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Early Assessment of Forest Growth in a Logged over Coastal Lowland Mixed Dipterocarp Forest in Bintulu, Sarawak, Malaysia

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ABSTRACT

Managing regrowth forests sustainably is a necessary tactic to address climate change as these forests' ability to capture and sequester carbon is much higher due to their potential high growth rate. These forests also retained high tree diversity if subjected to selective logging previously. The objectives of this study were to investigate growth rate of tree species in a logged over coastal lowland mixed dipterocarp forest. This study was carried out in 10 established plots (50 m × 20 m) at a logged-over forest in Universiti Putra Malaysia Bintulu Sarawak Campus, Sarawak, Malaysia and trees with 10 cm diameter breast height (dbh) and above were measured. There were 611 individual trees of 159 species and 43 families were found in a one-hectare. The majority of trees (86%) were found in smaller diameter classes (<30 cm) with only 2% in diameter classes of more than 50 cm. The study area still retains a mixed dipterocarp forest feature. The stand has a good growth rate. Overall *dbh* increment was 0.34 cm yr^{-1} with dipterocarps documented 0.39 cm yr^{-1}. A reverse growth dominance was observed in this study where smaller trees recorded higher growth. Thus contributing up to 72% of carbon sequestrated by this group of trees.

Keywords: Carbon sequestration, floristic composition, growth dominance, growth rate, logged-over lowland dipterocarp forest

INTRODUCTION

In 2020, about 31.1% of the earth's land surface is covered by forests with 45% found in the tropical region (FAO, 2020). Forest trees capture CO_2 from the air (one of the main greenhouse gases that causes climate change) and store carbon in biomass, forest litter and soil as they grow. Over a period of 19 years (2001 – 2019), annually it is estimated that global forests are able to remove 15.49 ± 19 Gt CO_2e. Tropical regions contributed 45.1% or 6.99 Gt CO_2e of this removal (Harris *et al*., 2021). The highest ability of tropical forests to capture and sequestration of carbon is due to the highest carbon density within this type of forests (FAO, 2020; Spawn, 2020). Thus managing forests sustainably including carbon capture is a crucial approach to help address climate change.

Changes in tree growth can have a significant impact, either shielding or impairing the increase in atmospheric CO_2. FAO (2020) estimated total carbon stock in forests at 662 Gt of which 45.2% in soil, 44.5% in living biomass, and 10.3% in dead wood and litter. South and Southeast Asia, Western and Central Africa, South America, Central America, and the Caribbean where most tropical forests can be found account for 53.7% of carbon found in living biomass (FAO, 2020). This indicates that tropical forests are a highly significant contributor to the global carbon budget. However, logged-over forests are now more widespread than unlogged forests in this region also. In the case of Borneo Island, Gaveau *et al*. (2014) estimated that by 2010 the total forested area only covers 52.8% of the island. Logged-over forests cover 46.2% of these persisted forests. They expected that about 42.0% or 88,150 km^2 of the remaining intact forests will be logged as they are categorized as production forest and only 32.2% of potential remain as intact forests in the coming decade. Although logged-over forests are more common, the understanding of carbon dynamics in response to timber harvesting in the tropics is limited. Following disturbance such as logging, forest regrowth is able to possibly provide a valuable carbon sink as forests regain their biomass during the succession process (Pugh *et* *al*., 2019). Carbon sequestration potential due to biomass accumulation rate from natural forest regrowth is still sparse. Many countries are depending on default rates from the Intergovernmental Panel on Climate Change as they do not have nationally specific forest carbon accumulation rates (Lewis *et al.*, 2019). The available rates do not take into consideration variations in local land-use history and environmental conditions (Cook-Patton *et al*., 2020).

Production of timber in Malaysia is based on a selective management system with a periodic harvesting cycle of 25 – 30 years that was introduced in 1978 (Thang, 1987). A number of commercial trees above a certain diameter limit will be harvested. This management system is sustainable only if able to maintain timber production (potential harvestable trees recover in time) and continue to provide ecosystem services between cuts (Edwards *et al*., 2014). Therefore recovery of forest stock estimation becomes a critical component of sustainable forest management and is imposed by certification schemes (Nasi *et al*., 2012).

