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A Decrease in Carbon Absorption Potential Due to Timber Harvesting in Natural Forest

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ABSTRACT

Timber harvesting is an activity in producing wood to supply the lumber industry. However, timber harvesting brought consequences such as decreasing the carbon sequestration potential of natural forests. This study aimed to determine the reduction in the potential for carbon sequestration due to timber harvesting in natural forests. Data were collected using non-destructive methods through stand inventory before felling for all tree species, cruising results report, and tree distribution maps. Biomass was calculated using the existing allometric, and carbon stocks were calculated using the Intergovernmental Panel on Climate Change method. The results showed that there were 238 trees (65.29 m^3) of stands in the study area (6 ha) based on stand inventory before felling. The potential biomass and carbon storage before trees felling were 16.12 ton ha^{-1} and 7.58 ton ha^{-1}, respectively. The results also revealed that the potential biomass and carbon storage after tree felling were 5.15 ton ha^{-1} and 2.42 ton ha^{-1}, respectively. Carbon absorption before and after tree felling is 28.37 ton CO_{2eq} ha^{-1} and 4.44 ton CO_{2eq} ha^{-1}, respectively. Carbon emissions during tree felling was 18.93 ton CO_{2eq} ha^{-1} (81.00%). The application of environmentally friendly wood harvesting shall be carried out appropriately to minimize a decrease in carbon absorption from timber harvesting.

1. Introduction

Forests could absorb carbon in vegetation and soil and absorb CO_2 from the atmosphere through photosynthesis. However, forests also could become sources of CO_2 emissions in the atmosphere when forests are disturbed. Forest type classification is an important determinant of the above-ground biomass estimation when altitudinal and other complex environmental gradients are included (Alvarez et al. 2012). Timber harvesting has an important role in timber production, and one of the activities is tree felling. Tree felling could result in a decrease in carbon absorption. Sist et al. (2003) stated that the high intensity of logging in natural forests that exceeds 10 trees/ha could decrease carbon stocks in Indonesia's tropical natural forests. Garcia et al. (2019) reported that in the 12,924 ha of forest dominated by *Pinus hartwegii* in plantation forest, 1,695,004 MgC was contained in above-ground biomass. Garcia et al. (2019) obtained data on forest harvesting by analysis of recent cut stumps and estimated the removal of 42,701 MgC. In addition, Garcia et al. (2019) accounted for carbon in the wind-thrown trees of 14,904 MgC, some of which were removed over time in harvests. Total loss of carbon from the forest corresponded to 211,218 $MgCO_2$ per year.

Ximenes et al. (2016) stated that loss of total biomass due to timber harvesting is not considered as direct carbon loss but is seen as a transfer of carbon stock from forest to wood products. The research result of Pukkala (2018) showed that when the long-term carbon balance of forestry is maximized, the harvesting level should be low. Poudyal et al. (2019) stated that the timely harvesting of mature trees and minimal damage to neighboring plants might help to stock more carbon in harvested forest products as well as in the forest biomass.

Timber harvesting for wood products has the potential to store more carbon than conserved forests over the long term given the higher standing tree volume and long-term use of wood products (Russel and Kumar 2017), with cascading wood use extending the time of storage, which further delays contribution to the greenhouse effect (Höglmeier et al. 2015). Heinonen et al. (2017) stated that timber harvesting reduces the carbon stocks of forests compared to unharvested forests. Cardenas et al. (2018) stated that the mechanism by which harvesting can exacerbate nitrogen losses at sites predisposed to such losses, potentially lowering plant productivity and increasing greenhouse gas emissions. Based on this background, the purpose of this study was to determine a decrease in the potential for carbon sequestration due to timber harvesting in natural forests.

2. Materials and Methods

2.1. Research Location

The research was conducted in the working area of Commercial Timber Forest Products Utilization Permit of Natural Forest (HPH) PT. Inhutani I Unit Sambarata, Berau Regency, East Kalimantan, Indonesia. The study was conducted from November-January 2016.

