BIODIVERSITAS
Volume 23, Number 12, December 2022
Pages: 6147-6154

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d231208

Spatial distribution of vegetation diversity, timber production, and carbon storage in secondary tropical rainforest at South Kalimantan, Indonesia

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Manuscript received: 20 October 2022. Revision accepted: 1 December 2022.

Abstract. *Suyanto, Nugroho Y, Harahap MM, Kusumaningrum L, Wirabuana PYAP. 2022. Spatial distribution of vegetation diversity, timber production, and carbon storage in secondary tropical rainforest at South Kalimantan, Indonesia. Biodiversitas 23: 6147-6154.* Sustainable management in secondary tropical rainforests requires basic information about stand characteristics, mainly related to productivity and biodiversity. This study aimed to quantify vegetation diversity, timber production, and carbon storage from various sites of secondary forests in South Kalimantan. Forest inventory was conducted using a census method at seven different natural forest management unit compartments. Four parameters were measured from each tree, including the type of species, commercial categories, tree diameter, and tree height. Individual tree volume and biomass were estimated using allometric equations, while carbon storage was determined using a conversion factor from biomass. Three indicators were used to evaluate vegetation diversity: richness, heterogeneity, and evenness. The analysis of correlations was applied to examine the relationship between vegetation diversity and stand productivity with a significant level of 5%. Results found that there were 41 tree species in the study site comprising 20 commercial and 21 non-commercial species. The highest richness (*R'*) was recorded in compartment 18X by approximately 4.0, while the most increased heterogeneity (*H'*) and evenness (*E'*) were observed in compartment 18Y by around 2.4 and 0.7, respectively. The accumulation of timber production varied in each site, with a range of 45.46-68.32 m^3 ha^{-1}. The highest carbon storage was noted in compartment 19Y (38.74±1.79 t C ha^{-1}), while the lowest was found in compartment 18W (20.76±0.93 t C ha^{-1}). The relative contribution of commercial species to timber production and carbon storage was substantially higher than non-commercial species at all sites. However, there was not a significant correlation between vegetation diversity and stand productivity ($P>0.05$). Overall, our study concluded that the secondary tropical forest ecosystems in the site had good vegetation diversity, timber production, and carbon storage.

Keywords: Biodiversity, ecosystems, inventory, natural forest, productivity

INTRODUCTION

Biodiversity conservation, climate change mitigation and economic development are essential issues in sustainable forest management, particularly in Indonesia. In this context, the management of forests is expected to stabilize wood supplies for commercial industries, support species conservation, and reduce carbon emissions in the atmosphere (Wirabuana et al. 2021b). To tackle these challenges, information about stand dynamics is required as baseline considerations to determine alternative forest management strategies (Pretzsch et al. 2014). It is related to timber production and includes vegetation diversity and carbon storage.

In general, the quantity of timber production will provide adequate information about the economic value of the forest and its capacity for supporting industry viability (Simmons et al. 2021). It also determines the maximum annual allowable cutting from the forest ecosystem (Asamoah et al. 2020). The number of timber production also describes the regeneration stock from different life stages of trees to maintain business sustainability (Zambiazi et al. 2021). Meanwhile, vegetation diversity information indicates the stability of environmental health and forest ecosystems (Pan et al. 2018). It also shows how many species live in the forest and their relative contribution to ecological functions (Matatula et al. 2021). The vegetation diversity can also be used to understand the natural competition in the ecosystems (Duan et al. 2021). On another side, the accumulation of carbon storage indicates the ability of the forest ecosystem to support climate change mitigation, primarily for reducing carbon emissions (Sadono et al. 2021a). Many studies explain forest vegetation generally absorbs CO_2 through the photosynthesis process. First, it converts it into biomass (Sasaki et al. 2016; Ma et al. 2017; Kocurek et al. 2020; Wirabuana et al. 2020; Sadono et al. 2021b; Setiahadi 2021). Then, the biomass will be distributed in components like roots, stems, branches, and foliage (Poorter et al. 2012; Yue et al. 2018; Altanzagas et al. 2019; Wirabuana et al. 2021a). Higher biomass indicates excellent carbon storage wherein the carbon absorption in forests will increase along with vegetation age (Arora et al. 2014). Another study report the critical role of vegetation on carbon absorption is also a part of the balance in biogeochemical cycles (Taillardat et al. 2018). To collect this information, forest inventory is necessary to support forest managers in monitoring the stand dynamics in each forest ecosystem, including secondary tropical rainforest (STR).