Forest certification, a market driven mechanism, gained traction after the United Nations Conference on Environment and Development, Earth Summit at Rio de Janeiro in 1992. The certification scheme aims to identify forest areas that are managed sustainably in terms of economic, social and environmental. An approach that allows timber harvesting to continue while at the same time ensuring forests are managed responsibly. In 1998 Malaysia Timber Certification Council was established and three years later, they launched their first certification scheme with the aim to encourage the implementation of sustainable forest management in Malaysia. This scheme was the first tropical forest scheme in the Asia Pacific region that gained endorsement by The Programme for the Endorsement of Forest Certification in May 2009.

The establishment of permanent sample plots is a crucial approach spelled out in the certification scheme documents in order to monitor and assess the health and vitality of the forests and the sustainability of managed forests. The plots are able to provide among other tree growth rates, regeneration status, and conditions of the forests. This collected information will be able to assist forest managers in determining the next harvesting cycle more accurately for their forest area. Information on the growth rate of tropical tree species found in the natural forests is still sparse especially in the logged-over forests. This study was conducted in an attempt to provide information on floristic composition, diameter, biomass and carbon content increments, and assessed the relationship between tree size and tree growth rate in a coastal logged-over lowland mixed-dipterocarp forest.

MATERIALS AND METHODS

Site Description and Plot Establishment

The study plots were established at a logged-over forest within Universiti Putra Malaysia Bintulu Sarawak Campus, Sarawak, Malaysia (Figure 1). The record from the Forest Department Sarawak indicated that this forest was selectively logged in 1977. In 1994, illegal logging activity was detected in this area resulting in major destruction with most of the trees with a diameter of 40 cm being felled. This forest is currently used for teaching and research purposes for forestry students. The forest area is situated at 20 – 110 m above sea level with an average annual rainfall of 2,327 mm. The soil in the area is acidic and classified as an Isohyperthermic Typic Dystropept known as the Nyalau soil series (Peli *et al*., 1984). One-hectare permanent sample plot was first established in 2007 by combining 10 subplots of 50 m × 20 m (Figure 2).

Diameter Measurement

All trees with a diameter of 10 cm and above at breast height (*dbh* – 1.3 m above ground height) were measured, tagged, identified and marked with a red paint to indicate the point of measurement. Remeasurement of *dbh* was conducted the following year at the marked measurement point.

