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Estimation of Carbon Stock of Red Meranti (*Shorea leprosula* Miq.) Stands at Natural Forests Applying Intensive Silviculture in Indonesia

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Abstract : One of the forest functions in protecting climate changes was through a carbon sink; vegetation in the forest absorbs carbon dioxide gas through photosynthesis process and keeps the gas in a biomass form. Carbon stock in the red meranti (*Shorea leprosula* Miq.) stands and the capacity of the species to absorb carbon dioxide (CO_2) gas was not sufficiently studied. The objectives of the research were to analyze the amount of (1) carbon stock in the red meranti stands at different ages, (2) carbon dioxide gas absorbed by the red meranti stands, (3) the economic value of the carbon stock in the red meranti stands. The results showed that total carbon stock in the red meranti stands increased with age. Total carbon stock in the red meranti stands with the age of 6, 8, and 10 years was 7.63 tons/ha, 47.10 tons/ha, and 74.89 tons/ha respectively. The average increase of carbon stock in the red meranti was 16.82 tons/ha per year. Red meranti stands with the age of 6, 8, and 10 years could be expected to absorb carbon dioxide gas as amount of 28.01 tons/ha, 172.83 tons/ha, and 274.86 tons/ha respectively. At a price of US$6, carbon stock in the red meranti stands with the age of 6, 8, and 10 years was worth US$168.04/ha, US$1,037.14/ha, and US$1,649.17/ha respectively.
Key words : Red meranti stand, carbon stock, CO_2 absorption.

Introduction

Planting forests are one of ways to reduce gas emission by increasing carbon (C) stock in vegetation in the biomass form. To support the program, the government of Indonesia has supported the REDD+ (Reducing Emission from Deforestation and Forest Degradation Plus) scheme as an international mechanism to provide incentive to the countries that are successful to reduce gas emission from deforestation and forest degradation. In this case, the Ministry of Forestry of Indonesia has established several Forest Management Units in Indonesia, one of which is at PT Inhutani II in South Kalimantan, Indonesia with the size of areas was about 12,000 ha. The activity included in the project was the application of intensive silviculture by planting red meranti (*Shorea leprosula* Miq.) species. The species is one of species included in *Dipterocarpaceae* family dominationg tropical forests in Southeast Asia including Indonesia. The intensive silviculture combined three components: species improvement, environment manipulation, and integrated pest control.Carbon stock in the red meranti stands and the capacity of the species to absorb carbon dioxide (CO_2) gas was not sufficiently studied.

The objectives of the research were to analyze the amount of (1) carbon stock in the red meranti stands at different ages, (2) CO_2 absorbed by the red meranti stands, (3) the economic value of the carbon stock in the red meranti stands. The significance of the study was to provide information to the government, the management of the state company (PT Inhutani II), and related institutions regarding carbon stock, absorbed CO_2 and economic value of the carbon stock at the red meranti stands.

Method

Place and time of study

The study was conducted at the location of the Establishment Project of Meranti Forest Management Unit (PMFMU) at PT Inhutani II Pulau Laut, South Kalimantan Province, Indonesia. Geographically, the location is situated at 3º37' – 3º45' South Latitude and 116º5' – 116º15' East Longitude. The study was conducted for 6 months, from March to September 2014, including the study preparation, data gathering, and report.

Objects and Equipment

The objects used in this study were:

1. Biomass of plants (trees, poles, saplings, and undergrowth or shrubs). Measurement of the biomass for trees was done with a non-destructive method, while measurement for the undergrowth or shrubs was done with a destructive method.
2. Necromass or dead organic matter was divided into two groups: woody necromass and non-woody necromass. Woody necromass was all biomass from dead trees, either standing dead trees, lying dead wood, or those underground with diameter > 10 cm. Non-woody necromass was all biomass from growing plants with diameter from > 2 mm to ≤ 10 cm.
3. Organic matter of soil (the remains of living creatures that have undergone decomposition), that is, all organic matter of soil in the depth of 30 cm, including roots and fine litter with diameter <2 mm.