Before the 1990s, STR played an essential role in economic development. It provided wood materials for forest industries like furniture, veneer, and plywood. STR also occupied the second position of important sectors contributing to country revenue (KLHK, 2015). However, the occurrence of deforestation has declined its contribution significantly to the gross domestic product. Most STR currently have low productivity and high biodiversity loss (Gaveau et al. 2014). To anticipate this condition, the government has conducted the effort of reforestation to recover forest productivity and prevent vegetation extinction. However, this program is not easy to implement because STR commonly has high variation in land configuration with low accessibility (Wardhana et al. 2020).

Moreover, soil quality in these sites is also dominated by mature soil with low fertility, like oxisols and ultisols (Fujii et al. 2018). Therefore, it causes the low survival rate of vegetation generated from the reforestation program. Nevertheless, several concession areas of STR still exist and maintain their functions for economic development, biodiversity conservation, and climate change mitigation. One of them is a secondary tropical rainforest area managed by PT Aya Yayang Indonesia (AYI) located in South Kalimantan. Although it has been managed for over 30 years, the information about forest dynamics in this location is still limited, mainly related to vegetation diversity and carbon storage. Therefore, it is essential to provide more comprehensive details on stand dynamics in this area to support better forest management efforts.

This study aims to document vegetation diversity, timber production, and carbon storage from several compartments of secondary tropical rainforests managed by AYI. This information will help forest manager to determine the forest planning strategy, mainly related to yield regulation and harvesting schedules. Thus, even though it is managed as a production zone, forest regeneration is still maintained and minimizes the risk of biodiversity loss. We hypothesize that: Every compartment has a different value for vegetation diversity, timber production, and carbon storage (i). Higher vegetation diversity significantly increases timber production and carbon storage (ii). The contribution of non-commercial species on stand productivity is higher than commercial species (iii).

MATERIALS AND METHODS

Study area

This study was conducted in the secondary tropical rainforest concession area managed by PT Aya Yayang Indonesia. It is situated in Tabalong District, approximately 270 km from Banjarmasin, the capital city of South Kalimantan Province (Figure 1). The geographic coordinates of this area are located in S1°39'-1°40' and E115°29'-115°30'. Altitude ranges from 225 to 470 m above sea level. Land configuration is dominated by hills with a slope level of 15-40%. The average daily temperature is 27.6°C with a minimum of 25.7°C and a maximum of 30.3°C. The mean annual rainfall during the past ten years is 2,589 mm year^{-1}, with an average air humidity of 87.6%. The highest rainfall is recorded in November. Dry periods are relatively short, only around two months from July to August. Oxisols and ultisols dominate soil types with high acidity levels.

