Research Article

Sedimentary Organic Matter and Phosphate along the Kapuas River (West Kalimantan, Indonesia)

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This study assessed the sedimentary organic matter (OM) and phosphate along the world's longest river on an island: the Kapuas River in West Kalimantan, Indonesia. The surface sediment was tested using the loss-on-ignition experiment to determine the % labile OM, % refractory OM, and % total OM and the Rp values (the ratio of refractory to total OM). The C/N ratios and the inorganic phosphate (IP), organic phosphate (OP), and total phosphate (TP) levels were also determined. The combination of high Rp values and low C/N ratios along the upper river indicated the possible presence of relatively degraded material; the low Rp values and high C/N ratios downstream were indicative of a fresher terrestrial signal. Sedimentary P levels were the highest along the densely populated areas downstream from the Kapuas River; the second highest along the midstream river, which is surrounded by oil palm plantations; and the lowest along the upper river, which is surrounded by forest. Higher levels of OM, IP, OP, and TP downstream along the Kapuas River indicated the presence of anthropogenic sources of OM and P.

1. Introduction

Rivers are major regulators of global climate change due to their role as contributors to atmospheric CO₂ emissions [1, 2]. Rivers, in turn, are greatly affected by global climate change and are consequently at risk [3]. For instance, increased temperatures affect the hydrological cycles of rivers worldwide [4], increasing river runoff in some regions of the world while reducing river runoff in other regions [5, 6]. One of the consequences of increasing river runoff is increased nutrient discharge to coastal zones. This has a significant impact, particularly in areas that were already receiving a high input of nutrients from their surroundings [7]. Human activities such as urbanization and deforestation have resulted in an increase in the amount of soil organic matter released into

rivers by erosion. However, building reservoirs has decreased the amount of sediment discharged into rivers and coastal zones and altered the timing of sediment discharge. In Indonesia, where there are few reservoirs, rivers still deliver a considerable amount of sediment to coastal zones [8]. This has major consequences because Southeast Asia contains a vast area of peatland [9, 10], and peat soils tend to leach dissolved organic carbon (DOC) into rivers in quantities several orders of magnitude higher than nonpeat soils do. Consequently, tropical rivers are major sources of DOC to the oceans [11–13]; this leaching is exacerbated by global climate change because increased temperatures [14] and precipitation [15] have resulted in the increased export of DOC from peat soils into rivers and coastal zones. Currently, management

FIGURE 1: Map showing the sampling locations along the Kapuas River (which includes the Kapuas Kecil River and Kapuas Besar River), the Mempawah and Landak Rivers, and the Lakes Sentarum, Pemerak, and Pengembung.

strategies to maintain the quality of river and estuary waters are more important than ever [4, 16]. Knowledge of sediment organic matter (OM) and nutrients along rivers is beneficial for developing these management strategies.

In this study, surface sediments were collected from the Kapuas River, the Landak River, and the Mempawah River and from the three lakes that drain into the Kapuas River. Using the loss-on-ignition experiment, these sediments were tested to determine the % labile OM, % refractory OM, and % total OM and the Rp values (the ratio of refractory OM to total OM). Additionally, inorganic phosphate (IP), organic phosphate (OP), and total phosphate (TP) levels were determined. This study presents a profile of OM and P along a Southeast Asian tropical river for the purpose of further understanding the dynamics of the river.