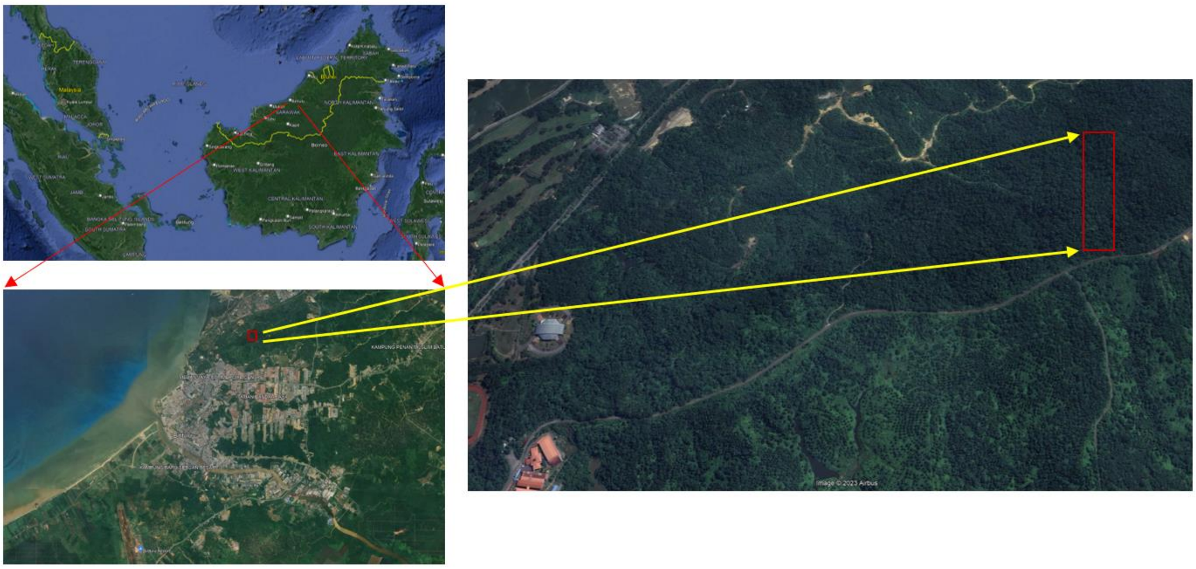

Figure 1. Study site location

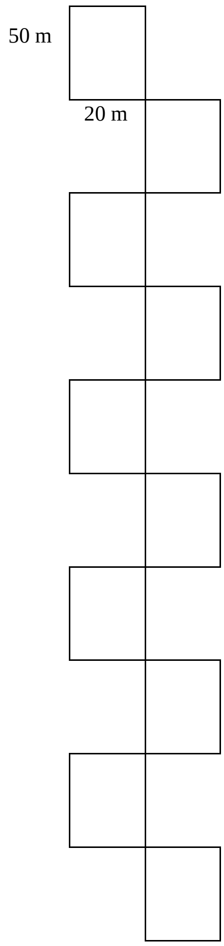

Figure 2. Plots layout

Data Analysis

Field data collected were quantitatively analyzed for growth dominance, biomass and carbon sequestration estimation, Important Value Index, species diversity and tree distribution within the study area. The methods are as follows:

Growth Dominance

The relationship between tree size and their growth can be analyzed using growth dominance (GD) as proposed by Binkley (2004). This quantitative approach looks at how different tree sizes influence productivity (Soares *et al*., 2017). GD was calculated using the Eq. (1) proposed by West, (2014):

$$GD = 1 + \sum_{i=1}^{n}(x_i - x_{i-1})(y_i + y_{i-1}) \qquad \text{Eq. (1)}$$

where n is the number of trees found in the plot, x is the cumulative percentage in stem biomass, and y is the cumulative percentage increment in stem biomass.

Biomass and Carbon Sequestration Estimation

Manuri *et al*. (2016) allometric equation [Eq. (2)] for tropical dipterocarp forests was used to determine the aboveground biomass (AGB) of trees in the current study.

$$\text{AGB (kg)} = 0.215\ dbh^{2.533} \qquad \text{Eq. (2)}$$

The conversion factor of 0.471 was used to calculate carbon in AGB (Thomas & Martin, 2012). The ratio of 3.67 (weight of C in CO_2) was used to determine CO_2 captured by growing trees.

Importance Value Index

The importance value index (IVI) for tree species recorded in this study was calculated based formula Eq. (3), Eq. (4), Eq. (5) and Eq. (6) provided by Curtis and McIntosh (1951).

$$\text{Relative Density (RD)} = \frac{\text{density for a species}}{\text{total density for all species}} \times 100 \qquad \text{Eq. (3)}$$

$$\text{Relative Frequency (RF)} = \frac{\text{frequency value for a species}}{\text{total frequency for all species}} \times 100 \qquad \text{Eq. (4)}$$

$$\text{Relative Dominance (RDo)} = \frac{\text{dominance for a species}}{\text{total dominance for all species}} \times 100 \qquad \text{Eq. (5)}$$

$$\text{IVI} = \text{RD} + \text{RF} + \text{RD}_o \qquad \text{Eq. (6)}$$

Species Diversity and Tree Distribution

Shannon-Wiener index (Pielou, 1969) and Fisher's α index (Whittaker 1960) were two indices used in this study to determine the tree species diversity. Meanwhile Pielou's index (Pielou, 1969) and variance to mean ratio (Greig-Smith, 1983) were used to determine tree distribution and disperser within studied plots. The existence of Borneo endemic tree species and their conservation status was also determined. This is determined by referring to the Tree Flora of Sabah and Sarawak, the IUCN Red List, and the Red List of Bornean Endemic Dipterocarps (Bartholomew *et al*., 2021). Furthermore, a species-area curve was developed by plotting species number as a function of the sample plot size or area. This has been used in studies of community ecology which provides the fundamental component for conservation biology.

RESULTS AND DISCUSSION

Tree Diversity and Distribution, and Stand Floristic Composition

In an area of one hectare, a total of 45 families with 157 species were enumerated and 611 stems were recorded. Of these, 98 were identified at the species level and 59 were identified at the genus level. The number of tree species recorded in this logged-over forest was lower than the ranges reported in primary forests of Peninsular Malaysia and Borneo for elevation below 250 m (Proctor *et al*., 1983; Sukardjo *et al*., 1990; Manokaran & Swaine, 1994; Poulsen *et al*., 1996; Davies & Becker, 1996; Kartawinata *et al*., 2004; Small *et al*., 2004; Wilkie *et al*., 2004). Stand density in the current study was within the ranges reported by Proctor *et al*. (1983), Sukardio *et al*. (1990), Newbery *et al*. (1992), Manokaran and Swaine (1994), Poulsen *et al*. (1996), Davies and Becker (1996), Kartawinata *et al*. (2004), Small *et al*. (2004), and Wilkie *et al*. (2004) for primary forests of Peninsular Malaysia and Borneo (422–759 stems ha^{-1}). A total of 170 stems (or 27.8% of total stems) were from the Dipterocarpaceae family. A common feature in a mixed dipterocarp forest.

