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Environments and People of Sumatran Peat Swamp Forests I: Distribution and Typology of Vegetation

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Abstract

We reconsidered the typology of Sumatran peat swamp forests according to the three zones of lowland plains proposed by Furukawa. Flood zones, occurring edges of lowland plains, are covered mainly by freshwater swamp forests. Central zones feature the sequential zonation of mixed peat swamp forests, *méranti paya* forests, and *padang suntai* forests. Tidal zones are covered by mangrove forests and mixed peat swamp forests. Sequential zonation was also reported in peat swamp forests of Sarawak and Brunei, but the flora of these two areas is unique within the western Malay Archipelago. By virtue of the distribution and composition of flora, the patterns of vegetation zoning are thought to be similar among the lowland plains of the Malay Peninsula, Kalimantan and Sumatra, although zonation was sometimes simpler than this because of climatological and geomorphological conditions.

Keywords: *méranti paya* forests, mixed peat swamp forest, *padang suntai* forest, tropical lowland plain, vegetation zonation

I Introduction

The objective of this three-part series on peat swamp forests is to clarify how the people who live in these forests have adapted to environmental changes, and how overexploitation of the forests has been avoided. The authors who studied villages in peat swamp forests previously [Furukawa 1992; Sumawinata 1992; Abe 1993; 1997] focused mainly on rather new migrant villages. In doing so, they overlooked the fact that Sumatran lowland plains include various environments and the fact that different types of villages are distributed in different kinds of environments. It is sometimes emphasized that exploitation of lowland plains is destructive. However, close relationships between forests and people are sometimes found, and observations of various kinds of villages provide evidences of people's adaptation to natural conditions.

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In order to clarify how people have adapted to environments and how overexploitation has been avoided, the diversity of natural environments should be understood scientifically. The best way to understand this diversity is through the classification of vegetation, which is a sharp indicator of environmental conditions. Thus, in this paper, we classify Sumatran peat swamp vegetation in relation to large-scale zoning of lowland plains in order to provide a framework for a general understanding of the diversity and conditions of natural environments. In this, the second paper in the series, one of the authors, K. Momose, uses those systematic findings on the environment to classify village types in relation to environmental conditions. Then he describes the relationships between forests and people. Finally he discusses the process by which people adapt to their environment, as well as the mechanisms by which they avoid overexploitation. The third paper, which may appear in a different journal, will support the conclusions of the present report through detailed ethnobotanical data.

The most detailed studies about the typology of vegetation in the tropical peat swamps of Sarawak and Brunei were carried out by Anderson [1961]. However, these areas have rather peculiar flora compared with the peat swamps of surrounding areas, including the Malay Peninsula, Sumatra and Kalimantan. Anderson [1976] and Page *et al.* [1999] also reported on the vegetation of peat swamps of Sumatra and Kalimantan. However, the typology they described is too simple and its correspondence with the vegetation zoning of Sarawak and Brunei is unclear.

In reconsidering the typology of vegetation in Sumatran peat swamps, we found that it corresponds well with the vegetation zoning of Sarawak and Brunei. In addition to typology, we should consider why different types of forests occur. We provide a model for the mechanisms by which forest zoning occurs; this model is a hypothesis to be tested in the near future.

Furukawa [1992] recognized three zones (tidal, central and flood) within the Indonesian lowland plains. His division, which was based mainly on geological viewpoints, is very useful for describing broadly the variety of environmental conditions of peat swamps on a large scale. However, he did not discuss vegetation. Thus, the present report examines the relationship between vegetation and Furukawa's zoning classification.

II Review of Vegetation Studies in Peat Swamps of Western Malay Archipelago

The western Malay Archipelago (Malay Peninsula, Sumatra, Borneo, Java, Bali, and surrounding islands) is characterized by extremely rich flora of Sundaland origin and a humid, tropical climate. Botanists call this area, which is bounded by the Isthmus of Kura (the neck of the Malay Peninsula) and the Wallace line (the straits of Lombok and Makassar), West Malesia. North of the Kura Isthmus it is drier, and the flora is different east of the Wallace line. Tropical peat swamps are found on the east and west coasts of the Malay Peninsula, the east coast of Sumatra, Sarawak, and Brunei (Northwest Borneo), West, Central, and South Kalimantan (West and South Borneo), and West Java (although the peat swamp forests in Java have disappeared through intensive development).

