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DISTRIBUTION OF CARBON STOCKS IN PEAT BOTTOM BASED ON THICKNESS CLASS IN PELALAWAN VILLAGE (RIAU PROVINCE, INDONESIA)

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Abstract. As is well known, tropical peatlands are deposits of terrestrial organic carbon of global importance. It is estimated that around 15% of carbon is stored in peatlands worldwide. Indonesia contains approximately 50% of the world's tropical peatlands with frequently cited estimates of about 21 Mha. Pelalawan district area (Riau Province) is dominated by peat soils. The land in Pelalawan is mainly covered by industrial plantations of acacia forests and oil palms. The area is very susceptible to the loss of carbon stocks in peat soils due to the opening of drainage channels. This study aims to calculate the carbon stocks of subsurface peatlands in Pelalawan, especially in the research location. The method used is a grid survey, the distance between the particular points is 500 m, which covers the total area of the research site, i.e. 2,500 ha. The number of observation points is 121, which includes measuring the thickness of the peat layer, calculating bulk density, and C organic content. The paper analysed the distribution of carbon stocks in the peat bottom based on the thickness class. The results showed that carbon stocks in the peat bottom in Pelalawan were 218,753.95 tons/ha consisting of 143,138.40 tons/ha in the peat thickness of >300 cm (very deep peatland), 44,999.10 tons/ha in the peat thickness of 200–300 cm (deep peatland), 21,577.67 tons/ha in the peat thickness of 100–200 cm (medium peatland), 4,780.78 tons/ha in the peat thickness of 50–100 (shallow peatland), and 4,258 tons/ha in the peat thickness of 0–50 (very

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shallow peatland). The research results of this study cover the information on the availability of carbon storage and carbon conservation.

Keywords: tropical peatlands, carbon store, palm oil plantation, carbon conservation, climate mitigation efforts

1. INTRODUCTION

A large proportion of the world's tropical peatlands occur in Indonesia where rapid conversion and associated losses of carbon, biodiversity and ecosystem services have brought peatland management to the forefront of Indonesia's climate mitigation efforts (Warren *et al*. 2017). Peat swamps in their natural state play a role of an efficient carbon stores in terrestrial environment (Afnanizam *et al*. 2019). Peat swamps in Sumatra and Kalimantan (Indonesian Borneo) have been large and persistent carbon sinks from around 15,000 years ago to present, sequestering between 0.5 and 1.5 Mg C/ha year^{-1} in peat (Dommain *et al*. 2014, Kurnianto *et al*. 2013).

Pelalawan (a village in Riau Province) is administratively located in Pelalawan District, Pelalawan Regency, Riau Province. The area of Pelalawan village is 317 km^2, almost all of the area is covered with peatlands covered in the peatland hydrological unit (KHG) of Sungai Kampar (BPS 2018). Land cover in Pelalawan village is dominated by industrial forest plantation (HTI) of acacia, PT RAPP and palm oil plantation. The area is very susceptible to the loss of carbon stocks in peat soils due to the opening of drainage channels.

Based on data from the Pelalawan District in 2008–2015, the area of plantation increased forty times, from 877 to 35,592 ha. The opening of a plantation is also accompanied by the opening of canal blocks for drainage purposes. Specifically, the construction of a drainage canal network in the peat ecosystem will increase the run-off flow rate and reduce the water retention capacity of the peat ecosystem. This condition will cause the peat water level to drop dramatically leading to drought stress and susceptibility to burning which has the potential to cause haze disasters and increase the release of carbon dioxide (CO_2) into the air. Consequently, it can trigger an increase in greenhouse gas emissions that have an impact on global climate change. Hooijer *et al*. (2006) estimate that Indonesia's peatlands emit 2,000 megatons (Mt) of CO_2 per year. Emissions from non-peat lands are estimated to be only around 500 Mt and from burning fuel oil and gas also around 500 Mt CO_2 per year. Even for emissions related to land use change and forestry (land use, land use change and forestry, LULUCF), emissions from Indonesia are estimated to be the highest in the world. Another impact of the decrease in peat water level is the increasing subsidence rate due to oxidation, consolidation, and peat compaction (Dohong *et al*. 2017). The increasing rate of peat subsidence will potentially increase the danger of flooding in the long term resulting in unproductive peatlands. This peat ecosystem damage will have a major impact on the local environment (*in situ*) and the surrounding environment (*ex situ*). Drought and flood in the downstream watershed are one of the impacts of the peat ecosystem destruction in the Pelalawan District (Noor *et al*. 2014).

Meanwhile, maintaining carbon stocks and increasing carbon uptakes can be done through conservation and management activities such as plant enrichment and water management (Rosalina *et al*. 2014). Sustainable management of peatlands is regulated in the Regulation of the Ministry of Environment and Forestry no. P.16/MENLHK/SETJEN/KUM.1/2/2017. The technical guidelines for restoring the functions of the peat ecosystem are expected to become a reference for sustainable peatland management. The implementation of technical guidelines for the restoration of peat ecosystems is supposed to become a reference for integration in sustainable peat management, especially the recovery of peat ecosystem functions, restoring the hydrological functions of peat as storage of carbon stocks.