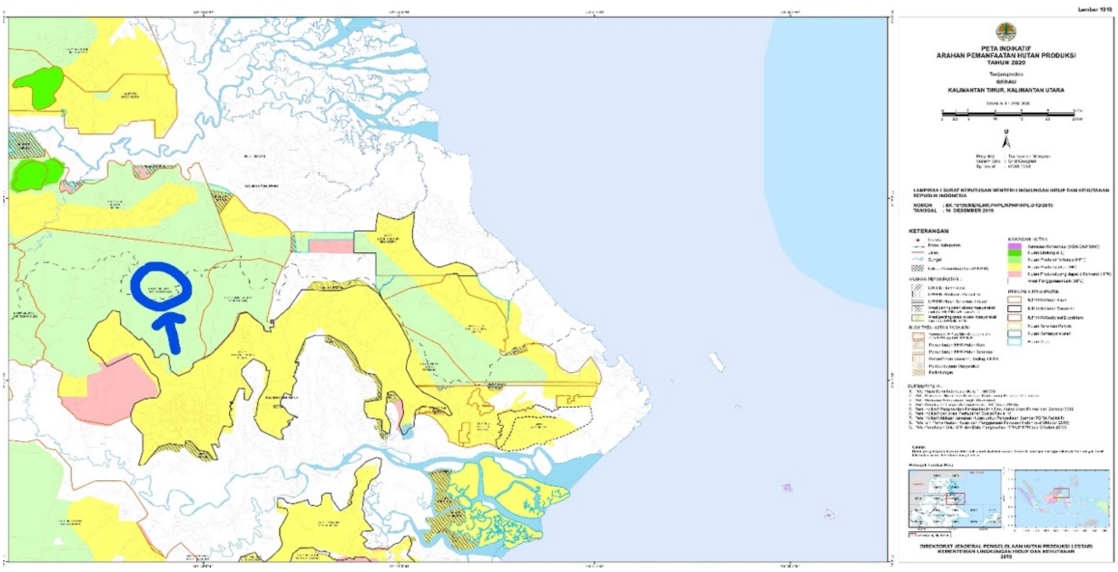

Fig. 1. The location of study.

2.2. Materials and Equipment

Materials used were trees, stand inventory before logging for all tree species, cruising results report, tree distribution maps, chalks, and paint. Equipment used were phi-band and measuring tape for measuring diameter and length of logged trees, tally sheet, clinometer for measuring slope, compass, digital camera for documentation, stationery, and machete.

2.3. Data Collection

This study used primary and secondary data. Primary data was obtained by direct observation in the field. The primary data collected were tree dimensions as diameter at breast height (DBH) and tree height. Secondary data were obtained by reviewing documents available in the research location, such as the general condition of the natural forest concession area (forest condition, position and area size, topography, climate, stand inventory before logging for all tree species, and cruising results report).

2.4. Working Procedures

In the selected logging compartments in the natural forest concession area, as many as 3 Observation Sample Plots (OSP) measuring 2.0 ha (200 m x 100 m) each, were constructed. Positions of the OSP were designed by systematic sampling with a purposive start (Kusmana 2017), where the first OSP was determined purposively in the selected logging compartment, and the next OSP was positioned systematically with a distance between OSPs of 100 m. The method used is non-destructive by direct measurement of DBH and tree height on 3 OSP. All tree species stand data on logging compartments number 339 were obtained from stand inventory before logging for all tree species, cruising results report, and tree distribution maps. To estimate the decrease in tree carbon stock and carbon sequestration obtained from the difference between the decreasing of carbon stock before logging and after logging. The estimation of the absorption of CO_2 released into the atmosphere is the result of multiplying the amount of carbon lost with the conversion factor from carbon (C) to carbon dioxide (CO_2) of 3.67 (IPCC 2006).

2.5. Data Analysis

2.5.1. Biomass calculation

Above-ground biomass (AGB) was calculated using allometric equations (Chave et al. 2005) as follows:

$$AGB\ (kg) = 0.0509 \times \rho \times D^2 \times H \quad (1)$$

where ρ is the specific gravity of wood (g/cm^3), D is the diameter at breast height (cm), and H is total tree height (m). The density of the wood used refers to a literature study according to Hairiah et al. (2011), namely 0.61 g/cm^3 in a logged-over forest.

