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Above Ground Carbon Stock across Different Land Use Types in Central Kalimantan Indonesia – First Step Toward Redd Implementation

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ABSTRACT

Climate change is one of the most critical threats to the human population and other living organisms on Earth. REDD+ is developed as a mechanism to acquire a global fund for addressing climate change, deforestation, and protecting the forest ecosystem while maintaining the livelihood of local communities. As a response to the need for carbon stock measurement at the specific forest and land-use types, this research aimed to estimate the above-ground carbon stock at seven land-use types in KPHP (Forest management unit) Katingan Hulu Central Kalimantan Indonesia. This research was conducted from May to September 2019. The data collected in 91 observation plots included diameter at breast height, total height, and fresh weight of understory vegetation and litter. Using an allometric equation, this research estimated the above-ground carbon stock in trees, understory vegetation, and litter. It was found that AGC varied across different land-use types: secondary peat forest 135.30 Mg C/Ha, secondary forest 212.19 Mg C/Ha, shrub 47.41 Mg C/Ha, oil palm plantation 73.76 Mg C/Ha, rubber plantation 65.56 Mg C/Ha, and forest with rattan 75.98 Mg C/Ha. It was concluded that AGC in KPHP Katingan Hulu varied according to the type of land use system. The forests with less human intervention, such as secondary forests, had higher AGC compared with highly disturbed forests such as shrubs. The findings from this research could help decision-makers to develop the REDD programs to rehabilitate forests and contribute to community development.

Keywords: climate change, above-ground carbon stock, land use types.

INTRODUCTION

Increasing requirement for land, energy, and food as a result of the exponential growth of the human population causes the pressure on natural resources. As further consequences, natural ecosystems including forests have deteriorated and lost their capability to preserve biodiversity as well as deliver ecosystem services, including fresh water, food, aesthetic value, and climate regulation. Thus, conservation of natural resources and sustainable development should be prominent strategies in this challenging era (Deguignet et al., 2017; MEA, 2005; van de Perre et al., 2018).

Climate change is one of the most critical threats to the human population and other living organisms on Earth (MEA, 2005; van de Perre et al., 2018). In their recent studies, NOAA recorded 100 times the acceleration rate of carbon accumulation in the atmosphere in the 21st century (NOAA, 2016). The main causes of climate change include massive forest clearing, especially in tropical forests, agriculture and plantation expansion, as well as the use of fossil fuels (Hansen et al., 2009). Besides climate change, the impact of deforestation also covers the loss of biodiversity, disrupted biological function, and ecosystem change (Foley et al., 2011; Zaki et al., 2018).

Conserving and maintaining carbon stock in tropical forests become increasingly important in addressing climate change, conserving biodiversity, and poverty alleviation (Darmawan et al., 2022; van de Perre et al., 2018; Qirom et al., 2021). Focusing on the conservation of tropical forests is a strategic action, since tropical forests are a host of enormous biodiversity and sequestrated considerable carbon dioxide (Marshall et al., 2012). Forest is a crucial carbon repository, annually sequestering approximately 1.7 ± 0.5 Pg C and storing 360 Pg C in aboveground biomass and necromass (Lorenz and Lal, 2010). Some studies suggested that the loss of forest cover contributed to 6–7% of global carbon emission (Baccini et al., 2012; Wood et al., 2019). In addition to climate change issues, loss and deforestation are also connected to poverty and food security problems. Tropical forests are mostly located in developing countries where the majority of the communities have low income, highly depend on forests, and are marginalized. All these issues should be taken into account in developing climate change mitigation and adaptation programs (Djalante et al., 2021; Oldekop et al., 2019; Roe & Elliott, 2010; White & Martin, 2002).