Estimation of carbon stocks in peat bottom can be carried out by referring to the guidelines for measuring peat soil carbon stocks (Agus *et al*. 2011). The procedure for carbon stocks measurement is based on the assessment of peatland area, peat thickness, maturity level, the volume of peat, organic C volume, and estimation of carbon stocks in peat bottom. The thickness and maturity level of peat can be determined by the survey method directly in the field based on the level of detail of the observation point and the purpose of the study. The bulk density and organic C of peat soil vary depending on the level of decomposition and maturity of peat. This study aims to calculate the carbon stocks of subsurface peatlands in Pelalawan village, especially in the research location

2. MATERIALS AND METHODS

2.1. Study area

This research was conducted in Pelalawan village (Pelalawan District, Pelalawan Regency, Riau Province) with an area of 2,500 ha (Fig. 1). Spatial analysis and mapping were carried out in the Laboratory of Pedology, while physical and chemical analysis was carried out in the General Soil Laboratory, the Laboratory of Chemistry and Soil Fertility, and the Laboratory of Soil Physics, Study Program of Soil Science, Gadjah Mada University. The research was conducted from September to November 2017.

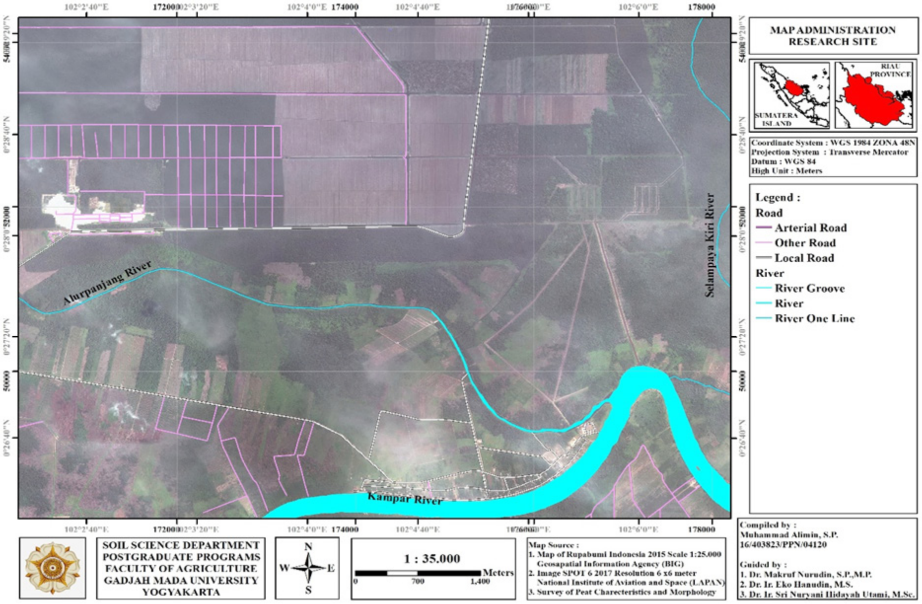

Fig. 1. Administrative map of the study area

2.2. Survey method

The survey of identification of characteristics and morphology of peat was based on the observation point map of the research area. The number of observation points is 121 with a distance interval between observation points of 500 m (Fig. 2). Field research covered morphological and physiographic observations referred to the properties of peat soil. Soil observation in the field was carried out using the Eijkelkamp drill to the depth of the mineral soil layer (substratum). Peat layers were drilled to the depth of 120 cm 6 times using a Belgi type mineral drill. The variables observed were recorded in the field observation sheet form (Nasrul 2017). The determination of peat soil samples to be analyzed was based on the peat thickness class. The peat was classified based on the thickness, then 3 sample points of peat soil and 1 sample point of composite peat soil in each thickness class were taken to be analyzed in terms of their properties related to the calculation of the carbon stocks in the peat bottom in the research site.