2. Methods

2.1. Study Sites. The Kapuas River is located in West Kalimantan, Indonesia. With a length of 1143 km, this is the longest river in Indonesia and the world's longest river on an island. Sampling was carried out from June to July 2007 and December 2007 to January 2008 at the three lakes (Sentarum, Pemerak, and Pengembung) that drain into the upper Kapuas River, at locations spanning the entire extent of the Kapuas River, and at the Landak and Mempawah Rivers. Downstream Kapuas River branches into Kapuas Kecil River

and Kapuas Besar River (Figure 1). Sediment was collected by deploying an Eijkelpamp peat sampler from a small boat into a water depth of approximately 2 m. The 0–5 cm surface sediment was saved for chemical analyses. In the laboratory, the sediment was dried at 60°C for a few days, ground using a mortar and pestle, and sieved through a 43-mesh sieve. Details describing the river and sampling locations, including the sampling timetable and distances between the locations and the river mouth, are given by Loh et al. [17, 18]. Detailed information on population densities, wet and dry seasons, and forest types (landscapes) along the Kapuas River, hydrological cycles, and sediment loading have been reported in previous studies [17, 18].

2.2. Analytical Method. The loss-on-ignition experiment was compiled from methods used by Kristensen [19], Kristensen and Andersen [20], and Sutherland [21]. A sample of approximately 0.5 g of dried, ground, and sieved sediment was weighed in a crucible. Crucibles with sediment were weighed and then combusted at 250°C for 16 hours in a temperature-monitored muffle furnace. When cool, the crucibles were reweighed. The sediment was then heated to 500°C for 16 hours. When cool, it was weighed again. The percentage of weight reduction after reaching 250°C is known as the % labile organic matter. The percentage of weight loss that occurs within the temperature range between 250°C and 500°C is the % refractory OM. The sum of the % labile and %

refractory OM is the % total OM. The Rp index is the weight loss that occurs in the temperature range between 250°C and 500°C divided by the total weight loss on ignition; hence, the Rp value is the ratio of the % refractory OM to the % total OM. Kristensen [19] defined Rp as $Rp = P_{II}/(P_I + P_{II})$, where PI is the weight loss that occurs after combustion in the first temperature range and PII is the weight loss after combustion in the second temperature range.

The method used for phosphate analysis was obtained from Strickland and Parsons [22], Aspila et al. [23], and Koroleff [24]. Dried sediment was weighed to 0.25 g and washed with 20 mL of 1 M HCl in a 50 mL centrifuge tube. The sediment was extracted with constant shaking for 16 hours at room temperature. On the following day, the supernatant was decanted, and the residue was washed with 5 mL of HCl, centrifuged, and combined with the supernatant for IP analysis. The residue was transferred to a crucible and heated in a muffle furnace at 550°C for two hours. When cool, the residue was transferred to a centrifuge tube and extracted with 25 mL of 1 N HCl for 16 hours at room temperature with constant shaking. The residue was then centrifuged and the supernatant decanted for OP analysis. P was analysed using the molybdenum blue method with a UV-visible spectrophotometer.

For the bulk elemental analysis, the sediment was acidified with 1 N HCl overnight to remove carbonates. The sediment was then rinsed with distilled water, dried at 60°C, and homogenized using a mortar and pestle. Precisely 20 mg of sediment was weighed into a 4 × 4 × 11 mm tin boat and crimped into a pellet. The sediment was analysed for TOC and total nitrogen (TN) using a Vario EL III Elemental Analyzer. The standard reference materials used were BSCC (2.24% TOC, 0.24% TN) and NIST2704 (3.34% TOC, 0.22% TN). The average coefficients of variation for each measurement (in duplicate and triplicate analyses) of a same-sediment sample were 2.32% for TOC and 3.08% for TN. All C/N ratios were calculated as TOC/TN molar ratios.

3. Results

Table 1 shows the results obtained for % labile OM, % refractory OM, % total OM, Rp values, IP, OP, and TP. The overall reproducibility was good, with the percentage reproducibility of duplicate and triplicate analyses of % labile and % refractory OM ranging from 0.02 to 6.41%. Percentage reproducibility from duplicate analyses of P ranged from 0.01 to 27.76%. Percentages of labile, refractory, and total OM ranged from 1.61 to 12.19%, 2.32 to 8.70%, and 4.46 to 20.89%, respectively. Both % labile and % refractory OM showed a constant range of values along the upper and middle sections of the Kapuas River and showed the highest values downstream of the river (Figures 2(a) and 2(b)). Both the labile and refractory fractions showed good correlations with total OM (Pearson correlation coefficient, $r > 0.95$; $p < 0.05$; $n = 21$) for the June to July 2007 sample. Refractory OM was slightly higher at the upper river and lakes for the December 2007 to January 2008 sample; hence, there was a lower but still significant ($p < 0.05$) correlation between the refractory fraction and labile and total OM during this