A species-area curve was developed to determine if the total number of species found in the current study signifies the total number of species in the whole studied area. A considerable number of species were steadily added as the number of subplots increased up to one hectare (Figure 3) which indicated that larger areas should be inventoried in order to get a better representative of tree species in this forest site. Similar results were reported by various authors who worked on tropical forests of Peninsular Malaysia, Borneo and Sumatra (Wyatt-Smith, 1966; Kartawinata *et al*., 1981; Riswan, 1982; Sist & Saridan, 1999; Kartawinata *et al*., 2004; Kueh *et al*., 2017).

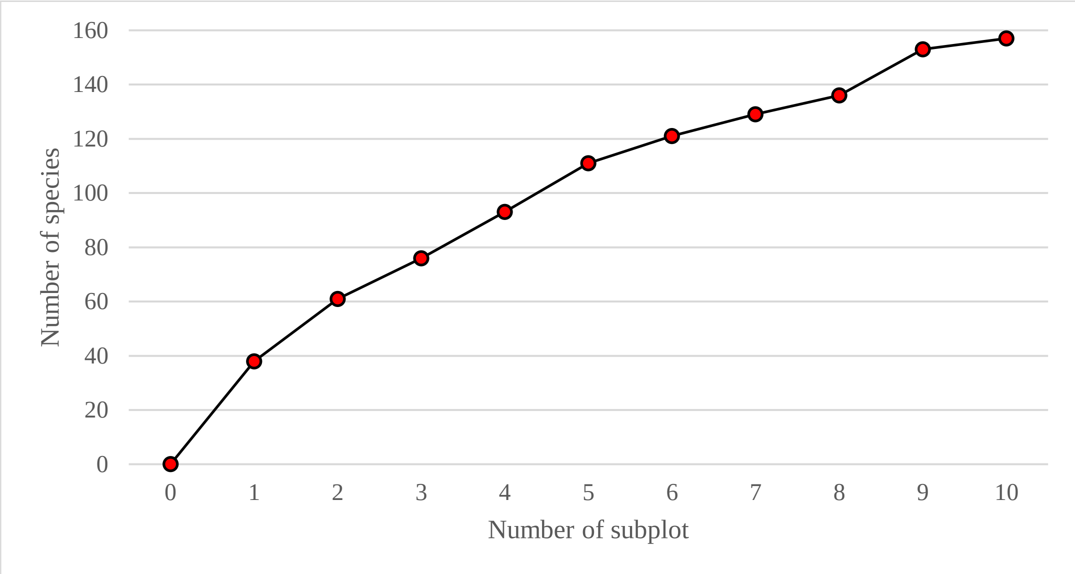

Figure 3. A species-area curve for this study

In this study, a total of 45 tree families were recorded. Only a few tree families were speciose among the sites, with 34.5% represented by ten or more species. Dipterocarpaceae with 37 species (23.6% of total species recorded) and Euphorbiaceae with 15 species were the most speciose families in this study. These two families were commonly found in most of the lowland mixed dipterocarp forests around Borneo and Peninsular Malaysia. Meanwhile four (or 8.9%) families were represented by only a single species. This logged-over forest recorded a higher number of tree families than a few other primary forests in north Sumatra (Kartawinata *et al*., 2004) and Brunei on Borneo Island (Poulsen *et al*., 1996; Small *et al*., 2004).

The species diversity of this logged-over forest is categorised by a profusion of tree species with a low rate of occurrence resulting in high Shannon–Wiener and Fisher's α diversity indexes (4.52 and 67.66, respectively). About 42.7% (or 67 species) of tree species recorded were represented by a single individual. A higher number of single individuals representing a species is a common characteristic found in the lowland forest of Borneo (Poulsen *et al*., 1996; Small *et al*., 2004). Interestingly, tree species stems found within this logged-over forest were almost evenly distributed and dispersed (E = 0.90 and VMR = 0.99). This forest is dominated by a group of understorey species.