Considering the important role of forests, the global community developed initiatives as a means of protecting carbon stock and biodiversity. For instance, The United Nations Framework Convention on Climate Change (UNFCCC) and the Convention on Biological Diversity generate funding from the global community to support natural resource conservation and mitigate climate change (Convention on Biological Diversity, 2011; van de Perre et al., 2018). In particular, REDD+ (Reducing Emissions from Deforestation and Forest Degradation) was developed as a mechanism to acquire a global fund for addressing deforestation, protecting forest ecosystem and carbon emissions while maintaining the livelihood of local communities (Brofeldt et al., 2014; Harada et al., 2015). As a carbon payment scheme, REED+ collected funding from emitter countries or companies to compensate countries or communities for maintaining their forest or other carbon sinks (Brown, 2013; Gardner et al., 2012; Marshall et al., 2012).

The demand for carbon credit is predicted to increase in the future, reaching USD 150 billion/year by 2050 (Wensing, 2021). However, the implementation of REDD+ is complex and requires a cost-effective and reliable method for carbon accounting (Angelsen et al., 2018; Pham et al., 2021). In Indonesia, the national strategy for REDD+ was enacted in 2012 and Environmental Fund Management Agency was formed in 2019 (Dwisatrio, 2021).

A reliable method of measuring carbon stock is an essential component of REDD+ (Darmawan et al., 2022; Gardner et al., 2012). Carbon stock is a function of integrated several factors including time, plant growth, plant mortality, and also anthropogenic and natural disturbances (Houghton, 2000). Estimating the carbon stored in the forest is useful because carbon stock is an indicator of forest productivity. In complete forest carbon stock measurement, there are five carbon pools: above-ground carbon biomass, below-ground biomass, necromass, and soil biomass. Among those five carbons stock pools, above-ground biomass (AGB) contributes to the largest carbon stock in the forest. Forest carbon stock in general is also influenced by forest type (e.g. peat swamp forest, dryland forest, and lowland forest) (Manuri et al., 2016; Marshall et al., 2012).

As a response to the need for carbon stock measurement at specific forest types, this research aimed to measure and calculate the above-ground carbon stock at seven land-use types in KPHP (Forest management unit) Katingan Hulu Central Kalimantan Indonesia. The information from this study could help decision-makers to develop the strategies, initiatives, and policies to conserve forests and contribute to the poverty elevation of communities around the forest. The carbon stock information along with biodiversity information, could promote the designation of the High Conservation Value (HCV) area. Above Ground Carbon (AGC) is also fundamental for designing and realizing the REDD scheme in Indonesia.

METHOD

Research site

This research was conducted from May to September 2019 at Production Forest Management Unit (KPHP) Katingan Hulu, Central Kalimantan Indonesia (Figure 1). Carbon stock measurement was focused on an area with a designated purpose where KPHP Katingan Hulu has full management rights (Wilayah Tujuan Khusus/WITU). KPHP