time. Rp values (ratio of refractory to total OM) ranged from 0.25 to 0.64, with the highest values observed in the upper river and lakes and the lowest values observed downstream (Figure 2(c)). Rp values showed good negative correlation with total OM ($r > -0.7$; $p < 0.05$; $n = 21$). The IP, OP, and TP ranged from 0.03 to 1.55 mg P/g, 0.30 to 0.82 mg P/g, and 0.40 to 2.37 mg P/g, respectively. Overall, IP, OP, and TP had similar distribution trends to OM, with slightly higher concentrations at locations downstream than at locations along the upper river (Figure 3). TP showed a better correlation with IP ($r > 0.9$) and a poorer correlation with OP ($r = 0.6$ to 0.8), and IP showed good correlation with labile OM ($p < 0.05$). Overall, the Landak River has the highest labile OM and the Mempawah River has higher Rp values than the Landak River. The Landak River has higher IP, OP, and TP than the Mempawah River (Figures 2 and 3).

4. Discussion

4.1. Use of Rp Values and C/N Ratios to Determine the Sources and Diagenesis of Sediment OM. A combination of Rp values and C/N ratios was used to further elucidate the sources and diagenesis of sedimentary OM along the river. It was found that Rp values of approximately 0.3 are indicative of plant material rich in carbohydrates, and higher Rp values of approximately 0.6 are indicative of biogenic material or more degraded OM. Furthermore, humic materials have high Rp values and C/N ratios, and an advanced stage of OM decomposition was associated with an increase in Rp values and a decrease in C/N ratios. Several scenarios based on these combinations have been observed: (i) low Rp values and high C/N ratios may indicate terrestrial plants as the OM source, (ii) increases in both Rp values and C/N ratios may be indicative of the process of humification, and (iii) high Rp values and low C/N ratios may be indicative of more degraded OM [19]. These combinations were observed along different stretches of the Kapuas River. Scenario (i) occurred at locations 1 through 6 along the lower Kapuas River, which showed lower Rp values but higher C/N ratios, indicating the contribution of fresher plant material. Rp values in the mid- and lower Kapuas River and the Landak and Mempawah Rivers ranged from 0.39 to 0.48, also indicating fresher plant material as the source of OM. Scenario (ii) occurred at location 16, which had a high Rp value and a high C/N ratio. Scenario (iii) was observed along the upper Kapuas River and in the lakes, which had overall higher Rp values (0.59 to 0.64) and lower C/N ratios; this is indicative of more degraded OM material (Figures 4(a) and 4(b)), consistent with the detection of older peat material along the upper Kapuas River than along the lower Kapuas River [25, 26]. Overall, these results are in accordance with our previous findings that the upper Kapuas River has slightly higher values of vanillic acid/vanillin and syringic acid/syringaldehyde ratios, indicative of more degraded lignin materials, compared to midstream and downstream Kapuas River [17].

4.2. Phosphate in the Sediment of the Kapuas River. The areas surrounding the Kapuas Kecil River were the most populated, followed by the areas surrounding Kapuas Besar.

TABLE 1: Loss-on-ignition, phosphate, and bulk elemental results.