Equipment used was:

1. GPS for determining the coordinate of the observation plots
2. Plastic rope for marking the observation plots
3. Phiband for measuring tree diameter
4. Soil ring samplers for collecting soil samples
5. Meter tape for measuring the observation plot
6. Woody quadrant with a size of 0.5 m x 0.5 m for marking the spots of colleting biomass and necromass of undergrowth/shrubs
7. Knife/scissors for collecting biomass samples from undergrowth
8. Plastic label for labeling each sample
9. Electric oven for drying biomass samples
10. Scale for weighing object samples
11. Tally sheet for recording observation data in the field
12. Calculator and computer for processing data and preparing reports
13. Stationery for recording Data
14. Laboratory equipment for analyzing carbon contents of samples.

Study Procedures

1. Data gathering

a. Determination of plots and samples

The Meranti Forest Management Unit of PT Inhutani II Pulau Laut has three compartments on the basis of three planting years: 2003, 2005, and 2007. At each compartment was made three observation plots with a size of 3 m x 50 m each.At each observation plot was observed 14 trees of red meranti. So, there were 42 trees (3 x 14) at each compartment and 126 trees (42 x 3) for the three compartments. Furthermore, at each compartment was taken four soil samples, so there were 12 soil samples analyzed for the study. For necromass and litter, two samples were taken from each observation plot, so there were 18 samples analyzed for the entire study area.

b. Biomass measurement[1]

1. Tree biomass measurement was done by measuring the diameter of plants (trees, poles, saplings). Then the diameter data were entered into the allometric equation.
2. Undergrowth biomass measurement was done with activities: sample spots were taken from each observation plot using a woody quadrant with a size of 0.5 m x 0.5 m. In this step, all undergrowth in the quadrant was cut over. Biomass of each quadrant was put into polybags and labeled according to the spot code. Total wet weight of the undergrowth was weighed. To measure dry weight of the undergrowth, 100 g of the wet weight was weighed and then put in an oven until a constant weight was reached. Then the dry weight of undergrowth was weighed.

c. Necromass measurement[1]

Woody necromass was measured at observation plots with a size of 3 m x 50 m with steps: (a) to measure diameter and length/height of all woody necromass that were standing and lying, (b) to calculate dead trees with the equation (Geometric method):

$V_{dt} = \frac{1}{4}\pi\,(dbh/100)^2 \times h \times f$

Note:

V_{dt} :Volume of dead trees (m^3)

dbh : Diameter at breast height (cm)

h : Height of dead trees (m)

f : Form factor = 0.6.

For measuring dead tree biomass, diameter was measured at the base and end of stem, and then the volume was measured using the Brereton system:

$$V_{dti} = 0.25\,\pi\left(\frac{bd + ed}{2 \times 100}\right)^2 \times l$$

Note:

V_{dti} :Volume of dead trees (m^3)

bd :Base stem diameter of dead trees (cm)

ed :End stem diameter of dead trees (cm)

l :Length of dead trees (m)

π : 22/7 or 3,14.

Organic matter or biomass of dead trees was calculated with the equation:

B = V x SG

Note:

B :Biomass of dead trees (kg)

V :Volume of dead trees (m^3)

SG :Specific gravity of dead trees (kg/m^3).

Collecting samples for coarse and fine litter at each compartment was done at the same spots of undergrowth samples. Collecting samples for coarse litter was conducted after collecting samples for undergrowth samples followed by collecting samples for fine litter. Further procedures were the same as the undergrowth ones.

d. Soil organic mattermeasurement[1]

Measurement of soil organic matter was done as follows: (1) collecting soil samples at the 5 spots in the observation plots, that is 4 samples at the 4 ends of the observation plots and one in the middle of the three observation plot at the same planting year of red meranti. Soil samples with a composite method by mixing soil samples from the five spots collected at different depth (0-5 cm, 5-10, 10-20 cm, 20-30 cm). Soil samples were taken using soil sampler rings with diameter of 5 cm. weighing wet weight of the soil samples, and then dried the soil samples out and weighed them. Final step was to analyze the specific gravity and soil organic carbon that was done in the laboratory.

