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A preliminary assessment of peat degradation in West Kalimantan

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Abstract

Degradation of tropical peats is a global concern due to large Carbon emission and loss of biodiversity. The degradation of tropical peats usually starts when the government clears closed peat forests into open and drained peatlands for agricultural uses. Tropical peats have high values of Water Contents (WC), Organic Matters (OM) and Total Organic Carbon (TOC), and low values of Total Nitrogen (TN) and Total Sulphur (TS). Dry Bulk Density (DBD) is commonly less than 0.1 $g\,cm^{-3}$. Decline of concentration values of OM (<90%) and TOC (<40%) indicate peat degradation. In disturbed peats, TN concentration tends to decrease and the concentration of TS slightly increases. Changes in OM, TOC, TN and TS are potentially important indicators for assessing peat degradation in the tropics.

1 Introduction

Peat degradation is characterized by a change of physical, biological and chemical properties leading to functional deterioration and ecological decline that harms environment and socio-economy development. Therefore, peat degradation is definitely a complex process associated with land uses and social perspectives. Unwise land uses drive significant changes of physical, biological and chemical properties towards peat degradation. These changes consist of subsidence, reduction of water holding capacity, increases in Dry Bulk Density (DBD), pH and Total Sulphur (TS), and a decrease in Total Organic Carbon (TOC) and Total Nitrogen (TN).

The underlying causes of peat degradation are commonly land use conversion from peat swamp forests into agriculture and other uses. As peat growth depends on inputs of fresh vegetation biomass, the removals of peat forming vegetation directly reduce the deposit of vegetation biomass into peat profile. Without consistent input of vegetation biomass, peats stop to grow (Moore, 1989; Clymo, 1984, 1991). In addition to vegetation removals, the peat forest conversion is usually associated with the construction of drainage canals that lower water table depths for creating favourable medium for growths of crops. A decomposition rate in drained peat with low water table depth is more rapid than in water-saturated peat with high water table depth. The decline of water table depths increases the thickness of oxidative layer (acrotelm), which is rich in oxygen (aerobic), fresh litter and moist. The acrotelm is active and more favourable for decays than the permanent water-logged layer (catotelm).

In this preliminary study, I present selected physical and chemical property changes from two different land uses, i.e. peat forest and frequently burnt peatland used for small-scale agriculture. I limit my discussion on the change of selected physical and chemical properties of peats from West Kalimantan Province. These include WC, BD, pH, OM, and concentrations of TOC, TN, TS, and C/N; C/S; N/S molar ratios. I propose important indicators for evaluating peat degradation, briefly assess the underlying cause of peat degradation, and address a policy change for conserving peat forests.

2 Methods

Peat core samples were retrieved from both peat swamp forests and converted peat forests into small-scale agriculture scheme (i.e. seasonal agricultural practices with the use of fire in land preparation). Cores from peat forests are from Nung peat forest (NF), Selimbau-Mantan forest (SMF), and Sungai Putri Forest (SPF). NF and SMF represent inland basin peat and high peat, and SPF belongs to coastal basin peat forest. The converted peats consist of disturbed Sungai Putri peat (DSP), and Rasau Jaya Peat (RJ). Both DSP and RJ sites belong to coastal basin peat, and are annually disturbed by fire. RJ site is located near Pontianak, and DSP site is located near Ketapang, in the South part of the province. NF site is located in Danau Sentarum National Park, about 700 km from the coast. The location of SMF is in the south of the National Park. SPF is a part of Sungai Putri peat dome near Ketapang, in the South of Pontianak (see Fig. 1).

I collected peat core samples using a Russian type auger by Eijkelkamp, Holland. The peat sample campaigns were done between 2007 and 2009. I made line transects and took a sample every 1000 m at SPF site. Samples from other sites were randomly collected.

I retrieved the core sample every 50 cm increment until reclaiming mineral substrate beneath peat. Every 50 cm peat core was transferred into half-cut PVC pipe (Φ=2 inch), and carefully wrapped with home cling wrap. I took subsamples from selected peat cores for analyses of pH (H_2O), pH (KCl), WC, LOI, Ash Free DBD, TOC, TN and TS.