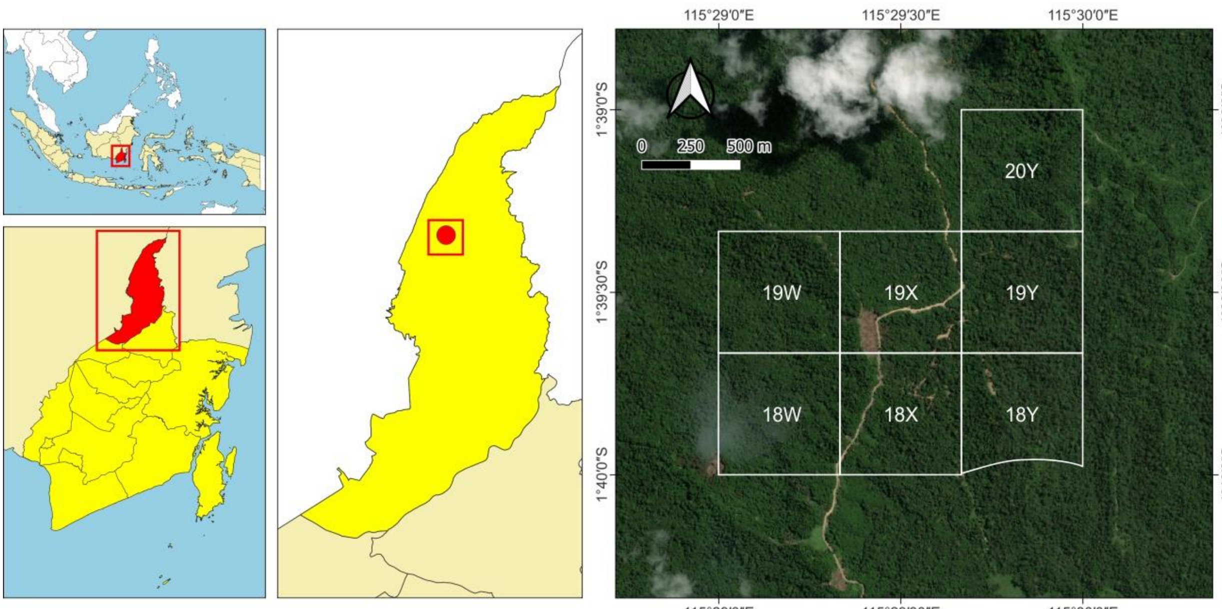

Figure 1. The study area of secondary tropical rainforest in South Kalimantan, Indonesia

Data collection

Forest inventory was conducted using a census method at seven compartments of the secondary tropical rainforest management unit, namely 18W, 18X, 18Y, 19W, 19X, 19Y, and 20Y. The total surveyed area reached 700 ha, with each site 100 ha. All trees in compartments could be covered and measured correctly. Four parameters were measured from each tree, i.e., type of species, commercial categories, tree diameter, and tree height. The determination of commercial and non-commercial species was undertaken, referring to the guidance from the company. Tree diameter was measured using a phi band at 1.3 m aboveground, while tree height was quantified using a haga altimeter from aboveground to the top crown. Moreover, the coordinate of trees was also recorded using a global positioning system (GPS).

Data analysis

Three indicators were selected to describe vegetation diversity, i.e., richness, heterogeneity, and evenness. Vegetation richness was determined by Margalef Index (*R'*), while its heterogeneity was quantified using Shannon-Wiener Index (*H'*). On another side, the evenness of vegetation was assessed by Pielou Evenness Index (*E'*). Detail equations for calculating those indicators are expressed below (Nugroho et al. 2022):

$$R' = S-1/ln(N) \quad (1)$$
$$H' = -\sum (n_i/N)(ln\ n_i/N) \quad (2)$$
$$E' = H'/ln(S) \quad (3)$$

Where: S was the number of species observed, N represented the total tree population in each compartment, and n_i described the sum of trees for each species.

To determine the quantity of timber production, individual tree volume was calculated using the following equation:

$$V = 0.25\ \pi\ dbh^2\ h\ f \quad (4)$$

Where: V was tree volume (m^3), *dbh* indicated tree diameter (cm), h represented total tree height (m), and f showed a constant of form factor (0.6) (Akossou et al. 2013). Then, the timber production degree was assumed to be the mean stand volume in hectare units. This value could be derived by dividing the total tree volume in a compartment by its area.

The quantification of carbon storage and CO_2 absorption were also calculated using a similar principle to timber production. However, we used biomass accumulation as a conversion to compute both parameters. In this context, the individual tree biomass was estimated using a generalized allometric model for secondary tropical rainforest as given (Krisnawati et al. 2012):

$$B = 0.047454 dbh^{2.078} \quad (4)$$

Where: B was aboveground biomass (kg), and *dbh* indicated tree diameter (cm). Next, the carbon stock of each tree was computed by multiplying its biomass with a percentage carbon content of 0.46 (Latifah et al. 2018), while CO_2 absorption was estimated by multiplying carbon stock with a constant of 3.67 (Latifah & Sulistiyono 2013). Then, the result was converted into a hectare unit.