2. Analysis

a. Carbon stock calculation

1) Tree biomass calculation

Tree biomass was obtained by entering tree diameter data into the equation that has been developed by previous researchers. Specific gravity of wood was taken from literature.

Allometric equation from the correlation between diameter (D) and total biomass of red merantitrees used was the allometry[2] that had the highest R^2:0.067 $(D)^{2.859}$ (R^2= 0.997 ; SE = 0.109).

Note:
D : Diameter of trees/poles/saplings
R^2 : Coefficient correlation
SE : Standard error of estimate.

2) Calculation of organic matter of necromass (litter, dead wood, and dead trees)[1]

$$Ow = \frac{Dw \times TW}{Ww}$$

Note:
Ow :Organic matter weight (kg)
Dw :Dry weight of samples (kg)
Tw :Total wet weight (kg)
Ww :Wet weight of samples (kg)

b. Carbon calculation

1) Carbon of biomass was calculated with the formula[1]:

Cb = B × % Organic C
Note:
Cb :Carbon content of biomass (kg)
B :Total biomass (kg)

% organic C : Percentage of carbon content using percentage carbon values based on the measurement results from the laboratory.

2) Carbon calculation of dead organic matter (litter, dead timber, and dead trees) was done using the formula[1]:

Cd = Bo × % organic C
Note:
Cd :Carbon content of dead organic matter (kg)
B :Total biomass/organic matter (kg)

% organic C : Percentage of carbon content using percentage carbon values based on the measurement results from the laboratory.

3) Carbon calculation of soil carbon used the formula[1]:

Cs = D × p × % organic C
Note:
Cs :Carbon content of soil (g/cm^2)
D :Depth of soil samples (cm)

p : Bulk density of soil (g/cm^3)

% organic C : Percentage of carbon content using percentage carbon values based on the measurement results from the laboratory.

4) Calculation of total carbon stock in the plots[1]

Cplot = Cboss+ Cbuss + Cbl + Cdt + Cdtr + Cs
Note:
Cplot :Total carbon content at plots (ton/ha)
Cboss:Total carbon content of biomass on the soil surface per ha at plots (ton/ha)
Cbuss:Total carbon content of biomass under soil surface per ha at plots (ton/ha)
Cbl :Carbon content of biomass of litter per ha at plots (ton/ha)
Cdt :Carbon content of dead timber per ha at plots (ton/ha)
Cdtr :Carbon content of dead trees per ha at plots (ton/ha)
Cs :Carbon content of soil per ha at plots (ton/ha).

5) Calculation of carbon dioxide (CO_2) absorption used the formula[2]:

$$
\begin{aligned}
W_{CO2} &= Rm.CO_2/Ra.C \times W_{tc} \\
&= 44/12 \times W_{tc} \\
&= 3.67 \times W_{tc.}
\end{aligned}
$$

Note:
W_{CO2} : Amount of CO_2absorbed (ton)
W_{tc} : Total carbon content of certain species and age of stands (ton/ha)
Rm :Relative molecular mass, C=12 and O=16, $CO_2 = (1 \times 12)+(2 \times 16)=44$
Ra :Relative atomic mass, C=12.

6) Economic calculation of carbon

Some assumptions used in the previous studies were used for economic calculation of carbon in the present study. It was estimated that compensation values of forest capacity to absorb carbon was about US$5 up to US$20 per hectare[3].Another assumption is that the economic value of carbon was calculated using the economic value approach from the REDD project for a life time of 5 years. The REDD project payment was done with a full payment mechanism at the beginning of the project (*ex-ante full credit*). Carbon price used was hypothetical price[4], that is:US$6, US$9, and US$12per ton of carbon dioxide equivalent (CO_{2}-e).