Measurements of pH (H_2O) and pH (KCl) were conducted with Inolab pH meter (type 720 Bench top ph meter). Fresh subsamples were diluted into distilled water and 1 M KCl at 1:5 and 1:2.5 ratios for pH (H_2O) and pH (KCl) measurements. A known volume of subsamples (100 cm^3) was analyzed to measure ash free DBD.

WC was determined by gravimetric method. First, we weighed the known volume of wet peat mass, and then put the sub-samples in the oven at 110 °C for 24–48 h until the samples reached a constant weight. LOI values were calculated after combusting the samples at 550 °C for 5 h. LOI value is used to represent OM value. WC, ash free DBD, and LOI were calculated using Eqs. (1), (2), (3), and (4).

$$\text{Water Content (g kg}^{-1}) = \frac{\text{WS (g)} - \text{DOW}_{110}\text{ (g)}}{\text{DOW}_{110}\text{ (g)}} \times 1000 \quad (1)$$

$$\text{DBD (g cm}^{-3}) = \frac{\text{DOW}_{110}\text{ (g)}}{\text{SV (cm}^3)} \quad (2)$$

$$\text{LOI (g kg}^{-1}) = \frac{\text{DOW}_{110}\text{ (g)} - \text{AW}_{550}\text{ (g)}}{\text{DOW}_{110}\text{ (g)}} \times 1000 \quad \text{(Heiri et al.,2001)} \quad (3)$$

$$\text{Ash Free DBD (g cm}^{-3}) = \text{DBD} \times \text{LOI} \quad (4)$$

Where: WS = wet sample weight, DOW_{110} = constant weight after drying at 110 °C for 24–48 hours, SV = sample volume, LOI = Loss on Ignition, DBD = Dry Bulk Density, AW_{550} = ash residue weight after combusting at 550 °C for 5 h.

The concentrations of TOC, TN and TS were determined by dry combustion at high temperature with El Vario CHNS Analyzer. Samples were prepared by drying at 40 °C for at least 24 h until constant weights. About 20 mg of dry samples were oxidized and the evolved gases were measured.

In order to know the age of peats, I also sent three samples of peats from RJ site to Waikato Laboratory in New Zealand for ^{14}C analysis. Other peat age data in this paper were adopted from secondary sources. I converted ^{14}C age into Calendar year age with an Oxcal 4.1 program (Ramsey, 2010).

3 Results

3.1 Peat age and formation

Peat is formed in thousands of years. The age of tropical peats is so variable, spanning from 30 000 to hundreds of years (Anshari et al., 2001, 2004; Page et al., 2004; Wüst and Bustin, 2004; Wüst et al., 2008). Tables 1 and 2 represent selected ages of peat from coastal and inland region of West Kalimantan.

The radio Carbon analysis indicates that peat in RJ site is formed around 3,000–4,000 yr BP. The basal dates show that the formation of peats in this coastal region probably occurred at the same time. In contrast, the formation of peats in the upper Kapuas river basin was probably erratic. Results of radio carbon dates indicate a variability of peat ages that may demonstrate a different history of peat formations in the upper Kapuas River basin. The peats from the upper Kapuas River are very much older than peats from the coast (See Table 2).

3.2 Peat and water table depths

According to Soil Survey Staff (2010), Histosol is organic soil that has a thickness of 40 cm organic matter in the upper part of 80 cm soil profile. Organic soil with organic matter thickness less than 40 cm is called peaty soil. In this research, I follow this definition in order to record peat depths. I recorded 113 peat depths between June 2007 and February 2009.

Peat depths are spatially variable (Anshari, 2010). Table 3 presents a record of average peat depths in the research sites. In coastal basin peats in Sungai Putri Forest (SPF site), peat depths range from very shallow (1.3 m) to very deep (±15 m). Peat depths in Nung Forest of Lake Sentarum National Park (NF site) are also varied, from 2 to 10 m. The Nung peat forest is classed as a small inland basin peat. In Selimbau Mantan Forest (SMF site), the variability of peat depths ranges from 40 cm to 5.5 m. This is high peat, with altitude between 30 and 50 m a.s.l. In disturbed sites (DSP and RJ), the variability of peat depths are also high.