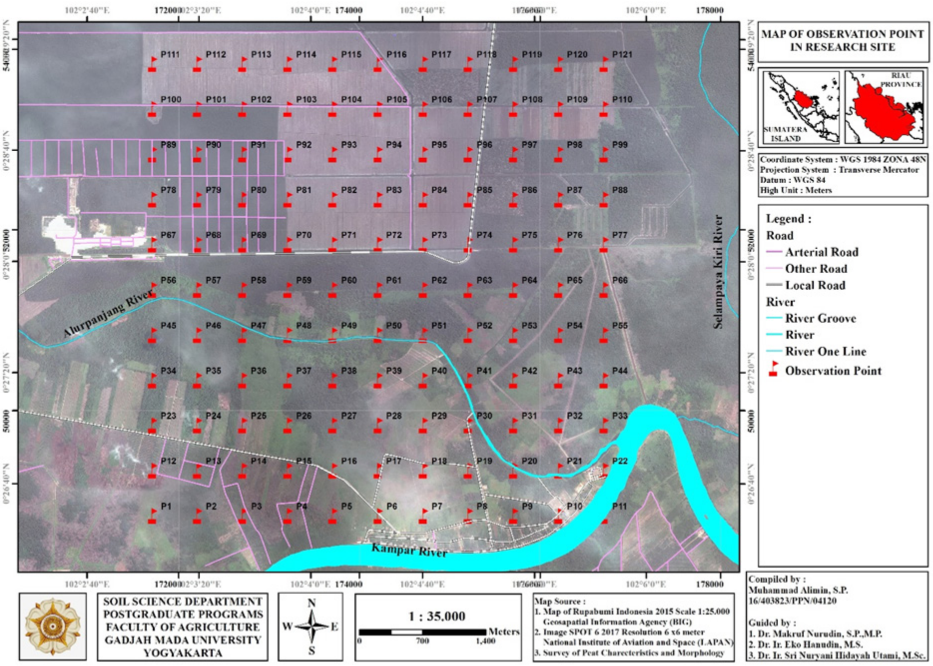

Fig. 2. Observation points in the study area

2.2.1. Tools and materials

The tools needed in this study consisted of hardware (laptop, printer, GPS, clinometer, compass, peat drill, Soil Munsell color chart, pH meter, EH and EC meters, ring samples, field knives, meters, field observation forms, plastic bags, and labels) and software (ArcGIS 10.3, Global Mapper 18.1, Microsoft Office 2016, and IBM SPSS Statistics 25). The secondary material used in this study was the Indonesian earthquake map with a scale of 1:25 000 compiled by the Geospatial Information Agency (BIG), and the 2017 SPOT image with a resolution of 6 × 6 m prepared by the National Institute of Aeronautics and Space. The primary material used in this study was the data on the characteristics and morphology of the peat in the research location.

2.2.2.a. Method of soil survey to identify peat thickness

The measurements of peat thickness were carried out at each observation point using the Eijkelkamp drill. The stages carried out included gradually modified drilling, lifting the drill to be recorded, and taking soil samples. If the drill had not reached the mineral layer, then it was extended to the next drill, and the recording was repeated until it reached the mineral soil. Besides identifying the peat thickness, the physiographic conditions of each observation point such as type of land cover, slope class, altitude, land ownership status, flood/inundation, type of substratum, groundwater level, and groundwater quality, were also recorded. Observation of peat morphology included the color of peat soil, the level of maturity, consistency, texture, and charcoal concretion (presence or absence of burning peat) (Nasrul 2017). Classification of peat thickness includes the following ranges: very shallow (<50 cm), shallow (50–100 cm), medium (100–200 cm), deep (200–300 cm), and very deep (>300 cm), presented in a spatial form with the kriging method. The research results of the characteristics and morphology of the study area provide some information, one of which was peat thickness at each location. The peat thickness at each observation point was then interpolated by the kriging method on the area of 2,500 ha. Based on the results of the interpolation of the kriging method, the area of each thickness class was determined. The area of peat thickness was then divided by the number of observation points in each class of peat thickness to obtain peat area at each observation point.

2.2.2.b. Method of soil survey to identify physical properties

Water depth

Groundwater data were obtained by measuring the depth of the groundwater table with a meter after drilling. The calculation of groundwater aims to monitor the groundwater level at each observation point. These data are useful for monitoring the depth of groundwater in peatland to prevent fire.

Peat maturity

According to the guidebook for the identification of basic characteristics and hydrology of peat (Nasrul 2017), the maturity level of peat soil is explained based on the level of decomposition of the original plant material (fiber). The three types of maturity are fibric, hemic, and sapric. Determination of the maturity/weathering level of peat soil in the field was done by taking a handful of peat soil which was then slowly squeezed with the palm. Then the fibers in the palm were observed and classified based on the following criteria: fibric (von post H1–H3 classification, fiber >60%), hemic (von post classification H4–H6, fiber 33–66%), and sapric (von post classification H7–H10, fiber <33%).

Bulk density

Peat samples used for bulk density analysis were obtained from 3 observation points in each peat thickness class using a sample ring. Bulk density was analyzed based on the peat maturity class, using the gravimetric method.

Organic C

Peat samples used for the organic C analysis were taken from 3 observation points in each peat thickness class and 1 peat composite sample taken from each depth of 20–120 cm. Organic C in each peat sample was analyzed using the loss on ignition (LOI) method. The LOI method was done by drying each of peat sample in an 80°C furnace for 24 h. The dried samples were then burned in a 600°C muffle furnace for 4 h. Organic C was calculated as 58% of the percentage of peat organic matter.

2.2.2.c. Method of calculation of carbon stocks in peat bottom

The variables used in calculating carbon stocks in peat bottom are bulk density (BD), area of peat thickness, peat thickness, and organic C content (Eq. 1). The equation used to calculate carbon stocks in peat bottom is based on practical guidance on measuring peat soil carbon stocks (Agus *et al*. 2011) is as follows:

$$KC = B \times A \times D \times C \quad (1)$$

where:
KC – carbon content (ton)
B – bulk density (BD), [g/cm^3 or kg/dm^3 or t/m^3]
A – area of land to be estimated [ha or km^2]
D – peat soil thickness. If samples consist of many layers, the thickness of each layer needs to be measured [cm or m]
C – organic C content [% weight or g/g or kg/kg]

RESULTS AND DISCUSSION

In its natural state, peat forests are a net sink of carbon. However, when peat forests are cleared, most of the carbon in plant biomass will be oxidized to CO_2, especially if forest clearing is accompanied by burning. Of the remaining peat forests, about 60% (12 million ha) contained from 1.8 to 2.4 Gt of carbon. On plantation land that has been productive it was about 100 t C/ha. Thus, based on this estimation, the amount of carbon contained in Indonesia’s peatlands is around 40 Gt (Agus and Subiksa 2008).