Results and Discussion

1. Carbon in trees

The amount of carbon stock in the red meranti stands at year 6, 8, and 10 was 0.54 tons/ha, 35.32 tons/ha, and 65.21 tons/ha respectively. This was consistent with the increase of biomass that is closely related to the process of photosynthesis in plants. Biomass and carbon increase because plants absorb CO2 from the air and convert it into organic compounds because of photosynthesis by which plants to grow, both horizontally and vertically. Organic biomass on forest vegetation consisted of 90-95% of the elements of C, H, O with the proportion of 44-59% C, 42-46% O, and 5-7% H, which amount in each organ increases as the rate of growth[5].

In addition, tree growth was influenced by genetic ability of individuals to interact with the environment. Environmental influences included: soil factors (soil physical and chemical properties, moisture, and microorganisms); climatic factors (temperature, rainfall, wind, and sunlight); topography (slope, altitude) and competition (the individual influences another tree, the influence of other types of plants and animals)[6].

Based on the observations in the field, the growth of red meranti stands did not meet expectations due to less exposure to sunlight or heavy shade in the lane and there were many weeds around the plants. Furthermore, ared meranti tree at the age of 6 years was described in Figure 1.

Figure 1. Red meranti treeat age 6 years.

The opening of the shade was lacking in planting pathway resulting in limited light that comes on the plant so that the need of red meranti for the sufficient light intensity was not fulfilled. Red meranti is a tree species that requires half the shade at a young age and subsequently require full light for growth. In addition, red mernati was the tree that required light on the early growth of 60-70% (relative light intensity) for seedlings in nursery and 74-100% for saplings in the field. Lack of intensity of light coming on the planting lines can cause growth inhibition of the red meranti[6].

Population density of weeds can hamper the plant growth because not only the high competition in nutrient uptake, but also the light competition. Weeding regularly needs to do for reducing interference to the red meranti stands. Weeding can be done manually by clearing the weeds with a hoe or machete, and weeding can be done chemically by using herbicides. Weeding activities should be performed with a frequency of every 3-4 months in a year for plants less than 2 years of age, a frequency of every 6-12 months to plants more than 2 years of age until the plant cannot be defeated by weeds[6]. Based on the information from the management of the PMFMU activities, in the area of PMFMU, weeding had been done manually 3 times a year, but because the growth of shrubs and lianas was very rapid, the growth of the red meranti was still not optimum.

2. Carbon in undergrowth, coarse litter, and fine litter

The study revealed that the increase of tree age did not provide an obvious trend on the increase of biomass content and carbon in the undergrowth and litter. Undergrowth contributed less carbon than other plants because the size of the undergrowth is much smalle rthan the tree size, but it has a role in absorbing carbon. Condition of undergrowth in the study plots which was occupied by ferns, ilalang (*Imperata cylindrica*), grasses, and lianas was described in Figure 2.

Figure 2. Undergrowth in the study plots.

Furthermore, coarse and fine litter in the study plots was described in Figure3.

Figure 3. Coarse and fine litter in the study plots.

Based on the laboratory test, carbon content of the undergrowth, coarse and fine litter was described in Table 1.