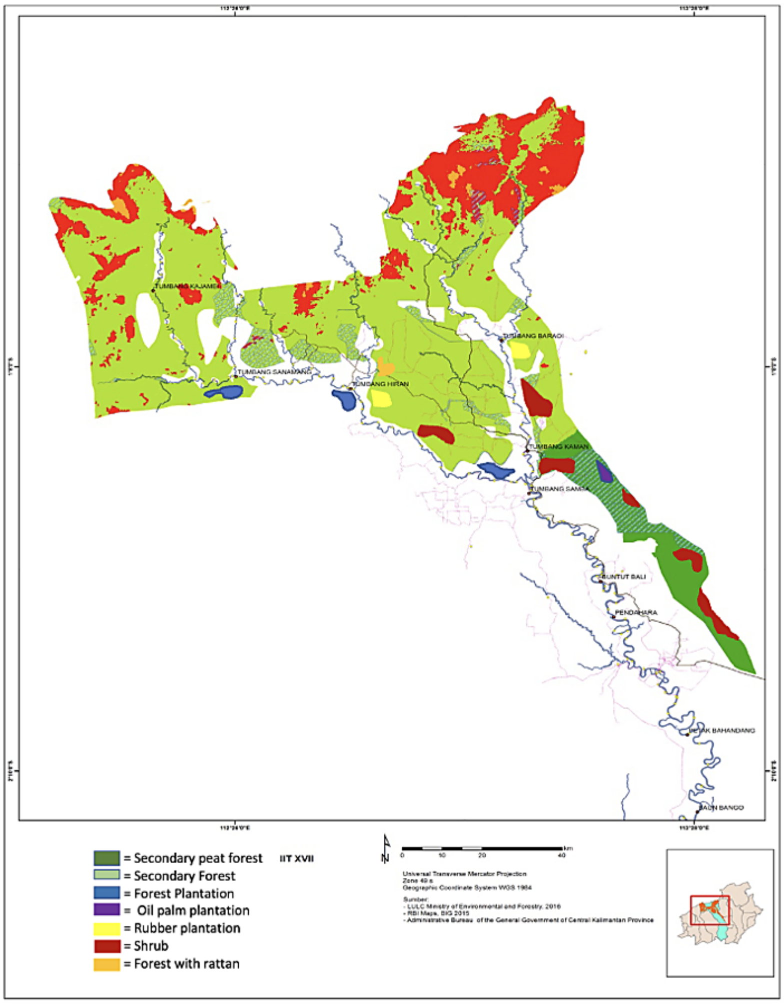

Figure 1. Map of research location

Katingan Hulu is located at 112˚00'51" BT–113˚ 36'19" EL and 0˚ 26'35" SL – 1˚ 55'10" SL. These areas are included in three regencies (Katingan, Kota Waringin Timur, Gunung Mas) and one capital city (Palangka Raya). KPHP Katingan Hulu covers an area of ± 711.379 Ha and received legal status from the Ministry of Forestry (MoF) through degree No. 2/Menhut-II/2012. In managing this area, KPHP Katingan Hulu collaborates with concession companies, universities, NGOs and local communities.

Forest in this area is classified as a humid tropical forest with rainfall ranging between 1,526 mm/year and 3,063 mm/year, with an average wet month reaching 7 months. The average daily temperature is 28.5 °C and the daily humidity reached 87%. The majority of KPHP Katingan Hulu area is hilly (north part) and about 25% is a flat low land area (south part) South part of the area is lowland and covered by secondary peat swamp forest (Ministry of Forestry and Environment, 2018). The north part of the area is characterized by hilly landscapes and is typically covered by dry land and secondary forests (Central Statistic Agency, 2021).

The communities around the forest are dominated by Dayak Ethnic and a small proportion of Java and Banjarnese ethnic. They engage in rubber plantation, shifting cultivation, hunting, logging, artisanal mining, and collecting Non-Timber Forest Products (NTFP) as their main livelihood. Recently, they also began cultivating oil palm, as many oil palm plantation companies expand rapidly in Central Kalimantan (Central Statistic Agency, 2021). Traditionally, local communities prepare their land for plantation using slash and burn and this method has been banned because it frequently causes forest and land fire.

Data collection and analysis

The estimation of above-ground carbon stock at KPHP Katingan Hulu was designed into five steps as presented at Figure 2.

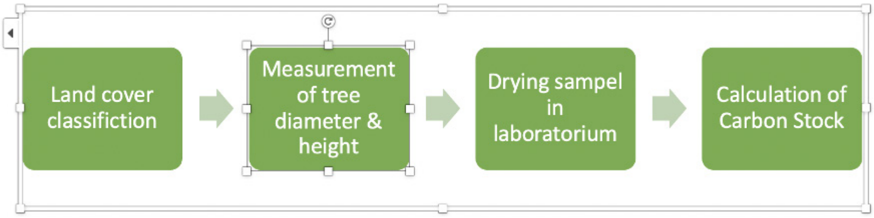

Figure 2. Data collection and analysis procedure

Land use classification

To obtain data from the various conditions at the research site, the research setting was classified based on land cover type. Using the 2018 land cover map, the study area was categorized into seven land cover types: secondary peat forest, secondary dryland forest, plantation forest, shrub, oil palm plantation, rubber plantation, and forest with rattan. Each land cover type has a specific vegetation density that may influence the above-ground carbon stock. The present research employed clustered 400 m^2 measurement plot. The number of plots from each land cover was determined proportionally, according to the large of each area. In total, tress in 91 plots or 36,400 m^2 were observed and measured. The number of plots in each land cover type is presented in Table 1.