Peat thickness

Based on a survey of the characteristics and morphology of peatlands in Pelalawan village, the research locations have varying peat thickness and area (Table 1). The study area is between the Kampar River and the Alur Panjang River. Peatlands on the banks of the Alur Panjang and Kampar Rivers have a thickness of 0–50 cm and are affected by tides and swings of the Alur Panjang River. Further to the south of the Alur Panjang River, the peat thickness is deeper reaching 200–300 cm (deep peatland) and still categorized in topogenous peat (Dohong *et al*. 2017). The distribution of peat thickness on the southern side of the Alur Panjang River is irregular. This is due to the transformation of peat land into plantations and the construction of drainage canals leading to the subsidence of peat soil.

Table 1. Area of peat thickness

No.	Peat thickness	Area (ha)	Area (%)
1.	0–50 cm	256	10.24
2.	50–100 cm	207	8.28
3.	100–200 cm	519	20.76
4.	200–300 cm	509	20.36
5.	300–525 cm	1,009	40.36
	Total	2,500	100.00

The northern side of the Alur Panjang River is dominated by the peat thickness of 0–50 cm. Getting further to the north of the river, the peat thickness is deeper, reaching a depth of >300 cm (very deep peatland). The formation of peatlands in the northern side is more influenced by rain, and the distance is farther from the Kampar River. Deep peat on the northern side of the research location has a thickness of up to 525 cm (Fig. 3) since the northern part of the research location is in the position of the peat dome.

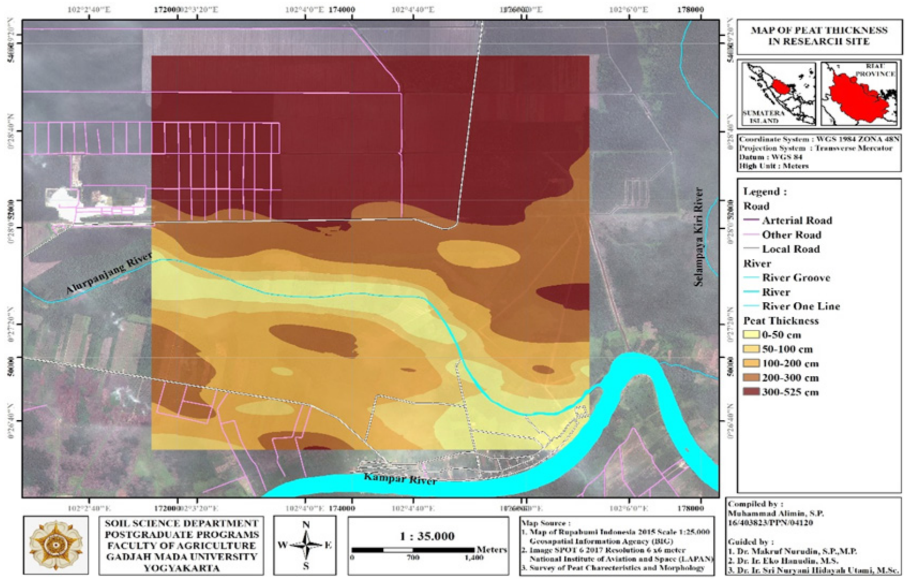

Fig. 3. Peat thickness of the study area

Carbon stocks in thickness class of 0–50 cm (very shallow peatland)

The bulk density of peat in the thickness class of 0–50 cm (very shallow peatland) was at the sapric maturity level. The bulk density of the samples taken from observation points of P8, P41, and P48 were 0.23 g/cm^3, 0.24 g/cm^3, and 0.26 g/cm^3, respectively, and the average value was 0.24 g/cm^3. The organic C content analyzed from the samples taken from the observation points of P8, P41, P48, and K1 were 46.87%, 46.55%, 46.57%, and 46.79%, consecutively, and the average value was 46.49%. The area of the peat thickness of 0–50 cm (very shallow peatland) was 256 ha which was divided into 22 observation points classified into the thickness class of 0–50 cm (very shallow peatland) with an average area at each point of 11.64 ha. The carbon stocks in peat bottom in the thickness class of 0–50 cm was 4,258 tons/ha. The calculation of carbon stocks in peat bottom in the thickness class of 0–50 cm (very shallow peatland) is presented in Table 2.

Table 2. Calculation of carbon stocks in peat bottom in the thickness class of 0–50 cm (very shallow peatland)

No.	Thickness (cm)	Area	Organic C (%)	BD (t/m^3)	C stocks	C stocks
	Sapric	(ha)	Sapric	Sapric	(ton)	(t/ha)
P8	20	11.64	46.87	0.23	2,508.57	215.58
P41	10	11.64	46.55	0.24	1,323.73	113.76
P48	5	11.64	46.57	0.26	704.48	60.54
∑	339	11.64	46.69	0.24	45,010.87	3,868.12
		Total			49,547.64	4,258.00

Carbon stocks in thickness class of 50–100 cm (shallow peatland)