2.5.2. Calculation of carbon stock

Carbon stock was calculated using IPCC (2006) equation as follows:

$$Carbon\ Stock\ (ton\ ha^{-1}) = B \times 0.47 \quad (2)$$

where B is total biomass (ton ha^{-1}), and 0.47 is the carbon content.

2.5.3. Calculation of CO_2 equivalent

CO_2equivalent was calculated using the following equation:

$$CO_{2eq} = \frac{44}{12} \times Carbon\ Stock \quad (3)$$

where CO_{2eq} is used to standardize the climate effects of various greenhouse gases (tonCO_2eq), 44/12 is the ratio of molecular weight of CO_2 to carbon.

3. Results and Discussion

3.1. Conditions of the Forest Stand Before and After Logging

In the study area, logging compartments number 339, the area of 3 OSP was 6 ha, with a distribution of 238 trees. The felling of 3 OSP was 30 trees. Tree species and composition at 3 OSPs before felling are presented in **Fig. 2**. Meranti (126 trees) and Keruing (56 trees) dominated the tree species in the study area (**Fig. 2**). Meranti has a diameter at breast height (DBH) of 30-80 cm with tree heights of 13-24 m, while Keruing has a DBH range of 40-60 cm and a tree height of 14-21 m (**Table 1**). The variation in the range of DBH and tree height in the study area has a high potential for carbon sequestration. Trees that dominate an area have the ability to grow large so that the size of the DBH becomes large, and in the end, it will be able to store more carbon. The stem diameter will be directly proportional to the biomass value. The greater the DBH indicated that old trees store more carbon than young trees (Istomo and Farida 2017). Kasianus et al. (2018) stated that the amount of potential carbon converted from biomass is strongly influenced by tree diameter.

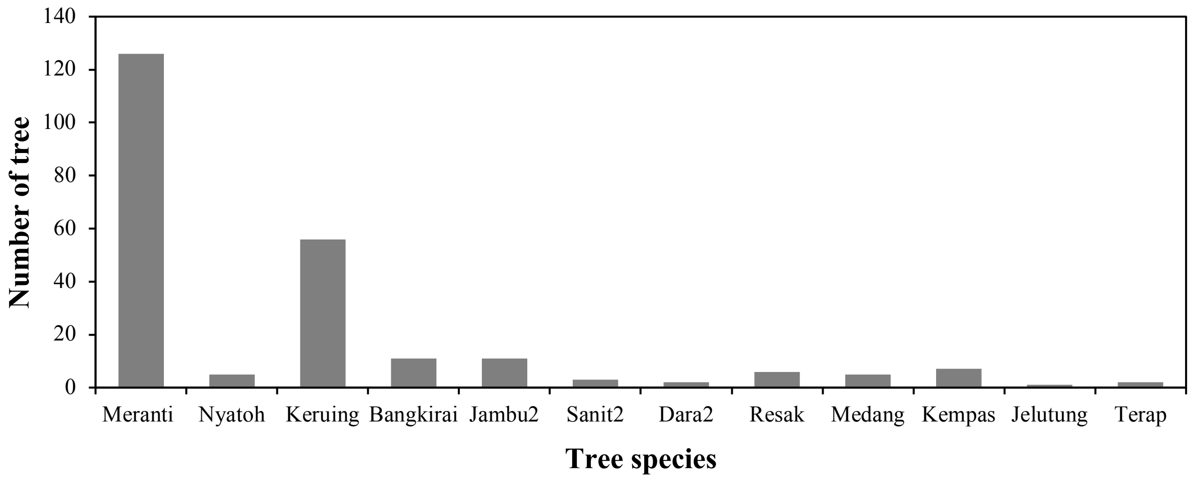

Fig. 2. Tree species and composition in the study area.