Descriptive analysis was selected to compare the value of vegetation diversity, timber production, and carbon storage among different compartments based on the trend of the histogram and the summarized information from the table. Meanwhile, the spatial distribution of three parameters was processed using QGIS (Figure 2). The diversity of vegetation, including richness, heterogeneity, and evenness was categorized, referring to the classification of ecological indices by Hussain et al. (2012). The quantity of timber production was classified into three categories, i.e. low (< 40 $m^3\ ha^{-1}$), medium (40-50 $m^3\ ha^{-1}$), and high (> 50 $m^3\ ha^{-1}$). We also stratified the carbon storage into three classes, namely low (< 20 t C ha^{-1}), medium (20-30 t C ha^{-1}), and high (> 30 t C ha^{-1}). Finally, to evaluate the relationship between vegetation diversity and stand productivity, both in timber production and carbon storage, Pearson correlation analysis was applied with a significant level of 5%.

RESULTS AND DISCUSSION

Vegetation diversity

Results found that vegetation diversity among compartments was substantially different (Table 1, Figure 3). The highest species abundance was recorded in the compartment of 18Y, while the lowest number of species was observed in the compartment of 20Y. Similar trends were also discovered in the richness, heterogeneity, and evenness, wherein the highest value of those indicators was noted in compartment 18Y. These findings directly confirmed our first hypothesis that assumed there was different vegetation diversity between compartments in the study site.

The diversity of vegetation in secondary tropical rainforests was generally caused by the interaction between vegetation and the environment. This process generated natural competition wherein trees compete with each other to obtain sufficient resources to support their survival (Wirabuana et al. 2022b). On another side, environmental variation also became a limiting factor for certain species; thus, it could inhibit some vegetation from growing well (Wang et al. 2019). Consequently, the regeneration capacity of each species in this ecosystem was highly dynamic depending on their adaptation to environmental conditions. Several previous studies also reported similar results wherein the natural regeneration in secondary tropical rainforests was exceptionally dynamics due to the impact of intraspecific and interspecific competition between trees for obtaining light, water, nutrients, and space (Barabás et al. 2016; Adler et al. 2018; Yang et al. 2019).