Table 1. Carbon content of undergrowth and litter

Sample	Red meranti age (year)	Organic C (%)
Undergrowth	10	39,70
	8	36,87
	6	36,43
Coarse litter	10	35,22
	8	34,63
	6	33,78
Fine litter	10	14,20
	8	19,46
	6	23,44

Based on the range of the carbon content of undergrowth and coarse litter (Table 1) around the red meranti stands with the age of 6, 8, and 10 years was likely to increase. The older of the red meranti stands, the greater the carbon content in the undergrowth and coarse litter. However, the opposite result occurred in the fine litter, although the percentage of carbon did not differ much. These results demonstrated that the value of carbon content of undergrowth, coarse and fine litter was relatively the same as the results found by[7] showing that for the carbon stored in the forests ranged from 27% herbaceous) to 44% (wood). The existence of undergrowth was influenced by soil fertility conditions at each location, climatic conditions and the influence of the surrounding environment[8]. In addition, the amount of biomass and carbon stock in the secondary forest or disturbed forest had varying percentages ranging from 3% to 30% depending on the age of the secondary forest and canopy openness. Although the value had small percentages, but the presence of undergrowth can not be ignored and had contributed to the total biomass and the formation of soil nutrients[9].

3. Carbon in necromass

The results showed that the increasing age of the red meranti did not provide a real trend toward the increasing content of woody biomass and carbon of woody necromass. Because its value was very small, the carbon in woody necromass was ignored in this study.

4. Carbon in organic matter of soil

The carbon content in each soil depth varied from 0.79% to 4.98% (Table 2). The deeper from the soil surface, the less the carbon content of the soil. Carbon sequestration at an area becomes larger when the condition of soil is good demonstrated with a high content of organic carbon[10].

Table 2. Carbon content in the soil

Red meranti age (year)	Depth (cm)	Organic C (%)
10	0 – 5	1.99
	5 – 10	1.53
	10 – 20	0.79
	20 – 30	0.86
8	0 – 5	4.98
	5 – 10	2.06
	10 – 20	1.53
	20 – 30	1.26
6	0 – 5	2.12
	5 – 10	2.25
	10 – 20	2.06
	20 – 30	1.33

Furthermore, carbon stock of soil in the planting areas of red meranti stands with the age of 6, 8, and 10 years was decline, i.e. 40.82 tons/ha, 35.28 tons/ha, and 13 tons/ha respectively. This happened due to leaching of nutrients in the soil because of the opening of canopy, especially on the planting locations of the red meranti aged 10 years. Moreover, the use of heavy equipment on the locations caused soil compaction that reduced the porosity of the soil. As a result, when it rained the rain water was not able to be absorbed into the soil, but flowed to the lower areas carrying particles of topsoil. The loss or decline in organic matter content was sometimes the result of land clearing. The different ages of the red meranti were not too big, which was 2 years old, also led to the small difference in soil carbon stock[11].

The main component storage of carbon is organic matter. The amount of carbon stored in organic matter is less than the total amount of carbon in the forest. This is because the organic matter is under decomposition and become prey of microorganisms so that the organic matter is changing continuously. The result of correlation test between quality of sites and carbon stock showed that pH, organic C, organic matter, N-total, and potassium had a correlation or influence on the carbon stored. Silvicultural practices need to be done to address the decline carbon stocks in soil through land covering. Land covering can hamper soil erosion and nutrient leaching.

5. Total carbon

Total carbon was obtained from the sum of soil, litter, undergrowth, and red meranti carbon. Carbon content of soil, litter, and undergrowth was obtained from the result of the laboratory tests, while the carbon content of the red meranti stands was obtained from measurement of diameter and then it was converted into the allometry: $0.067(D)^{2.859}$. The results showed that the older the red meranti stands, the higher carbon stock they had. At the red meranti stands with the age of 6, 8, and 10 years, it was found the amount of 7.63 tons, 47.10 tons, and 74.89 tons carbon/ha respectively. The amount of carbon in the red meranti with the age of 10 years (74.89 tons) was higher than the carbon stock in pine (*Pinus merkusii* Jungh. Et de Vriese) stands with the age of 15 years (50.09 tons/ha)[12].