Xanthophyllum sp. (4.7%), *Rubroshorea macroptera* (4.6%) and *Litsea* sp. (3.4%) were the three dominant species found at this study site (Table S1). These three tree species also recorded the highest ecological weights among the species found with IVI values of more than 10 (Table S1). In this study, a total of 23 endemic species of Borneo were recorded (Table 1), with which 14 were from Dipterocarpaceae (37.8% of dipterocarps found in this site were endemic to Borneo). *Shorea praestans* is a critically endangered endemic species recorded in this logged-over forest based on the Red List of Bornean Endemic Dipterocarps (Bartholomew *et al*., 2021). Two endangered endemic species, *Hopea aequalis* and *Shorea domatiosa* (Bartholomew *et al*., 2021) also recorded on this site. Meanwhile, four vulnerable endemic species, *Dipterocarpus stellatus*, *Neohopea isoptera*, *Rubroshorea quadrinervis*, and *Upuna borneensis* were recorded in this forest (Bartholomew *et al*., 2021).

Stand Diameter, Basal Area, Biomass, and Stand Growth

A total of 611 individuals with *dbh* ≥ 10 cm were recorded during this study. An inverted J-curve trend was observed in tree *dbh* classes in this forest, with the highest number of individuals having smaller tree *dbh* contributing to 63.0% (10–19.9 cm) of total stems recorded (Figure 4). The highest *dbh* was recorded for *Dryobalanops aromatica* at 83.0 cm. The average tree *dbh* was 20.3 cm with an annual rate of 0.34 cm yr^{-1}. The annual *dbh* growth for the dipterocarp was 0.39 cm yr^{-1}. Growth rates of *dbh* reduced as size increased (Figure 5), which resulted in small trees (*dbh* of 10.0 – 29.9 cm) contributing substantially more to AGB increment than large trees (Figure 6).

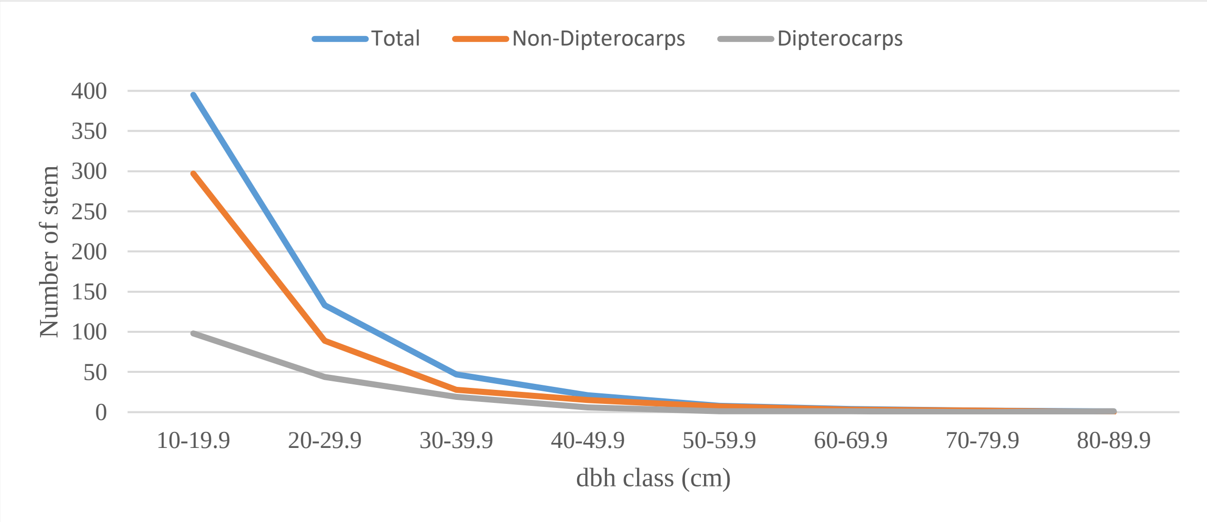

Figure 4. An inverted J-curve trend for tree diameter breast height classes in this study