(a) June-July 2007 sampling

Loc.	Loss on ignition			Phosphorus				Bulk elemental		
	Labile (%)	Refrac. (%)	TOM (%)	Rp	IP (mg/g)	OP (mg/g)	TP (mg/g)	OC (%)	TN (%)	C/N
KB1 (A)	6.83 ± 0.00	5.22 ± 0.02	12.05	0.43	0.63 ± 0.01	0.63 ± 0.01	1.26	3.04	0.19	18.67
KB2 (B)	7.70 ± 0.01	4.94 ± 0.03	12.64	0.39	0.62 ± 0.00	0.62 ± 0.00	1.24	3.22	0.20	18.78
KB3 (E)	6.10 ± 0.04	4.42 ± 0.04	10.52	0.42	0.62 ± 0.00	0.39 ± 0.11	1.01	2.72	0.16	19.83
1	8.96 ± 0.07	5.81 ± 0.03	14.77	0.39	0.78 ± 0.00	0.62 ± 0.00	1.40	5.04	0.24	24.50
2	8.60 ± 0.02	6.52 ± 0.01	15.12	0.43	1.55 ± 0.02	0.82 ± 0.05	2.37	5.11	0.30	19.87
3	12.19 ± 0.07	8.70 ± 0.08	20.89	0.42	1.12	0.78	1.90	8.88	0.44	23.55
4	8.52 ± 0.26	5.32 ± 0.16	13.84	0.38	0.63 ± 0.01	0.63 ± 0.01	1.26	4.69	0.22	24.87
5	6.93 ± 0.02	5.21 ± 0.03	12.14	0.43	0.62 ± 0.00	0.55 ± 0.11	1.17	3.32	0.20	18.67
6	4.62 ± 0.01	3.77 ± 0.02	8.39	0.45	0.47 ± 0.00	0.47 ± 0.00	0.94	2.11	0.12	20.51
7	5.63 ± 0.09	5.07 ± 0.07	10.70	0.47	0.63 ± 0.00	0.55 ± 0.11	1.18	2.47	0.16	15.17
8	5.92 ± 0.05	5.52 ± 0.03	11.44	0.48	0.47 ± 0.00	0.62 ± 0.01	1.09	2.51	0.19	15.41
9	6.69 ± 0.04	4.97 ± 0.02	11.66	0.43	0.62 ± 0.01	0.62 ± 0.01	1.24	3.11	0.20	18.14
10	3.06 ± 0.04	2.71 ± 0.01	5.77	0.47	0.39 ± 0.12	0.31 ± 0.00	0.70	1.36	0.08	19.83
11	5.22 ± 0.00	3.67 ± 0.06	8.89	0.41	0.32 ± 0.00	0.47 ± 0.00	0.79	2.28	0.13	20.46
12	4.13 ± 0.02	3.45 ± 0.01	7.58	0.46	0.46 ± 0.01	0.31 ± 0.00	0.77	1.92	0.11	20.36
13	5.49 ± 0.02	3.74 ± 0.03	9.23	0.41	0.63 ± 0.00	0.47 ± 0.00	1.10	2.63	0.15	20.46
14	5.61 ± 0.06	3.89 ± 0.09	9.50	0.41	0.63 ± 0.00	0.47 ± 0.00	1.10	2.77	0.15	21.54
15	6.56 ± 0.03	4.45 ± 0.04	11.01	0.40	0.62 ± 0.01	0.55 ± 0.12	1.17	3.22	0.21	17.89
16	2.24 ± 0.03	2.32 ± 0.02	4.56	0.51	0.47 ± 0.01	0.31 ± 0.00	0.78	0.86	0.05	20.07
17	3.30 ± 0.62	4.66 ± 0.61	7.96	0.59	0.31 ± 0.00	0.46 ± 0.00	0.77	1.94	0.17	13.31
18	2.91 ± 0.09	4.29 ± 0.01	7.20	0.60	0.16 ± 0.00	0.16 ± 0.00	0.32	0.59	0.08	8.60
19	2.65 ± 0.02	4.21 ± 0.02	6.86	0.61	0.32 ± 0.00	0.32 ± 0.00	0.64	0.62	0.09	8.04
20	1.61 ± 0.02	2.85 ± 0.03	4.46	0.64	0.16 ± 0.00	0.31 ± 0.00	0.40	0.55	0.06	10.69
21	2.59 ± 0.01	3.80 ± 0.01	6.39	0.59	0.31 ± 0.00	0.47 ± 0.00	0.51	1.04	0.12	10.11
LK1	20.76 ± 0.16	6.81 ± 0.22	27.57	0.25	0.93 ± 0.00	0.62 ± 0.00	1.55	14.20	0.55	30.12
LK2	16.35 ± 0.01	7.00 ± 0.02	23.35	0.30	0.31 ± 0.01	0.47 ± 0.01	1.41	8.96	0.30	34.84
LK3	8.05 ± 0.02	4.56 ± 0.04	12.61	0.36	0.47 ± 0.00	0.47 ± 0.00	0.94	3.84	0.17	26.35
MH1	6.57 ± 0.01	5.58 ± 0.03	12.15	0.46	0.63 ± 0.01	0.31 ± 0.01	0.94	2.90	0.13	26.03
MH2	3.92 ± 0.54	3.54 ± 0.52	7.46	0.47	—	—	—	1.80	0.07	30.00
MH3	3.76 ± 0.17	3.99 ± 0.23	7.75	0.51	—	—	—	1.47	0.06	28.58