Measurement of DBH (Diameter at Brest Height), total height, understory vegetation and litter

The procedure developed by Indonesian National Standard in carbon calculating was followed to collect data from the forest. Figure 3 presents observation plot design used in this research. Carbon stock estimation in this research was generated using destructive and non-destructive methods. The destructive method was applied on understory vegetation, rattan, and litter, and the non-destructive method was operated on trees. The size of the measurement plot is 20×20 m. Within this measurement, all trees with a diameter at breast high (DBH) of more than 5 cm were measured. The data collected included DHB, total height, as well as local and scientific names. Within the 20×20 m observation plot, four 0.5×0.5 m plots were set up to collect all understory vegetation and litter. All understory was cut and weighed. The same procedure was applied for litter. As many as 100 grams of understory vegetation and litter were sampled for further analysis in the laboratories (Indonesia National Standard, 2011).

Table 1. Number of plots in each land use type

Land use type	Number of plot
Secondary peat forest	7
Secondary forest	29
Shrub	20
Oil Palm Plantation	5
Rubber plantations	5
Forest with rattan	5
Forest plantation	20

Drying sample in laboratories

The samples from the forest were then dried in the oven at 800 °C until a constant weight was obtained. Then, the samples were weighted. The biomass of understory vegetation and litter is calculated using the equation:

$$\text{weight of dry biomass} = \frac{\text{weight of fresh biomass x weight of dry sampel}}{\text{weight of fresh sample}} \quad (1)$$

Calculation of carbon stock

The biomass of trees was calculated using an allometric equation developed by Manuri et al. (2016). This equation was specifically developed for the tropical forest in Kalimantan and resulted from an improvement of a previous allometric equation (Basuki et al., 2009; Brown Sandra, 1997; Hashimoto et al., 2004). The information regarding wood specific density was obtained from ICRAF (International Centre for

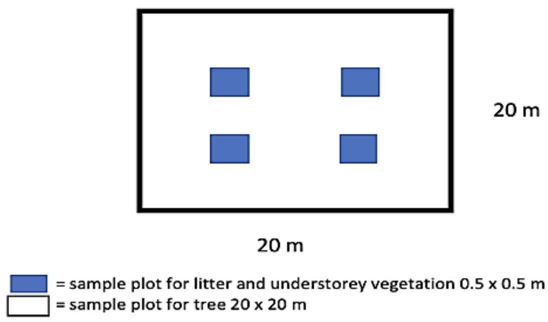

Figure 3. Observation plot design

Research in Agroforestry) wood database (http://db.worldagroforestry.org/wd).

$$DGH^{9} = 0.071\ (D^{2}GH)^{0.973} \quad (2)$$

where: DGH^{9} = tree biomass, kg; $D = DBH$, cm; G = specific wood density, gr/cm^3; H = total height, m.

Estimation of carbon stock used a default value of 0.47 (IPCC, 2006). In addition to field measurement, interviews were also conducted with local people and staff of KPHP Katingan Hulu to generate historical background and local community activities in the study area.

RESULT AND DISCUSSION

Result

In total, 3368 trees across 91 plots at seven different land-use types were measured. The total above-ground carbon stock (AGC) varies across forest types, ranging between 47 Mg/ha and 212 Mg/ha. AGC on each land use type is presented in Table 2. Secondary forests have the highest above ground carbon stock and shrubs have the lowest AGC. Besides being influenced by the density of trees, AGC is also affected by the average size of tree diameter. For example, secondary peat swamp forests have more dense trees with an average of 64 individual trees per plot (400 m^2) compared with secondary forests with 46 individual trees per plot but with a larger average diameter. However, the AGC in the secondary forest was higher than in the peat swamp forest. The higher carbon stock may be attributed to a higher average tree diameter. The average tree diameter in the secondary forest was 41.97 cm and 13.5 cm in the secondary peat swamp forest. In the study area, besides tree density and diameter size, AGC also might be influenced by the ecological disturbance, including forest and land fire and illegal logging. On the basis of an interview with local communities and staff from KPHP Katingan Hulu, the shrub area in this study suffered from a repeated forest fire. The great forest fire events in this area occurred in 1997, 2015, and 2019. As a result, vegetation in this area is dominated by fern, grass, and small trees. Picture of each land use type is presented at Figure 4.