Table 1. Condition of tree diameter and height in the study area

Scientific name	Local name/ commercial name	Diameter (cm)	Height (m)
Shorea	Meranti	30-80	13-24
Palaquim sp	Nyatoh	45-60	15-19
Dipterocarpus	Keruing	40-60	14-21
Shorea laevis Ridl	Bangkirai	45-80	15-22
Syzygium	Jambu-jambu	35-70	14-17
Sanit-sanit	Sanit-sanit	40	14-14
Dara-dara	Dara-dara	40	14
Vatica	Resak	40-51	14-16
Phoebe	Medang	40-63	14-17
Koompassia excelsa	Kempas	40-56	14-16
Dyera costulata	Jelutung	60	19
Artocarpus odoratissimus	Terap	40	14-15

The tree species and number before and after felling are presented in **Fig. 3** and **Table 2**. The results showed a reduction in tree species and number after felling by 208 trees (12.61%) (**Fig. 3** and **Table 2**). This reduction results in a reduction in the potential for carbon sequestration at the study site. Superales (2016) stated that plant stems act as carbon storage produced from the absorption of air carbon dioxide with the ability to store 34% greater than leaves. As the main constituent of forests, trees require sunlight, carbon dioxide (CO_2) absorbed from the air, and nutrients and water absorbed from the soil (Lukito and Rohmatiah 2013).

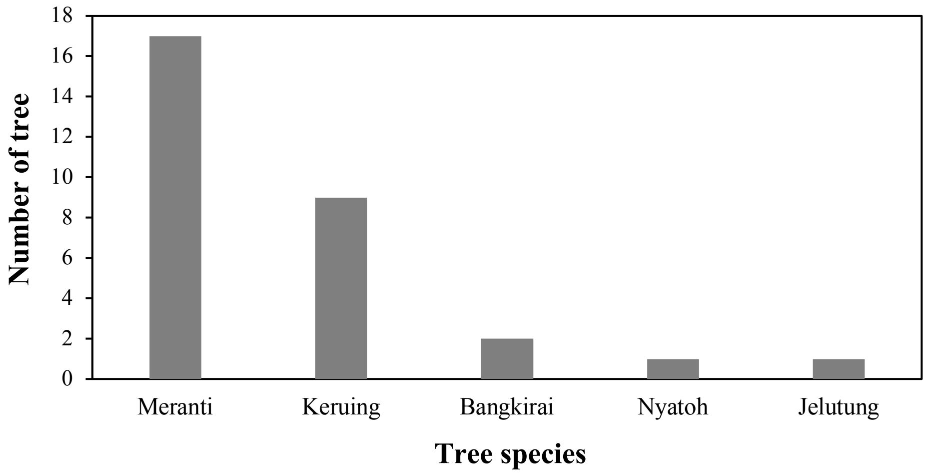

Fig. 3. The species of the felled tree.

Table 2. Number of trees before and after felling

Timber stand condition	Number of tree (tree)
Before felling	238
During felling	30
After felling	208

The average volume of logs felled at 4.92 m^3 whereas before felling was 3.26 m^3. This is because the diameter of the trees to be felled average is 60 cm with 30 trees in 3 OSP (**Table 3** and **Table 4**). The large diameter of the trees to be felled causes the volume of stands to be larger, whereas in the pre-felled condition, there is a mixture of tree diameter sizes ranging from 0.3-1 m^3. Stand volume indicates the potential for timber production in a certain area. The number of trees before felling will be reduced due to logging production activities.

Table 3. The average standing volume before felling

OSP	Height (m)	Diameter (m)	Volume (m^3/tree)
I	14.75	0.46	2.54
II	14.93	0.52	3.27
III	16.46	0.53	3.98
Average	15.38	0.50	3.26

Table 4. The average volume stands of felled

PCP	Height (m)	Diameter (m)	Volume (m^3/tree)
I	19.50	0.60	4.45
II	20.00	0.60	5.72
III	20.00	0.60	4.60
Average	19.83	0.60	4.92

3.2. Biomass and Carbon Before Felling

The tree stand biomass affects the potential for carbon storage. Maryadi et al. (2019) stated that the increase in the amount of carbon is directly proportional to the increase in biomass. The higher the amount of biomass, the higher the amount of carbon stored. The results of measurements of the potential biomass and forest stand before logging are presented in **Table 5**.