(b) December 2007-January 2008 sampling

Loc.	Loss on ignition			Phosphorus				Bulk elemental		
	Labile (%)	Refrac. (%)	TOM (%)	Rp	IP (mg/g)	OP (mg/g)	TP (mg/g)	OC (%)	TN (%)	C/N
KB1 (A)	—	—	—	—	0.52 ± 0.00	0.61 ± 0.03	—	—	—	—
KB2 (B)	—	—	—	—	0.64 ± 0.01	0.11 ± 0.00	—	—	—	—
KB3 (E)	—	—	—	—	0.94 ± 0.01	0.58 ± 0.06	—	—	—	—
1	8.66 ± 0.04	5.37 ± 0.05	14.02	0.38	0.75 ± 0.00	0.50 ± 0.02	1.24	4.84	0.30	18.8
2	6.08 ± 0.08	4.38 ± 0.01	10.45	0.42	0.72 ± 0.01	0.50 ± 0.00	1.22	3.90	0.23	19.8
3	6.59 ± 0.04	4.36 ± 0.03	10.95	0.40	0.73 ± 0.00	0.49 ± 0.00	1.22	3.49	0.23	17.7
4	12.95 ± 0.07	6.76 ± 0.38	19.71	0.34	0.23 ± 0.03	0.35 ± 0.00	0.58	9.24	0.35	30.8
5	8.88 ± 0.04	4.85 ± 0.01	13.73	0.35	0.61 ± 0.00	0.44 ± 0.01	1.05	4.22	0.27	18.2
6	8.83 ± 0.03	5.26 ± 0.01	14.09	0.37	0.74 ± 0.00	0.49 ± 0.00	1.23	5.01	0.30	19.5
7	3.65 ± 0.03	4.72 ± 0.00	8.37	0.56	0.30 ± 0.00	0.42 ± 0.03	0.72	1.43	0.17	9.8
8	5.49 ± 0.07	4.42 ± 0.01	9.91	0.45	0.40 ± 0.01	0.40 ± 0.01	0.80	2.47	0.20	14.4
9	2.74 ± 0.00	3.66 ± 0.00	6.40	0.57	0.12 ± 0.00	0.36 ± 0.02	0.49	0.87	0.14	7.3
10	2.34 ± 0.02	3.01 ± 0.03	5.35	0.56	0.16 ± 0.01	0.28 ± 0.00	0.44	0.94	0.13	8.4
11	3.43 ± 0.01	3.68 ± 0.03	7.11	0.52	0.26 ± 0.00	0.36 ± 0.00	0.62	1.34	0.13	12.0
12	4.18 ± 0.00	3.94 ± 0.00	8.12	0.49	0.27 ± 0.00	0.34 ± 0.00	0.61	1.71	0.15	13.3
13	5.41 ± 0.24	3.45 ± 0.11	8.86	0.39	0.42 ± 0.01	0.28 ± 0.01	0.69	2.62	0.16	19.1
14	2.41 ± 0.15	3.96 ± 0.08	6.37	0.62	0.14 ± 0.00	0.40 ± 0.01	0.55	0.63	0.11	6.7
15	4.09 ± 0.00	3.46 ± 0.01	7.55	0.46	0.50 ± 0.01	0.31 ± 0.01	0.82	1.96	0.15	15.2
16	4.75 ± 0.19	4.01 ± 0.02	8.76	0.46	0.53 ± 0.01	0.37 ± 0.02	0.90	2.62	0.18	17.0
17	5.19 ± 0.03	5.55 ± 0.18	10.76	0.52	0.15 ± 0.00	0.43 ± 0.01	0.58	3.33	0.30	13.0