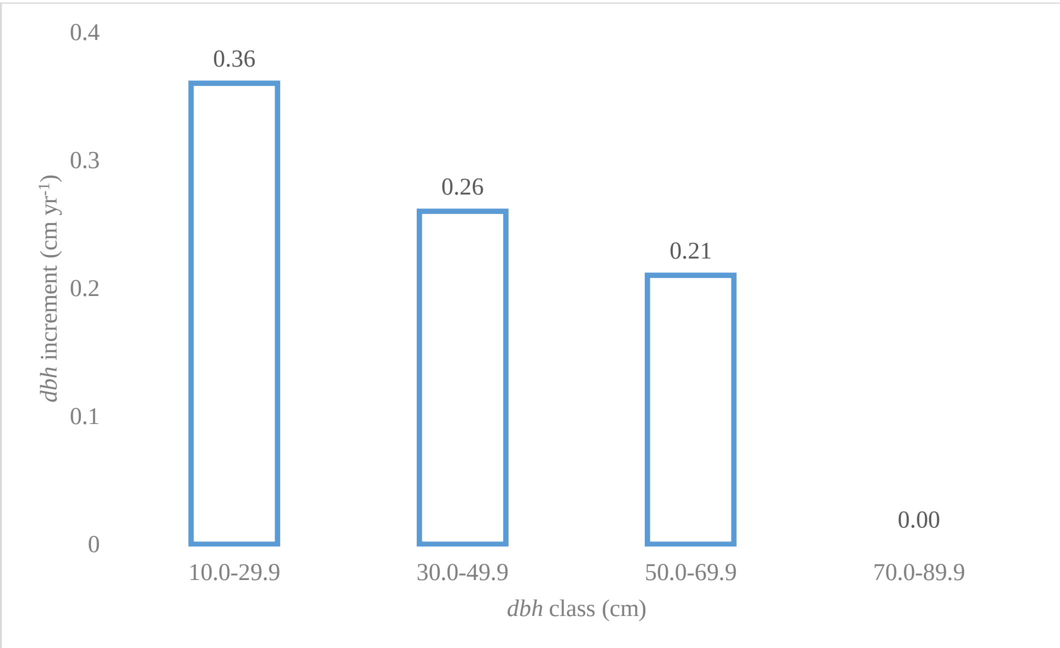

Figure 5. Annual diameter breast height growth rate according to diameter breast height classes

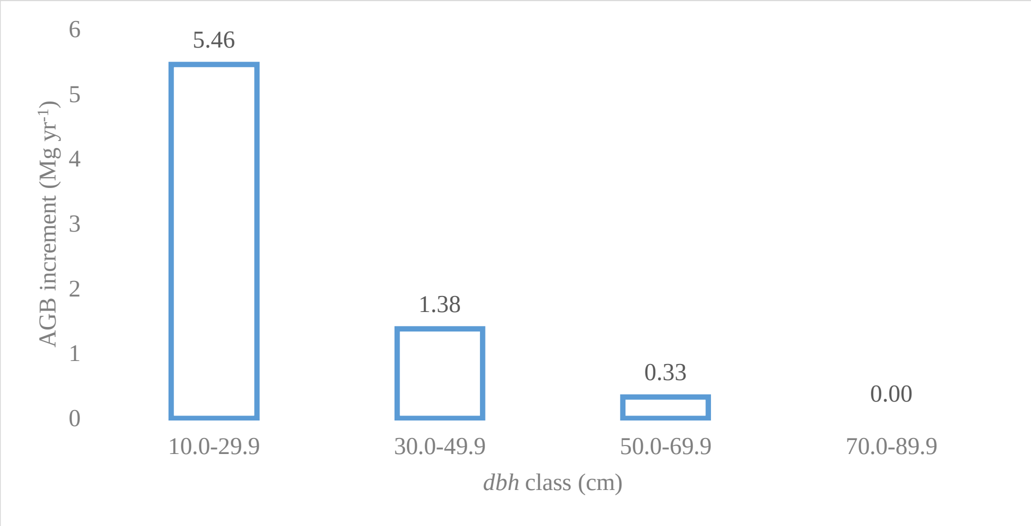

Figure 6. Above ground biomass increments according to diameter breast height classes

The total basal area in this forest was 25.16 m^2ha^{-1} (30.6% or 7.70 m^2 ha^{-1} contributed by dipterocarps) with annual growth of 0.64 m^2 ha^{-1} yr^{-1}. Meanwhile, total biomass was 435.03 t ha^{-1} (31.2% contributed by dipterocarps) with an annual of 11.51 t ha^{-1} yr^{-1}. In Sabah, Imai *et al*. (2012) found that dipterocarps contributed 43.4% of the total basal area when subjected to reduced-impact logging whilst the contribution of dipterocarps was lower (36.5%) in the area subjected to conventional logging.