The bulk density of peat in the thickness class of 50–100 cm (shallow peatland) was at the sapric and hemic maturity levels. Sampling was done at observation points of P14, P18, and P15 resulting in the bulk density at the sapric maturity level with values of 0.25 g/cm3, 0.23 g/cm^3, and 0.23 g/cm^3, respectively, and the average value of 0.24 g/cm^3. Meanwhile, the bulk density values at the hemic maturity level were 0.15 g/cm^3, 0.13 g/cm^3, and 0.13 g/cm^3, consecutively, and the average value was 0.14 g/cm^3. Organic C content was analyzed from the samples taken from the observation points of P14, P18, P15, and K2 at the sapric and hemic maturity levels. The results of the calculation of organic C content at the observation points of P14, P18, P15, and K2 at the sapric maturity level were 47.31%, 47.26%, 47.29%, and 47.37%, respectively, with an average value of 47.31%. Whereas at the hemic maturity level, the organic C content was 49.01%, 49.04%, 49.08%, and 49.06%, consecutively, with an average value of 49.05%. The area of the peat thickness of 50–100 cm (shallow peatland) was 207 ha divided into 6 observation points with an average area of 34.50 ha at each point. Carbon stocks in the peat bottom in the thickness class of 50–100 cm (shallow peatland) was 4,780.78 tons/ha. The calculation of carbon stocks in the peat bottom in the thickness class of 50–100 cm (shallow peatland) is presented in Table 3.

Table 3. Calculation ofcarbon stocks in peat bottom in the thickness class of 50–100 cm (shallow peatland)

No.	Thickness (cm)		Area	Organic C (%)		BD (t/m³)		C stocks	C stocks
	Sapric	Hemic	(ha)	Sapric	Hemic	Sapric	Hemic	(ton)	(t/ha)
P14	60	20	34.5	47.31	49.01	0.25	0.15	4,398.99	127.51
P15	60	20	34.5	47.29	49.08	0.23	0.13	26,917.53	780.22
P18	60	20		47.26	49.04	0.23	0.13	26,898.57	779.67
∑	153	95	34.5	47.31	49.05	0.24	0.14	81,565.07	2,364.21
Total								164,936.97	4,780.78

Carbon stocks in thickness class of 100–200 cm (medium peatland)

The bulk density of peat in the thickness class of 100–200 cm (medium peatland) was at the sapric, hemic, and fibric maturity levels. Sampling was done at the observation points of P25, P16, and P64. The values of bulk density at the sapric maturity level were 0.22 g/cm³, 0.25 g/cm³, and 0.28 g/cm³, respectively, and the average value was 0.25 g/cm³. Meanwhile, the values of bulk density at the hemic maturity level were 0.14 g/cm³, 0.18 g/cm³, and 0.14 g/cm³, consecutively, and the average value was 0.15 g/cm³. The bulk density value at the fibric maturity level is 0.11 g/cm³. The organic C content was analyzed based on the samples taken from the observation points of P25, P16, P64, and K3 at the sapric, hemic, and fibric maturity levels. The average values of organic C content at the sapric maturity level were 47.13%, 47.07%, 47.32%, and 47.05%, respectively, with an average value of 47.14%. Meanwhile, the average values of organic C content at the hemic maturity level were 49.09%, 49.06%, 49.05%, and 49.01%, consecutively, with an average value of 49.05%. The organic C content at the fibric maturity level was 49.38%. The area of the peat thickness of 100–200 cm (medium peatland) was 519 ha divided into 16 observation points with an average area of 32.44 ha at each point. The carbon stocks in peat bottom in the thickness class of 100–200 cm (medium peatland) was 21,577.67 tons/ha. The calculation of carbon stocks in peat bottom in the thickness class of 100–200 cm (medium peatland) is presented in Table 4.

Table 4. Calculation of carbon stocks in peat bottom in the thickness class of 100–200 cm (medium peatland)

No.	Thickness (cm)			Area (ha)	Organic C (%)			BD (t/m^3)			C stocks (ton)	C stocks (t/ha)
	Sap-ric	He-mic	Aver-age		Sap-ric	He-mic	Aver-age	Sa-pric	He-mic	Aver-age		
P16	60	93		32.44	47.07	49.06		0.25	0.18		49,718.10	1,532.74
P25	80	80		32.44	47.13	49.09		0.22	0.14		44,738.33	1,379.22
P64	40	115		32.44	47.32	49.05		0.28	0.14		42,807.72	1,319.70
∑	605	1,322	51	32.44	47.14	49.06	49.38	0.25	0.15	0.11	562,661.56	17,346.02
						Total					699,925.71	21,577.67

Carbon stocks in thickness class of 200–300 cm (deep peatland)

The bulk density of peat in the thickness class of 200–300 cm (deep peatland) was at the sapric, hemic, and fibric maturity levels. Sampling was done at the observation points of P62, P52, and P60. The values of bulk density at the sapric maturity level were 0.21 g/cm^3, 0.21 g/cm^3, and 0.24 g/cm^3, respectively, with an average value of 0.22 g/cm^3. Meanwhile, the values of bulk density at the hemic maturity level were 0.13 g/cm^3, 0.13 g/cm^3, and 0.14 g/cm^3, respectively, and the average value was 0.13 g/cm^3. The bulk density value at the fibric maturity level was 0.11 g/cm^3.

The organic C content was analyzed based on the observation points of P62, P52, P60, and K4 at the sapric, hemic, and fibric maturity levels. The values of the organic C content at the sapric maturity level were 46.92%, 46.99%, 46.96%, and 46.94%, respectively, with an average value of 46.95%. Whereas, at the level of hemic maturity, the values of organic C content were 49.08%, 49.24%, 49.07%, and 49.09%, consecutively, with an average value of 49.12%. The organic C content at the fibric maturity level was 49.70%. The area of the peat thickness of 200–300 cm (deep peatland) was 509 ha divided into 26 observation points with the average area of 19.58 ha at each point. The carbon stocks in the peat bottom in the thickness class of 200–300 cm (deep peatland) was 44,999.10 tons/ha. The calculation of carbon stocks in the peat bottom in the thickness class of 200–300 cm (deep peatland) is presented in Table 5.