Secondary peat forest

Peat swamp forest is situated in the south part of the study area adjacent to Sebangau National Park. This area is usually flooded in the rainy season for three until four months. Low altitude, combined with seasonal floods is enabling the formation of peat in this forest. The dominant tree species in this area include Parut (*Calophyllum* sp.), Banitan (*Polyalthia glauca*), Tumih (*Combretocarpus rotundatus*) and Madang (*Beilschmiedia glabra*). The authors identified 40 species of trees across seven plots in secondary peat forest.

The AGC stock at secondary peat forests varied from 73.55 Mg/ha to 229.05 Mg/ha with an average of 135.30 Mg/ha. The tree biomass contributes 93.37% of the total AGC, while understory vegetation and litter supplied 2.37% and 4.36% respectively. The findings of this study are consistent with the findings of other researchers. Rochmayanto (2009) found that AGC in secondary peat forests in Borneo Island ranged from 83.49 Mg/ha to 126.01 Mg/ha. The research conducted by the Indonesia Ministry of Forestry on secondary peat forests across Indonesia found an average AGC as high as 155 Mg/ha.

As a typical secondary forest, the density of trees with small diameters (10 – 20 cm) was

Table 2. AGC in each component across land use types

Forest type	Above ground carbon stock (Mg/ha)				
	Tree	Rattan	Understorey vegetation	Litter	Total
Secondary peat forest	126.31		3.21	5.78	135.30
Secondary forest	204.60		3.32	4.27	212.19
Shrub	34.29		6.40	6.72	47.41
Oil palm plantation	72.29			1.47	73.76
Rubber plantations	60.25		2.15	3.16	65.56
Forest with rattan	33.68	31.40	5.30	5.60	75.98
Forest plantation	95.05		4.62	4.74	104.41