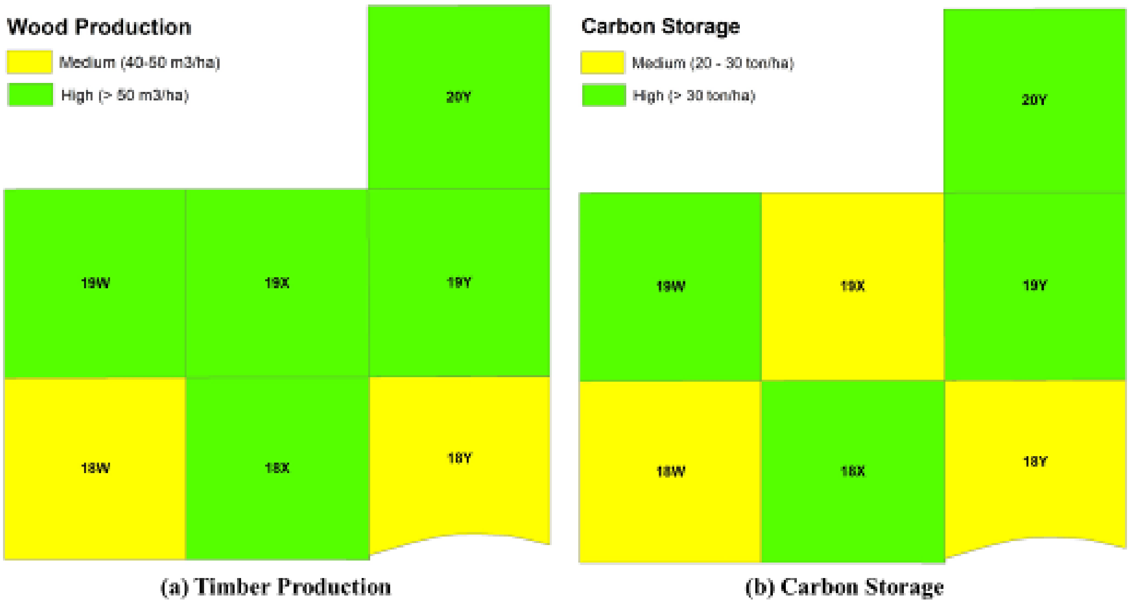

Figure 2. Spatial distribution of timber production and carbon storage in the study site

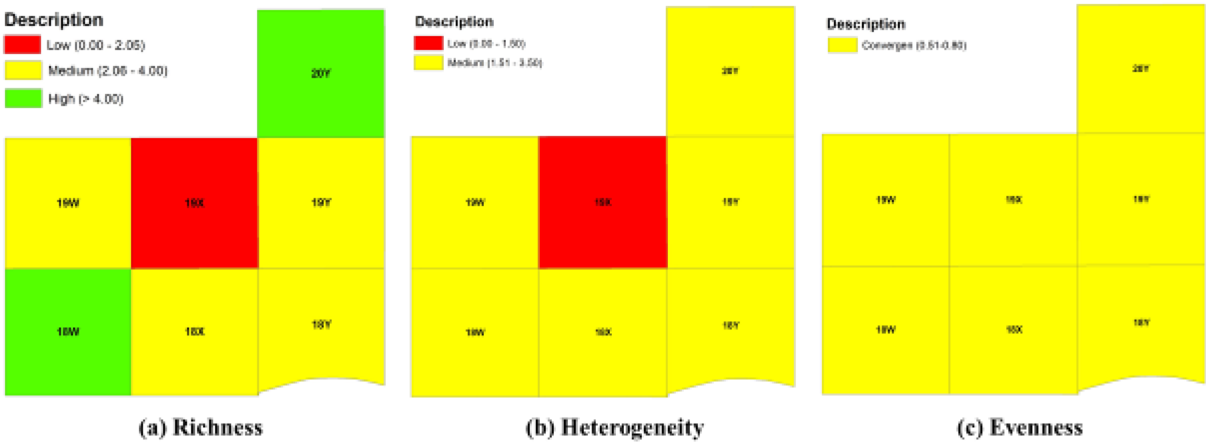

Figure 3. Comparison of species abundance, richness, heterogeneity, and evenness among compartments

Table 1. Comparison of species abundance, richness, heterogeneity, and evenness among compartments

Compartment	N species	Richness	Hetero-geneity	Evenness
18W	32	4.01	1.91	0.55
18X	31	3.79	2.10	0.61
18Y	36	4.43	2.42	0.68
19W	32	3.99	1.96	0.57
19X	30	3.59	1.84	0.54
19Y	31	3.89	1.86	0.54
20Y	4	0.38	0.81	0.58

This study recorded that the heterogeneity of vegetation in the study location was dominated by medium classes with a range of 1.51-3.50 (Table 1) (Hidayat 2013). It was similar to previous studies that documented the secondary tropical rainforests commonly had medium vegetation biodiversity (Siregar and Undaharta 2018; Murdjoko et al. 2021; Tawer et al. 2021). This condition could happen because this site was managed using a selective cutting system; thus, only certain species were maintained to support the ecological function of the forest (Butarbutar 2014). In addition, most trees with a limit diameter of more than 50 cm and having commercial values were harvested to provide better-growing space for younger trees (Matangaran et al. 2019). Therefore, this scheme was expected to stabilize the regeneration capacity of secondary forests without sacrificing its economic benefits.