Table 5. Calculation of carbon stocks in peat bottom in the thickness class of 200–300 cm (deep peatland)

No.	Thickness (cm)			Area (ha)	Organic C (%)			BD (t/m^3)			C stocks (t/ha)	C stocks (t/ha)
	Sap-ric	He-mic	Aver-age		Sap-ric	He-mic	Aver-age	Sap-ric	He-mic	Aver-age		
P52	20	218		19.58	46.99	49.24		0.21	0.13		31,183.09	1,592.85
P60	20	258		19.58	46.96	49.07		0.24	0.14		39,112.00	1,997.86
P62	20	244		19.58	46.92	49.08		0.21	0.13		34,337.51	1,753.98
∑	620	4,955	147	19.58	46.95	49.12	49.70	0.22	0.13	0.11	776,311.31	39,654.41
						Total					880,943.90	44,999.10

Carbon stocks in thickness class of >300 cm (verydeep peatland)

The bulk density of peat in the thickness class of >300 cm (very deep peatland) was at the sapric, hemic, and fibric maturity levels. Sampling was done at the observation points of P55, P97, and P118. The values of bulk density at the sapric maturity level were 0.23 g/cm^3, 0.22 g/cm^3, and 0.24 g/cm^3, respectively, with the average value of 0.23 g/cm^3. Meanwhile, the values of bulk density at the level of hemic maturity were 0.15 g/cm^3, 0.15 g/cm^3, 0.16 g/cm^3, respectively, and the average value was 0.15 g/cm^3. The value of bulk density at the fibric maturity level was 0.11 g/cm^3.

The organic C content was analyzed from the samples taken from the observation points of P55, P97, P118, and K5 at the sapric, hemic, and fibric maturity levels. The values of the organic C content at the sapric maturity levelwere 46.94%, 46.92%, 46.95%, and 46.96%, respectively, with an average value of 46.94%. Whereas, at the level of hemic maturity, the values of organic C content were 49.16%, 49.08%, 49.16%, and 49.22%, consecutively, with an average value of 49.16%. The organic C content at the fibric maturity level was 49.62%. The area of the peat thickness of >300 cm (very deep peatland) was 1,009 ha which divided into 51 observation points with an average area of 19.78 ha at each point. The carbon stocks in the peat bottom in the thickness class of >300 cm (very deep peatland) was143,138.40 tons/ha. The calculation of carbon stocks in the peat bottom in the thickness class of >300 cm (very deep peatland) is presented in Table 6.

Table 6. Calculation of carbon stocks in peat bottom in the thickness class of >300 cm (very deep peatland)

No.	Thickness (cm)			Area (ha)	Organic C (%)			BD (t/m^3)			C stocks (ton)	C stocks (t/ha)
	Sapric	Hemic	Average		Sapric	Hemic	Average	Sapric	Hemic	Average		
P55	20	302		19.78	46.94	49.16		0.23	0.15		48,997.34	2,476.58
P97	20	505		19.78	46.92	49.08		0.22	0.15		78,746.60	3,980.25
P118	20	400		19.78	46.95	49.16		0.24	0.16		66,699.32	3,371.32
∑	747	15,940	1,088	19.78	46.94	49.16	49.62	0.23	0.15	0.11	2,637,451.68	133,310.24
Total											2,831,894.94	143,138.40

Carbon stocks in the study area

Figure 4 shows the distribution of carbon stocks in the peat bottom in the research location. The highest carbon stocks are in the thickness class of >300 cm (very deep peatland) reaching 143,138.40 tons/ha followed by the thickness class of 200–300 (deep peatland) with a value of 44,999.10 tons/ha, the thickness class of 100–200 (medium peatland) reaching 21,577.67 tons/ha, and the thickness class of 50–100 (shallow peatland) with a value of 4,780.78 tons/ha. Meanwhile, the lowest carbon stocks can be found in peat thickness class of 0–50 (very shallow peatland) reaching 4,258 tons/ha with total carbon stocks in the research site of 218,753.95 tons/ha.