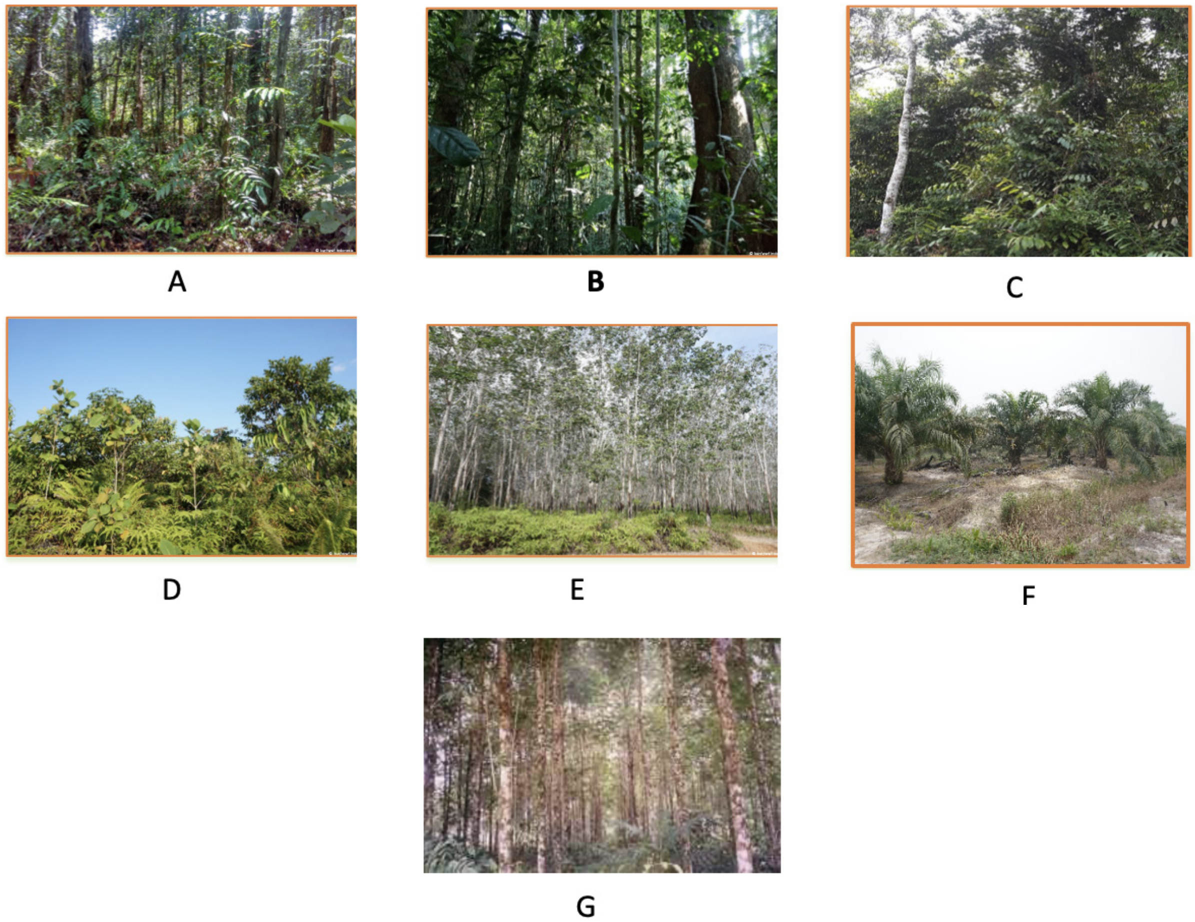

Figure 4. A – secondary peat forest; B – secondary forest; C – forest with rattan; D – shrub; E – rubber plantation; F – oil palm plantation; G – forest plantation

relatively high, which was 614 tress/Ha. The trees with a higher diameter (> 20 cm) were relatively rare, accounting for 260 tress/ha. The felling of large trees created a gap for sunlight to reach the forest floor and allow seedlings to grow.

Field observation and interviews with local communities revealed that peat forest in this area was subject to illegal logging. To fulfil their need for construction material and additional income, the locals usually cut down the trees with a diameter above 40 cm as a minimum requirement to make wooden boards. In addition, local communities also harvest non-timber forest products such as honey, fruits, and medicinal plants from the forest.

Secondary forest

Secondary forests in this research are of two types, i.e. lowland secondary forest, and highland secondary forest. Lowland secondary forest is located in the south part of the study site, adjacent to secondary peat forest. Highland secondary forest is situated in the north part which mostly is a mountain area. The authors identified 30 tree species in lowland secondary forest and 41 tree species in highland secondary forest. Lowland secondary forest is dominated by Meranti (*Shorea* sp.), Sindur (*Sindora bruggemanii*), Jambu Burung (*Syzigium* sp.), and Resak (*Vatica* sp.). Highland secondary forests are the most common species including Nyatu (*Madhuca* sp.), Meranti (*Shorea* sp.), and Keruing (*Dipterocarpus validus*). The average density of trees in both areas was measured at 1150 individuals/ha. The tree density in this forest type was lower than the density in secondary peat forests.

The AGC in the secondary forest is estimated at 212.19 Mg/Ha, ranging from 47.18 Mg/Ha to 344.17 Mg/Ha. Tree biomass supported the greatest proportion of total AGC (95.5%), followed by litter biomass (2.64%) and understory vegetation contributed 1.86%. The high variability of AGC in the secondary forest might cause by the differences in the type of soil and also the degree of human disturbances. On sandy soil usually, the tree diversity and diameter width were relatively low compared with vegetation on mineral soil. In addition, the secondary forest located near the local settlement or near road access is usually subject to logging and shifting cultivation. In the shifting cultivation system, indigenous communities commonly cleared and burned the forest and then planted paddy, vegetables, and fruits. After two or three years when the fertility of the soil decreased, the farmer will move to another place and start a new cycle. The fallow field then succeeds into a secondary forest. Most of the secondary forests in the study area were former logging concessions that operated from the 1880s until the late 1990s. This fact may attribute to the capacity of this area to maintain its biodiversity.