Table 5. Potential biomass before felling

	Biomass (kg)	Biomass (kg ha^{-1})	Biomass (ton ha^{-1})	C stock (ton ha^{-1})	CO_2 equivalent (tonCO_2eq)
Total	96,702.42	16,117.07	16.12	7.58	28.37
Average	406.31	16.12	0.07	0.03	0.12

Table 5 shows that there were as many as 238 trees in the study area with a total biomass of 16.12 ton ha^{-1} so that a carbon stock is obtained of 7.58 ton ha^{-1}. The high carbon stock before logging in this study was due to the high DBH of trees. DBH affects the high value of biomass. The greater the DBH CO_2 indicates more amount of CO_2 being absorbed. Previous studies (Ilyas 2011; Seto et al. 2014) revealed a close relationship between dry biomass and tree diameter variables. This is because the tree diameter grows through continuous cell division and gets slower at a certain age. This growth occurs in the radial direction of the cambium. Eventually, new cells will be formed which will increase the diameter of the stem.

Table 5 also shows that the 238 trees in the study area can absorb 28.37 ton CO_2eq of carbon. The high carbon uptake illustrates the ability of the stands in the study area to fix CO_2 which is then stored in the form of carbon stocks in tree stands. Setyowati et al. (2014) stated that the ability of plants to absorb carbon dioxide varies. Many factors affect the absorption of carbon dioxide, which is determined by the amount of magnesium that will give the leaves a dark green color. Hardjana and Fajri (2011) showed the contribution of CO_2 absorption from the atmosphere by *Shorea leprosula* plants in the IUPHHK-HA area of PT. ITCIKU ranged from 0.54 - 10.17 ton ha^{-1} CO_2, with an annual average ability to absorb CO_2 gas from the atmosphere of 0.27-1.69 ton ha^{-1}/year. Iticha (2017) showed that biomass accumulation was comparatively larger in natural forests than in plantation forests due to maturity, intactness, and species diversity. The total C storage capacity of the forest ranged from 107.12 Mg ha^{-1} for acacia plantation to 453.21 Mg ha^{-1} for the intact natural forest. Yunita (2016) showed that the increase in carbon stocks is due to the increasing age of the meranti stands. Meranti forests aged 6, 8, and 10 years are thought to be able to absorb CO_2 gas as much as 28.01 ton ha^{-1}, 172.83 ton ha^{-1}, and 274.86 ton ha^{-1}. Masripatin et al. (2010) stated that the carbon stock in various land cover classes in the natural forest ranged from 7.50-264.70 t.C.ha^{-1}.

Carbon stock in plantation forests showed by several studies. Ratnaningsih et al. (2014) showed that natural forest has a carbon stock potential of 76,651 ton ha^{-1}, shrub ecosystem of 0.973 ton ha^{-1}, and *Eucalyptus pellita* plantations of 33,706 to 70,930 tons ha^{-1}, depend on its age. Chairul et al. (2016) showed that the carbon content of plant life at the top of the primary forests was 1,359,884.68 kg ha^{-1}, logged forest 610,429.67 kg ha^{-1}, and timber mix 360,793.70 kg ha^{-1}. Rahmayanti et al. (2019) showed that the amount of carbon stocks in the biomass 2,808,363.28 ton C ha^{-1}, necromass 2004,437 ton C ha^{-1} and 560.938,5 ton C ha^{-1} in peatland. The results of several studies on carbon stocks in natural and plantation forests show that carbon stocks in natural forests are higher than in plantation forests. This is due to the high potential for stands in natural forests, especially the volume of wood in the form of diameter at breast height and tree height. The potential for carbon sequestration of a tree in natural forests is higher than in plantation forests.

3.3. Biomass and Carbon After Felling

Trees felling could affect the potential of carbon stock and CO_2 absorption. The biomass potential and carbon stock after felling are presented in **Table 6**. The results showed that there were as many as 30 trees felled, resulting in a reduction in the amount of biomass of 16.12 ton ha^{-1} to 5.15 ton ha^{-1} or a decrease of 68.05% (the amount of biomass before felling was 16.12 ton ha^{-1} minus the amount of biomass lost during felling namely 10.97 ton ha^{-1}) (**Table 6-8**). The reduction in biomass resulted in a decrease in the after-felling carbon stock of 2.42 ton ha^{-1} (68.07%). The reduction in carbon stock during logging in this study could decrease CO_2 absorption or an increase in CO_2 emissions calculated at the CO_2 equivalent (ton CO_2eq ha^{-1}) of 18.93 ton CO_2eq ha^{-1} (81.00%). CO_2 uptake by stands describes the stand's ability to fix CO_2 which is then stored in the form of carbon stocks in the tree stands.