Our results also indicated that species distribution in the study site was not evenly distributed. It was shown by the evenness index value ranging from 0.54 to 0.68 (Table 1). These outcomes signified that most species in this location grew in groups (Hussain et al. 2012). It was not surprising since Dipterocarpaceae families dominated most species in secondary tropical rainforests. Many studies explained that these families naturally live in groups and have a specific preference for their habitat (Purwaningsih 2004; Hadi et al. 2019; Sari et al. 2019).

According to the results, it was seen that vegetation diversity in the study site was still maintained well. It also implied that the forest management activity in this area fulfills the principle of sustainability by minimizing the risk of biodiversity loss. However, the effort of enrichment planting is required to improve biodiversity in the compartment with low diversity level. This scheme will also facilitate the conservation of native species from the secondary tropical rainforests.

Timber production

Summarized observation results documented that timber production in the study area ranged from 44.49±1.72 m^3 ha^{-1} to 68.32±2.69 m^3 ha^{-1} (Table 2). These values were substantially higher than the average productivity of Borneo's natural forests, ranging from 30 m^3 ha^{-1} (KLHK, 2019). Therefore, it indicated that the secondary tropical rainforest in this area had high productivity and could still support industry development. Moreover, this study recorded that the average timber production in each compartment was relatively different, wherein the most increased timber production was found in the compartment of 19Y. These findings also confirmed our first hypothesis that timber production was highly varied between compartments in secondary tropical rainforests.

Interestingly, the compartment of 18Y only occupied the fourth position of the most productivity compartments, even though it had the highest vegetation diversity (Table 2). Our study also did not find a significant correlation between vegetation diversity and timber production (Table 3). It was in contrast to previous studies that documented a substantial effect of vegetation diversity on stand productivity in tropical rainforest ecosystems (Cai et al. 2016; Gevaña et al. 2017; McNicol et al. 2018). These findings rejected our second hypothesis that higher vegetation diversity significantly increases timber production in the study site. However, several kinds of literature also found a similar outcome to ours wherein there was no significant relationship between vegetation diversity and forest productivity (Belote et al. 2011; Bravo-Oviedo et al. 2021). In this context, forest ecosystems may have diverse patterns regarding the connection between biodiversity and productivity.

Forest ecosystems in the study site had high productivity since their vegetation was dominated by trees with a diameter of more than 50 cm (Figure 4). On another side, the frequency of trees with a diameter lower than 20 cm was only around 2%. These indicated there was sufficient stock of timber production for selective cutting. Moreover, the relative contribution of non-commercial species to total timber production was considerably lower than commercial species (Figure 4). It demonstrated that the current standing stock had high economic value. These results confirmed our third hypothesis that commercial species' relative contribution to stand productivity was higher than non-commercial species. Although this site had increased productivity, forest managers should be careful to determine the quantity of annual allowable cutting (AAC) since the implementation of timber extraction can be impacted young trees' regeneration. Most importantly, the process of timber extraction should not harvest trees that generate seeds for maintaining natural regeneration.

Carbon storage

Carbon storage in each compartment varied, wherein the carbon stock in the study site ranged from 20.76±0.93 t ha^{-1} to 38.74±1.79 t ha^{-1} (Table 2). The highest CO_2 absorption was recorded in the compartment of 19Y by around 142.17±6.56 t ha^{-1}. In addition, the relative contribution of commercial species on carbons stock was considerably higher than species non-commercial (Figure 5). It was possible since the percentage of trees with a diameter of more than 50 cm in commercial species was higher than species non-commercial (Figure 4). These findings directly verified our first and third hypotheses in this study. However, similarly to timber production, our study did not find a significant effect of vegetation diversity on carbon storage in this area (Table 3).