The estimation of AGC resulting from this research is comparable with the finding from other research on the secondary forest. Dharmawan et al., (2010) in their research in Malinau East Kalimantan found AGC stock in secondary forest as much as 171.8 Mg/ha and Rahayu et al., (2005) estimated 249.1 Mg/ha.

Shrub

The shrub is generally formed from severe forest disturbance for example total land clearing for plantations, logging with high intensity, or repeat forest fire. The opening of a total or partly forest canopy allows understory vegetation and seedling to grow. The presence of seeding or sapling from various forest tree species indicated that the shrub experiencing natural succession. Another evidence of natural succession was the presence of 40 species of trees with a density reaching 800 individual/Ha.

AGC at shrubs was the lowest, compared with other forest types in this research, which was 47.41 Mg/ha. The composition of AGB at shrubs was also different from other land-use types. At other land use types, the proportion of carbon stock stored in the tree was greater than 90%, but in the shrub ecosystem it was less than 85%. The less carbon stock stored in the tree was compensated for the increasing carbon stock in understory vegetation. The carbon sequestered in understory vegetation in other land forests covers in general approximately 5%, and in shrub ecosystems it reaches 15.75%. Open area with no restriction of sunlight to reach the forest floor resulted in well-grown understory vegetations. Carbon stock stored in understory vegetation was valued varying from 3.02 Mg/ha to 19.41 Mg/ha. The carbon stock in litter showed a similar quantity, ranging from 3.13 Mg/ha to 11.26 Mg/ha. The findings of the research conducted by the Forest Research and Development Agency in Central Kalimantan showed that in general, the carbon stock of understory vegetation and litter is below 4% and 2% of total AGC, respectively (Krisnawati et al., 2014)

The carbon stock in the shrub ecosystem in this research was higher than the result from other researchers for the same ecosystem type. In this research, the total AGC in shrubs was estimated at 47.41 Mg/Ha; meanwhile, Tosiani (2015) found 30 Mg/Ha. The higher result from this research may result from the abundant presence of seedlings from trees.

Oil palm plantation

Oil palm plantations become the most expansive plantation in Indonesia and Central Kalimantan. Fast-growing and the good price make oil palm the most profitable plantation commodity. There are two schemes of oil palm plantation, smallholder plantations that are typically under 5 ha and extensive oil palm plantations run by large companies. Oil palm plantations are usually established by cutting and clearing the forest or shrubs and then planting in a monoculture system. The mean AGC of oil palm plantations measured 73.76 Mg/ha, ranging from 67.01 Mg/ha to 77.76 Mg/ha. Fluctuation of carbon density in oil palm plantations was relatively low as a result of uniform treatment and monoculture system. The largest proportion of carbon is contained in the oil palm tree, about 98.01%, and less than 2% is sequestered in the litter. Due to intensive maintenance by using herbicide, it was hard to find understory vegetation.

Rubber plantation

Rubber (*Havea braziliensis*) is a common plantation commodity that has been cultivated by local communities for centuries. Rubber can be planted in monoculture or mixed with other plants. The combination of rubber with fruit trees and forest vegetation often forms jungle rubber or rubber agroforest. However, the rubber plantations in this research are intensive monoculture plantations where the farmer or company only planted rubber. The density of rubber trees was calculated at 575 trees/ha with an average diameter of 13 cm. Rubber plantation contained AGC 65.56 Mg/ha, which is the largest proportion saved in rubber trees (91.89%), while litter and understory stored 4.82% and 3.28% respectively. The mean carbon stock in the rubber tree showed 60.25 Mg/ha, with relatively small variation between plots.