(b) Continued.

Loc.	Loss on ignition				Phosphorus			Bulk elemental		
	Labile (%)	Refrac. (%)	TOM (%)	Rp	IP (mg/g)	OP (mg/g)	TP (mg/g)	OC (%)	TN (%)	C/N
18	4.31 ± 0.01	5.31 ± 0.01	9.62	0.55	0.10 ± 0.01	0.23 ± 0.01	0.32	1.98	0.21	11.0
19	3.59 ± 0.05	5.05 ± 0.02	8.64	0.58	0.19 ± 0.01	0.68 ± 0.00	0.87	1.78	0.26	8.0
20	3.54 ± 0.04	5.02 ± 0.02	8.56	0.59	0.15 ± 0.00	0.47 ± 0.01	0.62	1.91	0.23	9.7
21	3.50 ± 0.00	5.31 ± 0.01	8.81	0.60	0.03 ± 0.00	0.30 ± 0.02	0.33	0.82	0.16	6.0
LK1	14.32 ± 0.01	7.07 ± 0.11	21.39	0.33	0.76 ± 0.00	0.52 ± 0.00	1.28	9.79	0.38	30.1
LK2	15.60 ± 0.24	7.69 ± 0.06	23.29	0.33	0.76 ± 0.00	0.58 ± 0.04	1.34	9.55	0.49	22.7
LK3	10.34 ± 0.04	4.24 ± 0.04	14.58	0.29	0.73 ± 0.02	0.41 ± 0.07	1.14	5.51	0.26	24.7
MH1	7.60 ± 0.04	5.82 ± 0.02	13.42	0.43	0.53 ± 0.00	0.44 ± 0.06	0.97	3.62	0.23	18.4
MH2	6.45 ± 0.01	6.27 ± 0.04	12.72	0.49	0.46 ± 0.00	0.42 ± 0.01	0.87	2.71	0.18	17.6
MH3	4.05 ± 0.06	5.29 ± 0.04	9.34	0.57	0.31 ± 0.00	0.34 ± 0.01	0.65	1.72	0.15	13.4

(a)

(b)

(c)

FIGURE 2: Charts with error bars showing the means and standard deviations for (a) labile OM, (b) refractory OM, and (c) Rp values along the downstream, mid-, and upper Kapuas River, the lakes, Kapuas Besar (KB), and the Landak and Mempawah Rivers (Mem).

FIGURE 3: Charts with error bars showing the means and standard deviations for (a) IP, (b) OP, and (c) TP along the downstream, mid-, and upper Kapuas River, the lakes, Kapuas Besar (KB), and the Landak and Mempawah Rivers (Mem).