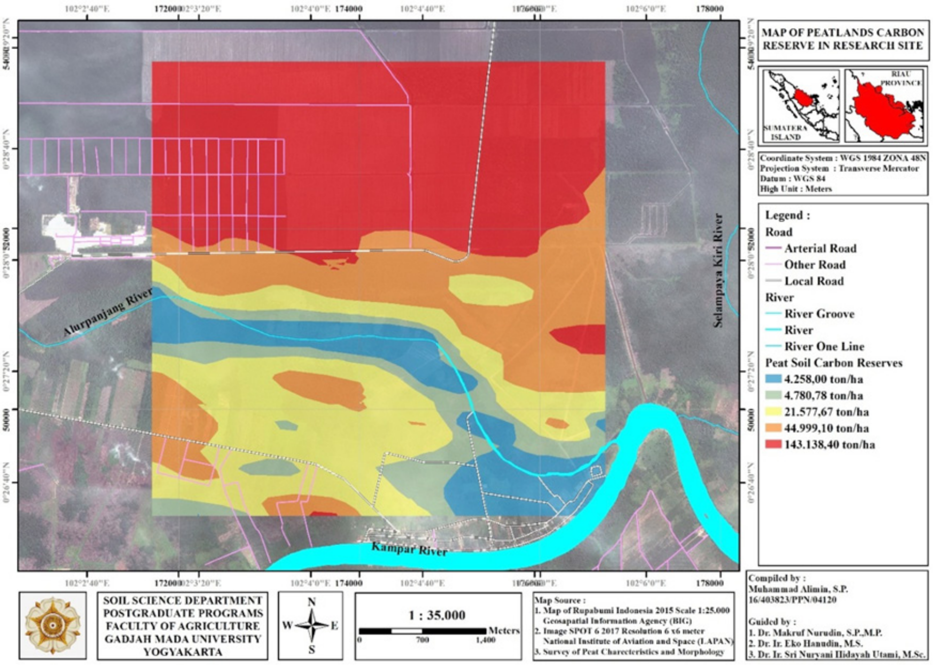

Fig. 4. Distribution of carbon stocks in peat bottom in the study area

Groundwater depth (Fig. 5) in the study locations varied from logged conditions to >120 cm. The diverse groundwater conditions are inextricably linked to the coverage of the research site, which is dominated by PT RAPP palm oil plantation and industrial forest plantation of acacia. Constructing excessive drainage canal lines without considering the hydrological function of peatlands causes flooding in the downstream area of the research area during the peak of the rainy season. The rainfall pattern in Pelalawan village is categorized into the equatorial rainfall pattern. It has two peaks of the rainy season and two peaks of the dry season. The peak of the first dry season is in January and the second one in June, while the peak of the first rainy season is in April, whereas the second one in November (Ardhitama and Sholihah 2014).

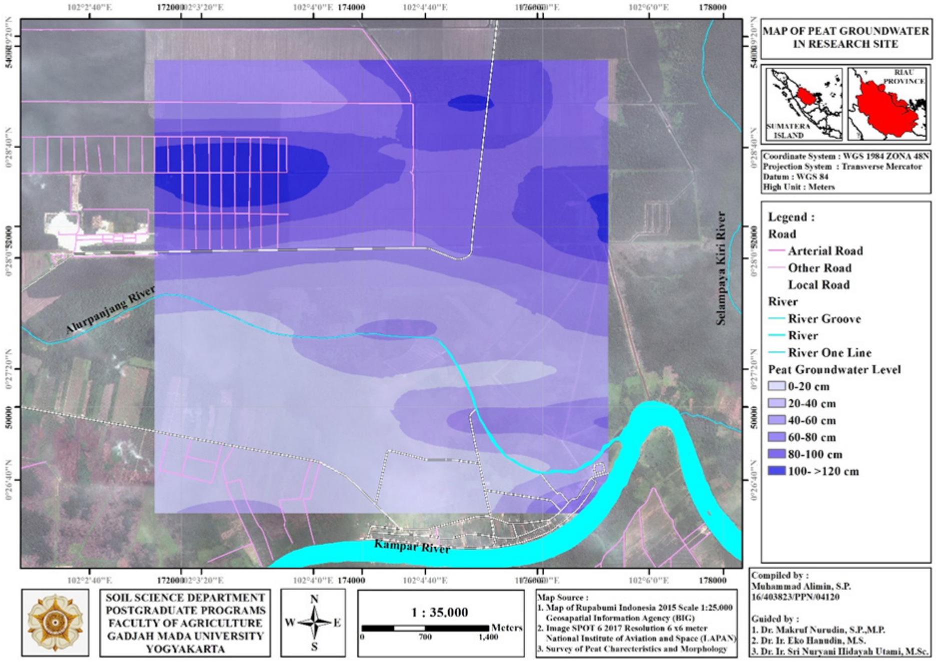

Fig. 5. Map of groundwater level in the study area

The peatland in Pelalawan village is quite large and thick. If the conservation of peatlands and the arrangement of peatland management are not immediately carried out, the rate of carbon stock emissions in Pelalawan village, especially at the research location, will be growing. With regard to its function, peatlands are divided into cultivation areas and conservation areas. The conservation area is on peatland with a thickness of >3 m or in the peat dome area. Flooding the peatlands by making canal blocks and stockpiling canals can be done to increase the groundwater level so that the subsidence rate on peat soils can be reduced (Ritzema *et al*. 2014, Sutikno *et al*. 2020).

The use of very deep peatlands (>3 m) is still controversial among experts. Some experts consider that deep peatland is potentially exploited as a limited production forest for native commercial timber, such as ramin (*Gonystylus bancanus*) and shorea species (*Shorea albida*). The use of peatlands for agricultural/plantation purposes will be sustainable if organizedaccording to the characteristics of the land and plants to be planted. The land arrangement includes the arrangement of the drainage network, leveling, stump cleaning, and intensive shallow drainage system. The dimensions of drainage network density are adjusted to plants intended for cultivation, food crops, vegetables, plantations, or industrial plants (Agus *et al*. 2014).