Table 4 presents a record of water table depths. In the forested peats of NF and SPF sites, the water table depths in dry months were fairly high. High water tables were also recorded in SMF site. In contrast, in disturbed site, the water tables may greatly fluctuate between dry and rainy months. In this research, water table depths in disturbed peats were recorded during rainy months (April and November 2008). A large proportion of DSP site was very much inundated due to close to rivers and lakes. Peat subsidence in RJ site seems to cause high water table depths during the rainy season.

3.3 Major peat properties

Table 5 presents average values of DBD, WC, LOI, TOC, TN, TS, molar ratios of C/N; C/S; and N/S, pH (H_2O), and pH (KCl) in the forested peats from SPF site. These forested peats are characterized by low pH and DBD values, with an average of

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3.81 and 0.08 g cm^{-3}, respectively. The average values of WC and LOI are very high. The average value of TOC is 54.21%, and the average values of TN and TS is very low.

Table 6 presents average values of DBD, WC, LOI, TOC, TN, TS, molar ratios of C/N; C/S; and N/S, pH (H_2O), pH (KCl), and pH (H_2O) in the disturbed peats from DSP site. Major properties of these disturbed peats are characterized by fairly high value of DBD, and low values of LOI, TOC and TN. Disturbed peats indicate an increase of TS content. In disturbed peats, drainage canal causes peat compaction, and subsequently lead to peat subsidence. The latter process also drives Carbon loss to air and water transport in the forms of CO_2 gas, and Dissolved Organic Carbon (DOC). It is also interesting to note that a decline of Nitrogen in disturbed peat may inhibit biological decomposition due to limitation of Nitrogen availability. It seems that seasonal fire may play an important role in Carbon removals from tropical peats.

4 Discussions and conclusions

Factors that support the growth of tropical peat are consistent deposit of biomass, persistent waterlogged environment, low pH (acidic), nutrient deficiency, high rainfall with even distribution all year, and absence of disturbances (i.e. fire and deforestation). These pedogenic, climatic, biogenic and anthropogenic factors are strongly influential in peat formations. There are three types of peat genesis. Sieffermann et al. (unpublished) proposed coastal, basin and high peats. Coastal peats occurs near sea level (3–10 m a.s.l.), and are moderately shallow (3–5 m), with close association with mangroves, brackish water, and tidal influences. Further, inland along the river valleys with the altitudes between 5 and 20 m, basin peat domes occur. Podzolization in the mineral substratum supports the development of water-logged environment. Tides influence the periphery of basin peat dome, and the centre of dome is commonly flat, and seasonally flooded by rain water. Small hills and rivers may cut basin peat dome.

High peats occur in the depressions at altitude greater than 20 m a.s.l. Sometimes, high peats are marginally developed between hills or undulating terrains of the upper river basin. High peats may form small domes, with variability of depths. The formation of hard-pan in the mineral substratum maintain inundated environment.

Biomass deposit into peat profile suffers from decomposition, and it is only between 5 and 10% of the biomass are preserved into peat. Poor nutrients and low pH inhibit the growth of decomposers. High lignin content in the peat forming vegetation species slows biological and chemical decomposition.

During a period of low water table depth, tropical peats might not accumulate. During the last glacial maximum, tropical peats might suffer from rapid decomposition due to seasonal climate. Tropical peats might have not accumulated in the Last Glacial Maximum. Some tropical peats in Central Kalimantan were developed in early Holocene (10 000 years) and then have experienced high decay rates since the last 3000–5000 years (Wüst et al., 2008; Sieffermann et al., 1988). In the future climate, it is predicted that rainfall is more variable and this would enhance the degradation of tropical peats (Li et al., 2007).

Indicators for evaluating peat degradation are essentially required. Changes in peat properties may be used to indicate peat degradation. In this study, peat properties in forested peats are used as a reference, and the properties in disturbed peats demonstrate some degrees of peat degradation.