In a dipterocarp forest of East Kalimantan, Sist and Nguyen-Thé (2002) reported a stand density of 530 stems ha^{-1} and a basal area of 35.1 m^2ha^{-1} before a logging operation. The number of stems was reduced to 402–498 stems ha^{-1} while the stands basal area was reduced to 18.7–28.7 m^2ha^{-1} four years after logging depending on logging intensities applied. In this study, our forest recorded higher stand density but similar stand basal area to that of East Kalimantan. Lower basal area per stem in the current study as compared to Sist and Nguyen-Thé (2002) report, might result in the indiscriminate felling of trees above 40 cm *dbh* during illegal logging operation years earlier in this forest.

Sist and Nguyen-Thé (2002) found that on average four years after logging, the overall *dbh* increment was 0.39 $cmyr^{-1}$ with dipterocarps recorded at 0.54 $cmyr^{-1}$. Meanwhile, the unlogged stand recorded *dbh* increment of 0.18–0.22 $cmyr^{-1}$ and a higher increment was recorded by dipterocarps (0.29–0.34 $cmyr^{-1}$). The current *dbh* increment was similar to the overall growth of logged-over stands in East Kalimantan. However, dipterocarp increment in this forest was considerably low when compared with the East Kalimantan site. The difference might be due to (i) recovery stages and (ii) a lesser number of larger *dbh* trees. It is well known that disturbed stands will experience a higher growth rate at the early stages of recovery (Chiew & Garcia, 1988; Thang & Yong, 1988; Sist & Nguyen-Thé, 2002: Bischoff *et al*., 2005). The forest in this study was subjected to logging more than 15 years ago while East Kalimantan stands only logged four years before. A higher number of large *dbh* (> 50 cm) was still available in East Kalimantan stands after logging while only 15 stems (2.5% of the total number of stems) larger than 50 cm were recorded on this site. Sist and Nguyen-Thé (2002) found that higher increment was recorded by trees with larger *dbh*. An opposite trend was observed in this forest, where smaller trees recorded a higher growth rate thus contributing more to AGB increments.

A reverse size-asymmetric of 0.42, where small trees contributed unduly more to stand increment than stand biomass, of GD was observed in this regrowth forest. Based on the conceptual model proposed by Binkley *et al*. (2006), the fourth phase of reverse GD could be observed in old growth forests. Higher growth of co-dominance and understorey trees and or reduction growth of dominant trees may result in reverse GD. A long-term observation would be required to assess the main factor contributing to reverse GD although decreasing growth of dominant trees is expected to be the main reason. A slower growth rate of large trees in forest stands has been substantial research over the past few decades but the detailed mechanisms remain uncertain (Martinez-Vilalta *et al*., 2007; Hinckley *et al*., 2011). The current study only supports the general observation of the trend of diminished growth in larger trees, but is unable to give any insights into the mechanism involved.

Imai *et al*. (2014) conducted tree assessment in three different forest management units, i.e., Segaliud Lokan Forest Reserve in Sabah, Sapulut Forest Reserve in Sabah, and PT Ratah Timber in Kutai Barat, East Kalimantan. In the finding, they found that forest stands contained 345–670 stems ha^{-1} with 3.1–45.9 m^2ha^{-1} of basal area and 24–581 tha^{-1} of biomass in Segaliud Lokan Forest Reserve, 294–543 stems ha^{-1} with 3.6–51.4 m^2ha^{-1} of basal area and 25–653 tha^{-1} of biomass in Sapulut Forest Reserve, and 366–622 stems ha^{-1} with 4.7–66.2 m^2 ha^{-1} of basal area and 22– 969 t ha^{-1} of biomass in PT Ratah Timber. These variations of the tree density, volume and basal area per hectare depends on the degree of disturbances occurred in these areas. In an inventory work at Mulu National Park, Sarawak, Malaysia, Proctor *et al*. (1983) found that virgin dipterocarp forest contained 778 stems ha^{-1} with 57 m^2ha^{-1} of basal area and 650 tha^{-1} of biomass. They also recorded a stand density of 615–645 stems ha^{-1} with 28 m^2ha^{-1} of basal area and 210–250 tha^{-1} of biomass in poor alluvial forests. Meanwhile Kira (1978) estimated that undisturbed dipterocarp forest in Peninsular Malaysia contained 431 t ha^{-1} of biomass. The lower values of stand density, basal area and biomass in this study as compared with the Mulu forest (Proctor *et al*., 1983) as well as the Pasoh forest (Kira, 1978) indicated that this forest stand is still in a recovery stage and needs a longer time to reach climax stage. Stand and soil disturbance were still obvious after 15 years of recovery indicating that this stand was subjected to high logging intensity.