However, the red meranti carbon was lower than the total carbon in *Acacia*sp. stands (155.97 tons/ha)[13], cempedak (*Artocarpus integer*) trees (196.61 tons/ha), durian (*Durio zibethinus*) trees (134.11 tons/ha), and langsat (*Lansium dometicum*) trees (109.08 tons/ha)[14]. Yet, there was no information about the ages of the Acacia, cempedak, durian, and langsat trees. In addition, carbon content of the red meranti with the age of 6 years (7.63 tons/ha) and 8 years (47.10 tons/ha) was higher than the carbon content of the red meranri studied by[3] who found that the red meranti with age of 2-7 years in West Sumatra has carbon potential as amount of 0.99-7.33 tons/ha.

6. The increase of carbon stock with the increasing age of red meranti stands

The study revealed that the increase of total carbon stock of the red meranti stands from the age of 6 year to 8 years was 19.73 tons/ha/year, from the age of 8 years to 10 years was 13.90 tons/ha/year or 16.82 tons/ha/year on average. This result was higher than the mean annual increment of the red meranti stands applying intensive silviculture with the age of 2-7 years in West Sumatra (0.03-1.05 tons/ha/year)[3].

The increase of total tree biomass was affected by forest types, species, density, age, site conditions, and management practices of the stands. In general, the potential of biomass and carbon stock for each age class is affected by stand age, site indexes, stand density, tree size, and silvicultural treatments including spacing of the stands[8].

7. Carbon dioxide absorbed by red meranti stands

The potential of CO_2gas absorption in the red meranti was measured using the comparison of the chemical formula between molecular weight of CO_2gas and a mass of elements C (Rm CO_2:Ra C) = 44/12 or 3.67, which was used as a constant value and then multiplied by the number of carbon content. Based on the calculation, the red meranti stands with the age of 6, 8, and 10 years were estimated to absorb CO_2 gas as amount of 28.01 tons/ha, 172.83 tons/ha, and 274.86 tons/ha respectively. The CO_2 gas absorption increased with the age increase of the red meranti.

The tropical rain forest was expected to provide 176 tons carbon/ha or approximately 644.16 tons CO_2 absorption/ha[8].The amount of CO_2 in the air changes and varies from one place to another one, but on average is 0.03%[3] . In addition, rain and fog would increase CO_2 content. Carbon dioxide is returned to the atmosphere when the wood or litter in the forest to rot or be burned[8].

8. Calculation of economic value of carbon stock in red meranti stands

The economic value of carbon stock was calculated with the approach of the economic value of the REDD project in the project period of 5 years. Payments of the REDD projects were carried out with full payment mechanism at the beginning of the project (ex-ante full credit). The price of carbon using a hypothetical price was US$6, US$9, and US$12 per ton of CO_2-e[4].Based on the data obtained, the amount of CO_2 absorbed by the red meranti at the age of 6 years, 8 years, and 10 years were converted to US$ per hectare as shown in Table 3.

Table 3. Calculation of carbon stock value of red meranti stands

Carbon price (US$/ton CO_2)	Red meranti age and economic value		
	6 Years (US$/ha	8 years (US$/ha)	10 years (US$/ha
6	168.04	1,037.14	1,649.17
9	252.07	1,555.71	2,473.76
12	336.09	2,074.28	3,298.34

Conclusions and Recommendations

Total carbon stock inthe red meranti *(Shorea leprosula* Miq.) stands by using the allometry: 0,067 $(D)^{2,859}$ with the age of 6, 8, and 10 years was 7.63 tons/ha, 47.10 tons/ha, and 74.89 tons/ha respectively. Total carbon stock increased with age. The average increase of carbon stock in the red meranti was 16.82 tons/ha/year. Red meranti stands with the age of 6, 8, and 10 years could be expected to absorb CO_2 as amount of 28.01 tons/ha, 172.83 tons/ha, and 274.86 tons/ha respectively.At a price of US$6, the red meranti with the age of 6, 8, and 10 years was worth US$168.04/ha, US$ 1,037.14/ha, and US$ 1,649.17/harespectively.

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