Peat pH, WC and DBD are not very good indicators for measuring peat degradation. Peat pH is consistently low in both peat forest and open peat profiles. Water contents are usually very high in peats. Degraded peats may reduce water-holding capacity as the decline of organic matter. However, WC measurement is not practical as peat sample substantially loses the water during transportation from research site to laboratory. In general, DBD of peats is less than 0.1 g cm^{-3}. An increase in DBD value in disturbed peat indicates compaction and shrinkage. It is currently not known the relation between DBD and decomposition that leads to Carbon emission. Therefore, the use of high BD values due to compaction and shrinkage in Carbon loss prediction

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leads to inaccurate estimates. Depending on land uses, DBD in peats for agricultural uses tends to be greater than 0.100 g cm^{-3} due to drainage influences. DBD values in forested peats are generally less than 0.100 g cm^{-3} (See Tables 5 and 6).

The major properties of tropical peats in a natural state contain high values of OM or extremely low values in ash. An increase in ash residue or a reduction of OM indicates a process of peat degradation. In general, forested peats have greater than 90% OM. The concentration of TN in degraded peat is extremely low, and the concentration of TS in degraded peat is sufficiently high.

In this study, effective indicators for assessing peat degradation are the concentrations of OM and TOC. These variables are relatively easy to measure, and seem to be reliable for assessing peat degradation in the tropics. Low values of organic matters and TOC below 90% and 40%, respectively indicate peat degradation. An increase of TS in disturbed peats from coastal region may also be used to demonstrate peat degradation. An increase in Sulphur content in coastal peat might lead to formation of acid sulphate soil. TN commonly decreases in degraded peats due to peat fire.

Peat degradation is embedded in the present land use policy that supports large private investments to convert peatland forests into other land uses. The present government policies (The Presidential Decree No. 32/1990 and The Ministry of Forestry Regulation No. 14/2009) treat peat as a potential medium for agriculture, and insufficiently consider peats as a protected forest. Both policies wrongly perceive that only peat depth greater than 3 m should be conserved. In facts, the environmental function of peats is not dependent upon peat depths, but intact structure of the whole peat dome. The use of shallow peat (<3 m) for agricultural uses slowly destroys the ecosystem of peat complex. The present policies lack to consider differences in peat habitats, pedogenic factors, and resilience capability to disturbances. Ecological functions as Carbon sink and storage are principally forgotten.

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Table 1. ^{14}C and Calibrated Calendar Ages of peats from RJ site.

No	Lab Code	Depth (cm)	Age (^{14}C yr BP)	SD	Calibrated Date (Cal yr BP) Mean	SD	Median
1	Wk 26756	40	631	33	607	34	599
2	Wk 26758	440	3175	39	3402	38	3401
3	Wk 26757	700	3784	40	4164	73	4163
4		450*	6590	60	3896	90	3896
5		580*	3410	40	3665	63	3661
6		700*	3600	60	3911	90	3910
7		700*	3410	60	3668	86	3664

Note: Those last four ages are adopted form Diemont and Supardi (1987).

Table 2. ^{14}C and Calibrated Calendar Ages of peats from NF site (Source: Anshari et al., 2004).

No	Lab Code	Depth (cm)	Age (^{14}C yr BP)	SD	Calibrated Date (Cal yr BP) Mean	SD	Median
	Core A						
1	OZE 137	10–11	12 440	60	14 547	241	14 531
2	OZE 138	27–28	28 900	250	33 562	457	33 509
3	OZE 139	49–50	28 250	150	32 502	329	32 521
4	OZE 140	102–103	24 250	120	29 041	237	29 063
5	Wk 5777	120–150	23 570	170	28 325	214	28 318
6	OZE 141	149–150	32 800	300	37 476	501	37 401
	Core B						
7	OZE 133	14–15	265	35	320	93	313
8	Wk 6278	41–42	1366	72	1276	72	1285
9	OZE 134	60–61	2920	50	3077	83	3073
10	Wk 6275	67–68	3117	57	3330	68	3338
11	OZE 135	71–72	13 070	70	15 809	344	15 804
12	Wk 6277	91.5–92.5	16 840	120	19 982	201	20 005
13	OZE 136	94–95	28 600	250	33 011	469	33 019
14	Wk 5779	104–124	28 780	100	33 273	255	33 250

Table 3. A record of peat depths from forested and disturbed peats.

