath forest, Ib = Iban, Mal = Malay, Bid = Bidayuh, Ked = Kedayan