The sediment along the stretches of river with the highest population density had the highest IP and OP levels. Hence, we concluded that the sedimentary IP and OP originated from human activities and were discharged into the lower river via fluvial input. Other external sources of P could be from groundwater, fluvial, and atmosphere [27]. Eutrophication can cause high OM input to sediments, which results in increased sedimentary TC, OC, TN, TP, and OP levels [28], followed by increased decomposition of OM [29]. This sequence of events occurred in the downstream Kapuas River, where the sediment also showed high labile, refractory, and total OM and high OP, IP, and TP (Figures 2 and 3). The midriver, which is surrounded by oil palm plantations, has

higher levels of IP and OP than the upper river but lower P levels than the lower Kapuas River. These results show that higher levels of P are found near the oil palm plantations than in the forested area surrounding the upper river, but the P level was nonetheless lower than in the downstream portion of the river.

4.3. Dynamics of the Kapuas River. Forests and tributaries are continuous sources of different amounts of carbon to surrounding reaches of a river [30]. OM is delivered in particulate form such as wood fragments and leaves or sometimes bound to mineral surfaces. Factors such as rainfall, runoff, and snowmelt can affect the supply of organic and inorganic

FIGURE 4: Figure showing the transect profiles of (a) Rp values and (b) TOC/TN molar ratios for samples taken during June-July 2007 and December 2007-January 2008. All the sampling locations numbered from 1 to 21 in Table 1 and Figure 1 are presented in the graph, with location 1 situated nearest to the river mouth and location 21 farthest from the river mouth.

material to sediment [31]. Few studies have determined the levels of OM and nutrients along a river system. CO_2 emissions and the influx of O_2 along a river system may be due to respiration activities fuelled by autochthonous OM [30]; thus, carbon has been found to outgas during transport further downstream [1]. Relatively fresh OM was also a major source of atmospheric CO_2 emissions because fresh material has been found to be respired by organisms fairly rapidly, thereby contributing to atmospheric CO_2 emissions [2]. In a study of fine particulate OM (FPOM), course particulate OM (CPOM), and dissolved OM (DOM) in upstream and downstream Bolivian tributaries of the Amazon River, it was determined that all fractions became more degraded further downstream [32].

In the upper Kapuas River and lakes, logging activities may have exposed the forest soil, causing elevated aerobic OM degradation. This degraded material was then discharged into the river because of erosion. Due to the discharge of more degraded OM but less P into the upper river, we concluded that less OM decomposition occurred in the upper Kapuas River. The midriver, which is surrounded by oil palm plantations, had medium levels of IP and OP compared to the upper and lower Kapuas River and less degraded OM than the upper river. This shows that there were higher levels of P near the oil palm plantations than near the forested areas surrounding the upper river. The most densely populated areas along the Kapuas River were located along the lower river. A high abundance of fresher sedimentary OM and P in this location may have resulted in increased phytoplankton blooms and high rates of OM decomposition. The Landak River has high levels of labile and refractory OM, low Rp values, and high P levels, whereas the Mempawah River has low levels of labile and refractory OM, high Rp values, and medium P levels. Hence, the Landak River may be more prone to phytoplankton bloom and OM decomposition than

the Mempawah River. Overall, June-July 2007, the period with higher rainfall than December 2007-January 2008 [17], also showed higher IP, OP, and TP for most of the locations (Figure 3), indicating some leaching of P from soil into the river.

5. Conclusions

This study is one of few to use the loss-on-ignition experiment to examine sedimentary OM in terms of labile, refractory, and total OM and Rp values and to measure P levels in the sediment along a complete transect of a tropical river in Southeast Asia. This is also one of the few studies to make further use of the Rp values and C/N ratios developed by Kristensen [19] to determine the sources and diagenesis of sedimentary OM. The highest P level was located in the downstream Kapuas River, which was the most densely populated area. The next highest P level was located along the midstream river, which was surrounded by oil palm plantations. The sediment in the upper river, which was surrounded by forest, had the lowest P level. Phytoplankton blooms and high OM decomposition most likely occurred along the downstream Kapuas River where the sediment OM was fresher and more bioavailable and the P level was the highest.

Competing Interests

The authors declare that they have no competing interests.

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