Table 6. Biomass and carbon stock potential during felling

	Biomass (kg)	Biomass (kg ha^{-1})	Biomass (ton ha^{-1})	C stock (ton ha^{-1})	CO_2 equivalent (tonCO_2eq)
Total	65,836.30	10,972.72	10.97	5.16	18.93
Average	2,194.54	365.76	0.37	0.17	0.63

Table 7. Biomass and carbon stock potential after felling

	Biomass (kg)	Biomass (kg ha^{-1})	Biomass (ton ha^{-1})	C stock (ton ha^{-1})	CO_2 equivalent (tonCO_2eq)
Total	30,866.12	5,144.35	5.15	2.42	4.44
Average	148.39	2.47	0.02	0.01	0.02

Table 8. Percentage reduction in carbon sequestration potential

Observation	Before felling	During felling	After felling	% Decrease
Amount of tree	238	30	208	12.61
Research area (ha)	6	6	6	0.00
Amount of biomass (kg)	96,702.42	65,836.30	30,866.12	68.08
Amount of biomass (kg ha^{-1})	16,117.07	10,972.72	5,144.35	68.08
Amount of biomass (ton ha^{-1})	16.12	10.97	5.15	68.05
Carbon stock (ton ha^{-1})	7.58	5.16	2.42	68.07
CO_2equivalent (tonCO_2eq ha^{-1})	28.37	18.93	4.44	81.00

Felling activities have consequences for the loss of biomass so that the ability to absorb CO_2 is reduced. The CO_2 used by plants in the photosynthetic process will be stored in the form of biomass. If the CO_2 absorption volume is reduced, there will certainly be an additional accumulation of CO_2 in the atmosphere. Hardjana and Fajri (2011) stated that tree releases carbon into the atmosphere when it is felled. Pukkala (2017) stated that felling had a negative effect on carbon balance for about three decades compared to a no-cutting alternative. Because the net effect of cuttings is negative in the short term, a short-sighted analysis always leads to a no-cutting decision when the aim is to maximize carbon sequestration. However, this is a wrong decision in the longer term.

Several research results have studied the reduced carbon stocks and carbon emissions due to timber harvesting. Junaedi (2014) showed that timber harvesting with the TPTI silvicultural system caused carbon loss of 80.94 ton CO_2/ha/year and CO_2 emissions released into the atmosphere of 297.02 ton CO_2 h^{-1}/year. Wayan (2011) reported the average potential carbon storage of 114.14 ton C ha^{-1}. After the timber harvesting activity was carried out, the potential carbon emission was 34.53 tons C ha^{-1}, or a reduction in carbon storage of 30.25%. This potential carbon emission derived from carbon due to harvesting trees of 27.64 ton C ha^{-1} and carbon loss due to tree damage caused by timber harvesting is 6.89 ton C ha^{-1}. Firma and Rusolono (2012) stated that timber harvesting activities were potentially releasing carbon into the air from tree stands that are heavily damaged with an average of 46,74 ton C ha^{-1} or 38,90% of potential carbon stocks prior to harvesting timber.

The reduction in carbon absorption due to timber harvesting could be minimized if the application of reduced impact logging (RIL) in the field is implemented correctly and appropriately. In addition, the application of RIL could reduce the amount of felled waste produced to minimize CO_2 emissions. Ceruttia et al. (2017) stated that FMPs showed substantial opportunity to reduce carbon emissions from forests while presenting logging companies with acceptable financial trade-offs. Sustainable production of natural forest management can reduce carbon loss by 90,521 ton C $year^{-1}$, reduce CO_2 emissions due to tree/stands damage by 39%/year (Fitri 2013).

4. Conclusions

Timber harvesting could contribute a negative effect in reducing carbon stocks by 2.42 ton ha^{-1} or a 68.07% decrease in comparison to the condition before felling. A decrease in carbon stock brought consequences in the decreasing ability of these areas to absorb CO_2. A decrease in CO_2 absorption due to felling in the study area was 81.00%. Therefore, timber harvesting activities must be carried out following the principles of reduced impact logging (RIL) to reduce the occurrence of carbon stock decrease and the decrease in the ability of forests to absorb CO_2.

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