Freshwater swamp forests develop in clay or silt deposited around rivers by flooding [Whitemore 1982]. In such cases, the ground surface is seasonally (or aseasonally but temporarily) covered in water. The soil is rich in minerals, and the content of organic matter is not high. The surface water or underground water is neutral (high pH) [Anderson 1964]. If flooding is not heavy, such forests grow to over 40 m. *Alstonia* (*pelai*, Apocynaceae) is a typical dominant genus in freshwater swamp forests, and is often recognized as an indicator of lands suitable for rice fields. If forests suffer heavy flooding for a few to several months, the forest height is reduced to 2–10 m. Such heavily flooded forests are dominated by a few species of *Syzygium* (*ubah* or *kelat*, Myrtaceae).

However, because rivers in the humid tropics in non-continental areas are stable in water flow and seldom cause flooding, freshwater swamp forests occur only in limited areas. Usually they are restricted to the edges of lowland plains near the foot of hills. Unlike continental Southeast Asia, where almost all lowland plains had been covered with freshwater swamps and have been replaced by highly productive rice fields, most of the lowland plains of the western Malay Archipelago are covered by peat swamp forests as described below.

Huge areas of the lowland plains of the western Malay Archipelago, except for marginal areas near the foot of hills, are covered with peat swamp forests (18 million ha, according to Driessen [1978]). Flooding does not occur year-round, but small pools sometimes appear when the water table rises. The soil is mineral-poor (the content of organic matter is higher than 75%). The underground water and the water of seasonal pools is acid (pH 3–5) [Anderson 1961; 1964].

When we leave the riverbanks of the lowland plains for the interior of the peat swamps, we observe remarkable shifts in vegetation. Peat swamp forests found in zones neighboring riverbanks are called mixed peat swamp forests. In mixed peat swamp forests, the peat is less than 2 m deep, allowing tree roots to reach mineral soils. In Sarawak and Brunei (Northwest Borneo), this vegetation is characterized by *Dryobalanops rappa* (*kapur paya*, Dipterocarpaceae) [Anderson 1961]. In the rest of the western Malay Archipelago, *Koompasia malaccensis* (*menglis* or *kömpas*, Leguminosae) and several species of *Gluta* (*kelakap* or *réngas*, Anacardiaceae) are typical elements, according to a review by Yamada [1991]. The forest height is over 40 m.

As we proceed further from the rivers, the peat becomes thicker and thicker [Anderson 1964; Supiandi 1988a; 1988b; 1998; Supiandi and Furukawa 1986; Furukawa

1992]. The vegetation also changes. In Sarawak and Brunei, the vegetation shifts as follows: 1) mixed peat swamp forests, 2) *alan batu/alan bunga* forests, 3) *padang alan/padang médang* forests, and 4) *padang kerntum* forests. According to Anderson [1961], however, some intermediates are recognizable.

Alan batu forests and *alan bunga* forests are as high as (or sometimes higher than) freshwater and mixed peat swamp forests: over 40 m (sometimes up to 70 m [*ibid.*]). Forest height is lower in *padang alan/padang médang* forests (30 m) and *padang kerntum* forests (10–20 m). The dominant species in *alan batu* and *alan bunga* forests is *Shorea albida* (*alan* or *empenit*, Dipterocarpaceae). Although these two forest types share a common dominant species, they differ in the species compositions of some minor components and in the wood quality and diameter of *alan* (namely, *alans* of *alan batu* forests have harder woods and larger diameters). *Padang alan* forests are also dominated by *alan*, but the trees are much smaller and the minor components differ greatly from *alan batu/alan bunga* forests. *Padang médang* forests occur in the same habitat as *padang alan* forests, and are dominated by *Litsea palustris* (*médang*, Lauraceae). The species composition varies in *padang kerntum* forests, but there are common important members, such as *Combretcarpus rotundatus* (*kerntum* or *garam-garam*, Rhizophoraceae).

The rest of the western Malay Archipelago has been poorly studied. Anderson [1976] also reported on the vegetation of peat swamps in Sumatra and Kalimantan. He recognized only two forest types, mixed peat swamp forests and *padang* forests. The typology was too simple in that study, and the correspondence in the vegetation zoning of Sarawak and Brunei is unclear. More-detailed studies on the vegetation zonation of peat swamp forests are required in areas other than Sarawak and Brunei.