Table 3. Correlation between diversity indicators and stand productivity parameters

Diversity parameter	Productivity parameter	
	Timber production	Carbon Storage
Richness	0.123^{ns}	0.420^{ns}
Heterogeneity	0.116^{ns}	0.442^{ns}
Evenness	-0.056^{ns}	0.098^{ns}

Note: ns: non-significant based on correlation test

Table 2. Comparison of timber production, biomass accumulation, carbon storage, and CO_2 absorption among compartments

Compartment	Timber production (m^3 ha^{-1})	Biomass accumulation (t ha^{-1})	Carbon stock (t ha^{-1})	CO_2 absorption (t ha^{-1})
18W	44.49±1.72	45.13±2.02	20.76±0.93	76.18±3.40
18X	56.05±2.05	68.35±2.85	31.44±1.31	115.38±4.81
18Y	54.3±2.43	69.25±3.74	31.86±1.73	116.92±6.32
19W	45.56±1.86	48.83±2.42	22.46±1.12	82.44±4.08
19X	54.96±1.55	67.11±2.44	30.87±1.12	113.29±4.11
19Y	68.32±2.69	84.22±3.89	38.74±1.79	142.17±6.56
20Y	50.57±2.30	46.37±2.36	21.33±1.09	78.29±3.98

The accumulation of carbon storage in forest ecosystems has a positive relationship with stand productivity. Higher stand productivity increases carbon stock since it was generated from photosynthesis (Cai et al. 2016; Brancalion et al. 2019; Alam et al. 2022; Wirabuana et al. 2022a). A study reported the average carbon stock in tropical rainforest ecosystems was 51.18 t ha^{-1} (Butarbutar et al. 2019). This value is higher than carbon storage in the study site. However, this study's carbon stock measurement is still limited to the tree level. We still have not quantified the carbon stock in other life stages like poles, saplings, seedlings, and understorey. Thereby, the actual carbon storage in the study area may be higher than the current estimation. It is also essential for forest managers in the study location to consider the quantity of carbon stock as the additional value of sustainable natural resources management.