Site	Peat Type	Date of sample collection	Peat Depth (cm) Mean	SD	Median	Number of Measurements
NF	Inland Peat Forest	Jun 2007	−568	339	−500	5
SPF	Coastal Peat Forest	Jun–Nov 2008	−717	278	−776	53
SMF	Inland Peat Forest	Jan–Feb 2009	−293	161	−300	20
DSP	Coastal Disturbed Peat	Nov 2008	−441	272	−350	21
RJ	Coastal Disturbed Peat	Apr 2008	−467	211	−425	14

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Table 4. A record of water table depths from forested and disturbed peats.

Site	Peat Type	Date of sample collection	Peat Depth (cm) Mean	SD	Median	Number of Measurements
NF	Inland Peat Forest	Jun 2007	−36	32	−28	5
SPF	Coastal Peat Forest	Jun–Nov 2008	−25	16	−25	53
SMF	Inland Peat Forest	Jan–Feb 2009	−9	15	−3	20
DSP	Coastal Disturbed Peat	Nov 2008	13	45	5	21
RJ	Coastal Disturbed Peat	Apr 2008	−28	15	−24	14

Table 5. Major properties in forested peat from SPF site.

Plot	subsample	DBD ($g\,cm^{-3}$)	WC ($g\,kg^{-1}$)	LOI ($g\,kg^{-1}$)	TOC %	TN %	TS %	C:N	C:S	N:S	pH (H_2O)	pH (KCl)
W2	7	0.102	7014.36	888.53	53.36	0.98	0.25	67.66	3484.57	58.71	3.78	3.46
W5	7	0.086	6351.10	969.90	55.97	1.09	0.02	62.24	8754.73	142.09	4.09	3.70
W8	6	0.088	7388.54	969.73	57.49	0.97	0.02	74.50	6256.95	134.29	3.98	3.42
X10b	15	0.088	9451.44	937.94	55.77	1.03	0.51	66.72	295.94	4.63	3.49	2.72
X10	11	0.096	7046.51	973.72	56.19	0.91	0.03	76.70	6355.32	90.82	4.34	3.54
E11	16	0.076	10 459.99	966.23	55.12	1.18	0.30	56.79	488.76	8.89	3.85	2.81
E13	11	0.069	11 228.08	935.56	55.42	1.20	0.37	57.37	397.73	7.37	3.62	2.98
E14	18	0.080	8731.63	919.19	54.68	0.95	0.23	71.13	634.70	9.42	3.25	2.68
E16	18	0.066	11 012.71	974.72	53.97	0.92	0.14	68.69	2063.11	30.06	3.68	2.97
E20	22	0.077	10 518.98	947.81	54.29	1.13	0.13	60.51	1532.65	27.33	3.52	2.80
E22	24	0.082	10 062.18	935.03	52.02	0.98	0.06	62.76	4217.57	68.40	3.96	2.95
E23	21	0.074	10 317.77	964.29	52.21	1.01	0.06	60.87	3504.49	58.45	4.23	2.86
E24	20	0.081	10295.09	964.89	49.89	1.09	0.06	54.32	3830.16	72.48	4.04	2.74
E27	8	0.067	11 103.92	957.17	53.52	1.25	0.18	53.24	825.43	15.93	3.99	3.04
E30	10	0.074	10 559.14	923.05	53.21	1.13	0.13	56.16	1084.92	19.79	3.36	2.77
Total	214											
Grand Mean		0.080	9436.10	948.52	54.21	1.05	0.17	63.31	3115.14	49.91	3.81	3.03

Table 6. Major properties in disturbed peats from DSP site.