CONCLUSIONS

The carbon stocks in the peat bottom in Pelalawan village, especially in the research location, were 218,753.95 tons/ha out of which 143,138.40 tons/ha were in the peat thickness of >300 cm (very deep peatland), 44,999.10 tons/ha in the peat thickness of 200–300 cm (deep peatland), 21,577.67 tons/ha in the peat thickness of 100–200 cm (medium peatland), 4,780.78 tons/ha in the peat thickness of 50–100 (shallow peatland), and 4,258 tons/ha in the peat thickness of 0–50 (very shallow peatland).

Peatlands in Pelalawan village, especially in the research sites, need to be reorganized based on protection and cultivation functions. Protection of peat areas is intended to control the hydrology of the area, which functions as a water storage and flood prevention, as well as to protect the unique ecosystem in the area concerned. The thicker the peat, the more important its function in protecting the environment. Agriculture on thick peatlands is more difficult to manage and more expensive because of the low fertility and low bearing capacity of the soil, making it difficult for vehicles to transport agricultural facilities and crops. Peat with a thickness of <3 m can still be used for plant cultivation provided it is not included in a protected area, the substrate is not quartz sand and the maturity level is not sapric or hemic (Agus and Subiksa 2008) and has no potential for acid sulfate. Summing up, the research needs to be continued with reference to the pattern of changes in land cover and the emission rate of carbon in the peat bottom.

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REFERENCES

[1] Agus, F., Subiksa, I.G.M., 2008. *Lahan Gambut: Potensi untuk Pertanian dan Aspek Lingkungan*. Balai Penelitian Tanah dan World Agroforestry Centre (ICRAF). Bogor, Indonesia.

[2] Agus, F., Hairiah, K., Mulyani, A., 2011. *Pengukuran Cadangan Karbon Tanah Gambut. Petunjuk Praktis*. World Agroforestry Centre dan Balai Besar Penelitian dan Pengembangan Sumberdaya Lahan Pertanian (BBSDLP). Bogor, Indonesia. 58 p.

[3] Agus, F, Anda, M., Jamil, M., Masganti, 2014. *Lahan Gambut Indonesia. Pembentukan, Karakteristik, dan Potensi Mendukung Ketahanan Pangan* (edisirevisi). IAARD Press. Jakarta.

[4] BPS, 2018. *Kabupaten Pelalawan Dalam Angka*.

[5] Dohong, A., Cassiophea, L., Sutikno, S., Triadi, B.L., Wirada. F., Rengganis, P., Sigalingging, L. 2017. *Modul Pelatihan: Pembangunan Infrastruktur Pembasahan Gambut Sekat Kanal Berbasis Masyarakat*. Badan Restorasi Gambut Republik Indonesia. Jakarta. Indonesia. 72 p.

[6] Dommain, R., Couwenberg, J., Glaser, P., Joosten, H., Suryadiputra, I., 2014. *Carbon storage and release in Indonesian peatlands since the last deglaciation*. Quaternary Science Review, 97: 1–32.

[7] Hooijer, A., Silvius, M., Wösten, H., Page, S., 2006. *Peat–CO_2: Assessment of CO_2 emissions from drained peatlands in SE Asia*. Delft Hydraulics Report Q3943.

[8] Kurnianto, S., Warren, M., Talbot, J., Kauffman, B., Murdiyarso, D., Frolking, S., 2013. *Carbon accumulation of tropical peatlands over millennia: A modeling approach*. Global Change Biology, 21(1): 431–444. doi:10.1111/gcb.12672.

[9] Nasrul, B., 2017. *Pedoman Indentifikasi Karakteristik Dasar dan Hidrologi Gambut*. Univesisitas Riau. Pekanbaru. 82 p.

[10] Noor, M., Masganti, Agus, F., 2014. *Pembentukan dan Karakteristik Gambut Tropika Indonesia*. Lahan Gambut Indonesia: Pembentukan, Karakteristik dan Potensi Mendukung Ketahanan Pangan.

[11] Ritzema, H., Suwido, L., Kitso, K., Jauhiainen, J., Wösten, H., 2014. *Canal blocking strategies for hydrological restoration of degraded tropical peatlands in Central Kalimantan, Indonesia*. Catena, 114: 11–20.

[12] Rosalina, Y., Kartawinata, K., Nisyawati, N., Nurdin, E., Supriatna, J. 2014. *Floristic Composition and Structure of a Peat Swamp Forest in the Conservation Area of the PT National Sago Prima, Selat Panjang, Riau, Indonesia*. Reinwardtia, 14(1): 193–210.

[13] Sutikno, S., Nasrul, B., Hendri, A., Haryati Silviana, S., Saputra, E. *et al*., 2020. *Neraca Air Kesatuan Hidrologis Gambut. Kedeputian Penelitian dan Pengembangan, Badan Restorasi Gambut, Republik Indonesia, Jakarta*. Retrieved from https://www.researchgate.net/profile/Sigit-Sutikno/publication/348655867_Neraca_Air_Kesatuan_Hidrologis_Gambut/links/6009758792851c13fe273ff2/Neraca-Air-Kesatuan-Hidrologis-Gambut.pdf

[14] Warren, M.W., Hergoualc'h, K., Kauffman, J.B., Murdiyarso, D., Kolka, R., 2017. *An appraisal of Indonesia's immense peat carbon stock using national peatland maps: Uncertainties and potential losses from conversion*. Carbon Balance and Management, 12(1). doi:10.1186/s13021-017-0080-2.