Forest with rattan

Forest with rattan is a unique and distinctive forest type. Mostly found in the north part of the study site and near the rivers. Rattan is a climbing palm that is harvested and utilized by local communities for various handicrafts and household products. From the 1970s until the 1990s, rattan was the main NTFP and provides the main income for the locals. However, the band of rattan exported by the government made rattan no longer harvested rattan and rattan in their garden and forest are abundant (Afentina et al., 2020). The proportion of AGC in the forest with rattan is different from other land-use types. In general, the carbon stock in tree components is above 90%; however, in the forest with rattan approximately 44%. The carbon contained in rattan accounted for 41.28 and less than 20% was stored in understory vegetation and litter. On the basis of the observation, the rattan grows aggressively, the cover canopy of the tree and also the forest floor and causing the growth of tree and litter vegetation to be hampered. The tree density in this forest was 645/Ha.

Forest plantation

Forest plantation is managed by KPHP Katingan Hulu to provide construction material for industries. Sungkai (*Peronema canescens*) from the family *Verbenaceae* was the main species in the forest plantation. This species is suitable for building construction due to its properties: strong but light. Sungkai could reach 30 m in height and 60 cm in diameter. The mean diameter of Sungkai was 25 cm and the density was 546 trees/ha. Forest plantation showed AGC at 104.41 Mg/ha, with the composition 92.72% stored in trees, 4.15% restrained in understory vegetation, and 3.13% in the litter.

DISCUSSION

Regarding the management of KPHKP Katingan Hulu, the information related to carbon stock could be used as a basis for developing land rehabilitation programs. The effort to mitigate climate change is not necessarily conducted exclusively in a conservation area, such as a national park or conservation forest. In other words, increment of carbon stock can be implemented in the productive area such as forest plantations or secondary forests. For the forests where interaction with local communities is taking place, an integration conservation program with a poverty elevation program can be an alternative solution. However, finding the balance between different interests is quite challenging.

The AGC in KPHP Katingan varied between land-use types. Estimation of AGC indicates that the less disturbed forest types, such as secondary forest and secondary peat swamp forest showed higher AGC compared with the more disturbed forest types, for example plantation and shrubs. This finding is consistent with the research by Asner et al., (2017) in the Malaysian Borneo forest, the undisturbed ex-logged forest could be maintained at 60–140 Mg C/ha. The carbon stock is a function of natural processes (plant growth, mortality) and human interference (logging, plantation expansion) (Asner et al., 2018; Brown & Lugo, 1982; Houghton, 2000). The high diversity of tree species in shrub forest types indicated that natural succession, forest recovery, and carbon increment are taking place. Natural succession of ex burn area could be formed from seed that is resistant to fire or tree seed that came from the adjacent forest. Birds, wind, animals, and humans were potential seed dispersal agents that contribute to the recovery of disturbance forests. Conserving and improving carbon stock programs in forested areas in Indonesia should be integrated with poverty elevation efforts, because one of the core problems of deforestation in Indonesia is poverty. Local communities highly depend on the forest to fulfil their daily needs. Thus addressing social and economic problems is as important as technical forest management. An alternative solution for these difficulties is social forestry programs or forest community management. Through this program, local communities were given the authority to manage the forest and provide their need for food, fodder, and fore wood still maintaining the sustainability of the forest (Sunderlin et al., 2008).

The REDD+ scheme offers a new approach to maintaining and rehabilitating forests in Indonesia. However, the implementation of this scheme in Indonesia is quite challenging. The obstacles include unclear land tenure system, communities participation, corruption, lack of funding, and lack of comprehensive plans and strategies (Enrici & Hubacek, 2018)

CONCLUSIONS

The AGC across different types of land use in KPHP Katingan Hulu showed variation, ranging from 42.41 Mg C/ha to 212.19 Mg C/ha. The less disturbed area with, such as secondary forests accounted for higher AGC, and contrary, the area with severe disturbance, such as shrubs showed lower AGC.

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