Plot	Subsample	DBD ($g\,cm^{-3}$)	WC ($g\,kg^{-1}$)	LOI ($g\,kg^{-1}$)	TOC %	TN %	TS %	C:N	C:S	N:S	pH (H_2O)	pH (KCl)	pH (H_2O_2)
DSP2	2	0.123	6897.186	924.329	38.835	1.227	0.470	48.811	221.275	6.053	3.965	2.985	N/A
DSP4	6	0.145	1370.130	255.031	14.617	0.358	0.899	47.018	59.195	1.236	3.623	2.655	2.198
DSP5	6	0.095	6062.928	690.872	34.830	0.437	1.995	96.013	65.527	0.733	3.952	2.897	1.530
DSP7	5	0.162	4179.435	799.433	30.393	0.495	1.351	65.531	67.854	1.003	3.724	3.412	1.560
DSP8	8	0.102	6703.422	895.786	48.253	0.864	0.269	63.571	472.129	7.313	3.713	3.203	2.347
DSP9	5	0.133	1155.253	212.449	10.689	0.220	1.483	52.931	22.684	0.412	3.802	3.846	1.550
DSP10	9	0.077	9705.617	992.082	52.817	0.900	0.300	68.530	471.676	6.884	4.033	3.211	2.570
DSP15	7	0.047	10 337.449	832.495	52.019	1.077	0.300	57.235	475.358	8.343	3.854	3.116	N/A
DSP18	2	0.072	6518.439	575.862	41.858	0.791	0.271	61.436	409.974	6.679	5.150	4.705	N/A
DSP19	4	0.077	9190.359	723.438	43.358	0.785	0.221	62.636	501.813	7.874	4.523	3.723	2.075
DSP22	4	0.086	2475.462	347.711	20.615	0.263	2.513	89.210	144.940	0.800	4.085	3.663	1.445
Total	58												
Grand Mean		0.102	5872.335	659.044	35.274	0.674	0.915	64.811	264.766	4.303	4.039	3.401	1.909

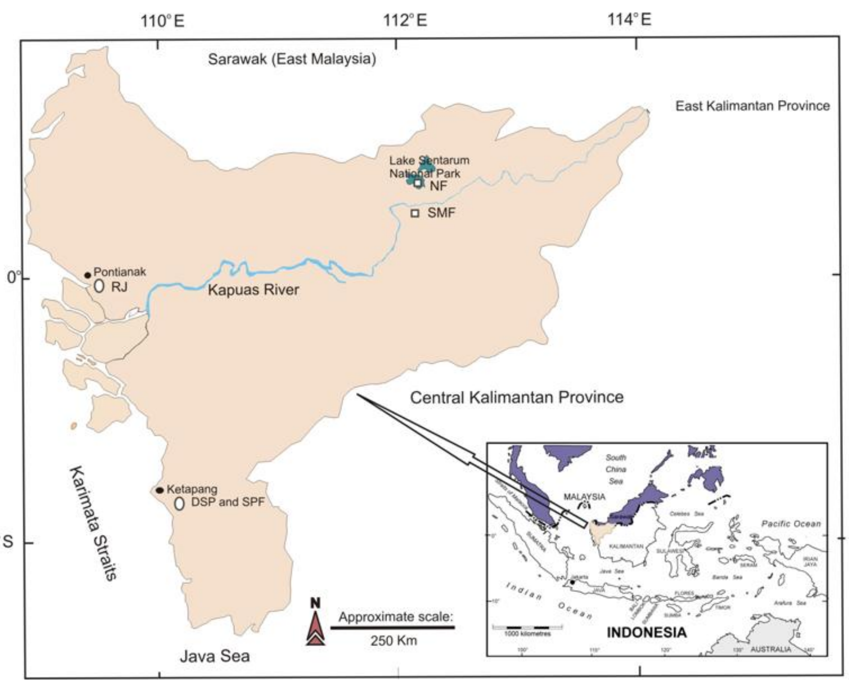

Fig. 1. A map of West Kalimantan Province, showing research sites, the Kapuas River and Lake Sentarum National Park.