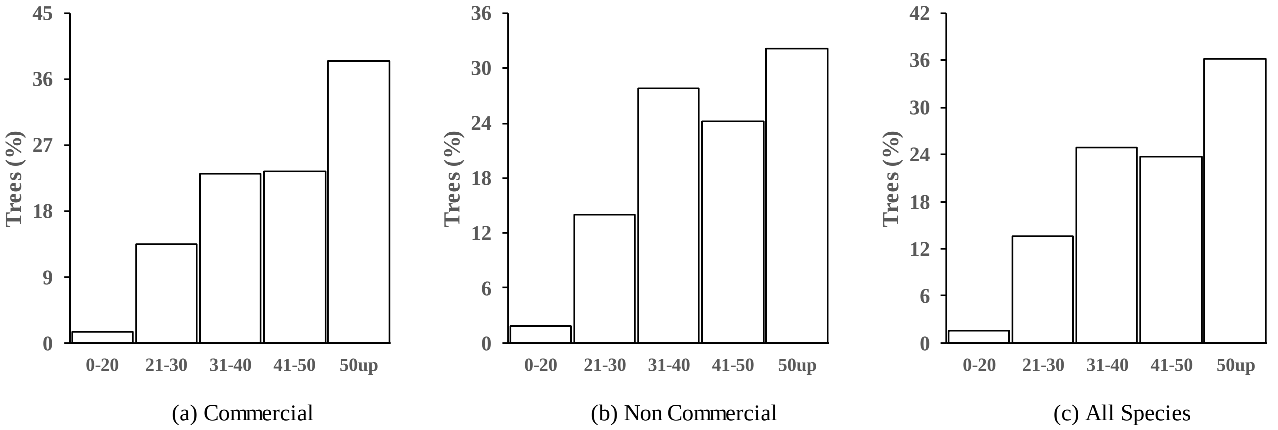

Figure 4. Diameter distribution of tree species in the study site

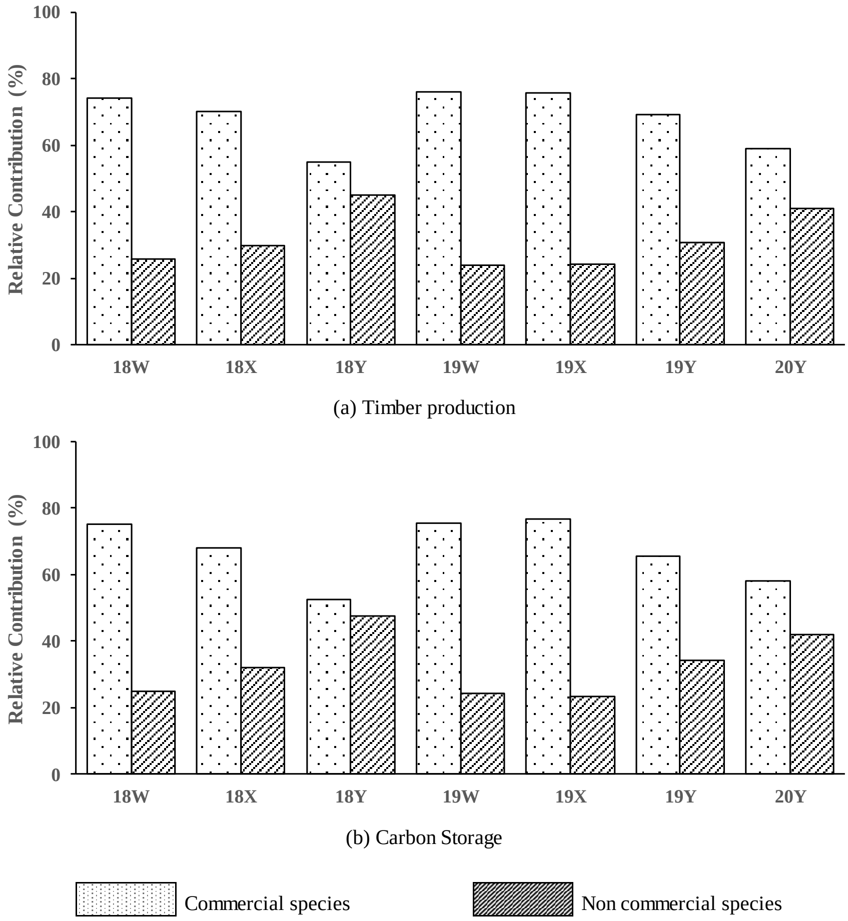

Figure 5. The relative contribution of commercial and non-commercial species on timber production and carbon storage

Implication results

This study concluded that the secondary tropical rainforest ecosystems in the study site had good vegetation diversity, timber production, and carbon storage. Furthermore, it indicated that forest managers had applied sustainability principles in the context of operation scale. Nevertheless, some improvements are still required to increase the value of forest management on this site. Besides conducting enrichment planting in the compartment with low biodiversity levels, we also suggest forest managers determine the scheme of yield regulation to minimize forest disturbance due to the impact of harvesting operations. Furthermore, the cutting process has a high potential to decline regeneration capacity since the felled trees will override the younger plants like seedlings and saplings.

We also suggest forest managers identify the distribution of mother trees in their concession area for obtaining seed as plant material in artificial regeneration. The seed collection is also essential to maintain the genetic diversity in this area. On another side, it is also necessary to document the carbon dynamics during the rotation periods, including loss and increment, since it will provide comprehensive information about forest management's effectiveness in tackling the climate change mitigation issue. We also encourage forest managers in this area to share their knowledge with other natural resources managers who fail to manage the secondary tropical rainforest ecosystems. It is highly required since forest ecosystems play an essential role in economic development, climate change mitigation, and biodiversity conservation. They have a strategic position in hydrological cycles related to food security and natural disaster.

ACKNOWLEDGEMENTS

The authors address our appreciation to the management of PT. Aya Yayang Indonesia, who allows us to conduct this study in their concession forest area. We are also grateful to the Faculty of Forestry, Lambung Mangkurat University, Indonesia, which provides a surveyor team to help with forest inventory. Finally, the authors also thank the anonymous reviewer who offers suggestions to improve this article.

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