Carbon Sequestration

The smaller diameter size classes (10–29.9 cm) contributed 39.8% of the total AGB and carbon (Figure 7). About 86.4% of trees recorded in this study are found in these diameter size classes. Meanwhile trees more than 50 cm *dbh*, only added 26.3% to the total AGB and carbon although with simply 2.5% of total trees recorded. A total of 11.51 t $ha^{-1}yr^{-1}$ of AGB gained, 5.42 t C $ha^{-1}yr^{-1}$ was accumulated, and 19.87 t CO_2 $ha^{-1}yr^{-1}$ was sequestrated by trees in the current study with smaller diameter classes (10–29.9 cm) contributed 71.6%.

Based on 49 long-term forest monitoring plots across Borneo, Qie *et al*. (2017) estimated that AGB increment of intact forest interior plots (>100 m from the forest edge) at 0.91 t $ha^{-1}yr^{-1}$ while C gain is estimated at 0.43 t C $ha^{-1}yr^{-1}$ during 1958–2015.

Regrowth forests have a good possibility to capture carbon via tree growth as shown in this study reducing CO_2 emission. These forests are usually faster in gaining biomass than intact natural forests. These figures can serve as a baseline for understanding the contribution of regrowth forests in capturing and sequestering CO_2 from the atmosphere.

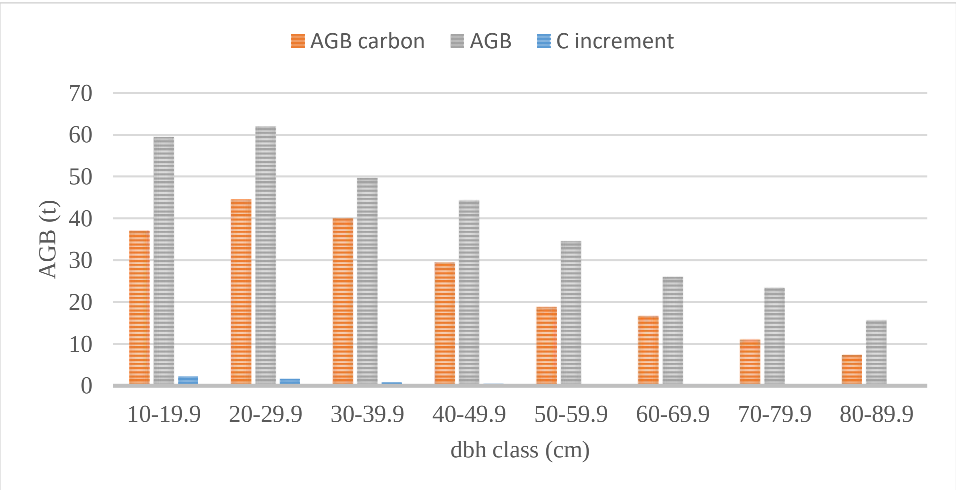

Figure 7. Aboveground biomass, and carbon content and increment according to diameter breast height classes

CONCLUSION

A total of 611 tree stems of 157 different species comprising 45 tree families were inventoried in a one-hectare area. Dipterocarpaceae and Euphorbiaceae dominated the area, a widespread characteristic of a mixed dipterocarp forest. The two most abundant species in this area were *Xanthophyllum* sp. and *R. macroptera*. A total of 23 Bornean endemic tree species were recorded with three species under the endangered species list (*R. praestans* – critically endangered; *H. aequalis* and *S. domatiosa* – endangered) indicating the area is high in conservation value.

In the current study, the *dbh* annual increment rate was 0.34 cmyr^{-1} where smaller size trees recorded higher growth rates. Thus contributed markedly to AGB and carbon increment compared to larger trees. GD further confirmed that small trees contributed greatly to stand increment. From the early assessment of the growth data, it would suggest an indication of higher growth rate in regrowth forest in the current study which indicates high potential for carbon sequestration compared to intact forests. Long term monitoring of these data is still crucial to enhance our understanding of forest growth rates and the potential carbon sequestration of logged over forest

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