III Vegetation Zonation of Peat Swamps around the Kerumutan River

We settled seven plots in Sumatra's Kerumutan Wildlife Sanctuary (KWS), located between the Kampar River and Inderagiri River (N0° 0–8′, E 102° 27–33′) in Riau province. Seven plots were located along a line from the river to the interior of the swamp at intervals of ca. 500 m. The distance was measured by counting steps. In each 40 × 60 m plot, each tree over 10 cm in dbh (diameter at breast height) was identified and its dbh was recorded. In 20 × 20 subplots, each tree over 1 cm in dbh was identified. Voucher specimens were donated to Herbarium Bogoriense. The height of the highest tree in each plot was measured trigonometrically. Peat depth was measured in each plot by hand boring. The water quality of each small pool (1–3 m^2) found in each plot was measured at the beginning of April, 2001. pH was measured with a Horiba compact pH meter, B-211. EC (electric conductance) and ORP (oxidation reduction potential) were measured with a Horiba model D 21. Concentrations of Cl^-, NH_4^+, NO_2^-, NO_3^-, phosphoric P, and SO_4^{2-} were measured with a Kyoritsu Aquasearch Lambda 8020. Levels of underground water were measured on a single day (24 March, 2001) at 10 points per plot at intervals of 2 m along a 20 m line within each plot.

As shown in Fig. 1 and Table 1, the dominant species changed as follows. In the plot nearest the river, *Koompasia malaccensis* and *Durio lowianus* (*durian*, Bombacaceae) were dominant among canopy trees. *Gluta rostrata* was another conspicuous trees near rivers, although it was not found in this first plot. This result corresponds with the typical composition of mixed peat swamp forests reviewed by Yamada [1991].

When we proceeded to ca. 500 m from the river, the dominant species changed. *Shorea teysmanniana* (*méranti onék*, Dipterocarpaceae) was the dominant top canopy species, followed by *Swintonia glauca* (*ongös*, Anacardiaceae). The third plot (ca. 1 km from the river) had similar components. When we reached ca. 1.5 km from the river, the dominant top canopy species were *Palaquium burckii* (*suntai*, Sapotaceae) and *Swintonia glauca*.

Among sub-canopy trees, *Ganua mottleyana* (*boangku*, Sapotaceae) was dominant throughout the seven plots. However, some selected species (*Knema intermedia, Mangilietia glauca, Neoscortechinia kingii,* and *Stemonuros scorpioides*) showed remarkable changes in dominance as the distance from the river changed (Fig. 1). Species diversity

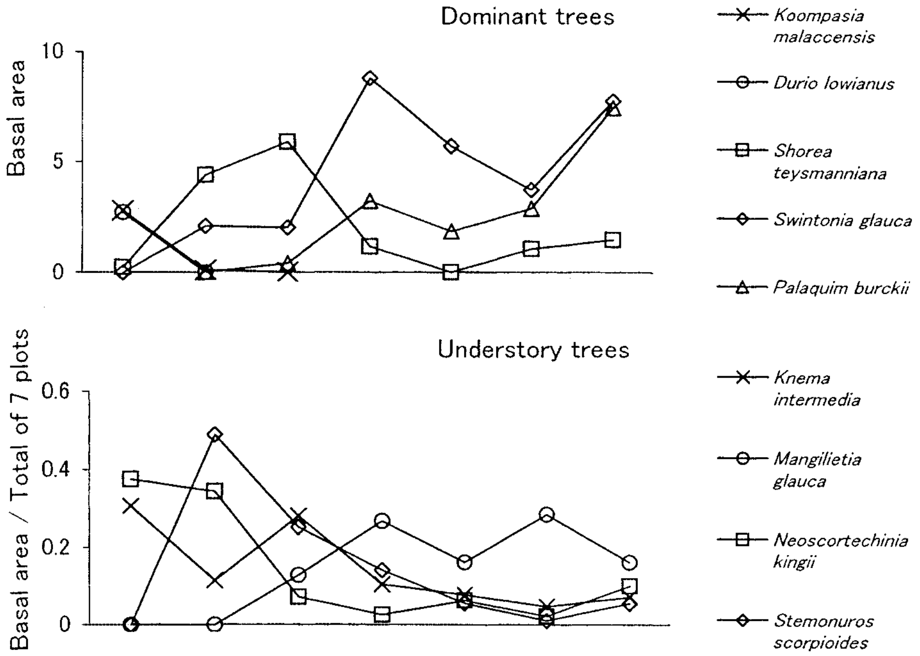

Fig. 1 Changes in Basal Areas of Dominant Species (top) and Selected Understory Tree Species (bottom) against Distances from the River

Table 1 Species Composition of Seven Forest Plots of Peat Swamp Forests

	% basal area
Plot A	
Ganua mottleyana Pierre ex Dub.	13.2
Koompasia malaccensis Maing. ex Benth.	8.7
Durio lowianus Sort. ex King	8.4
Diospyros diepenhorsii Miq.	6.4
Vatica pauciflora （Korth.） Bl.	6.1
Stemonuros secundiflorus Bl.	4.1
Crudia subsimplicifolia Merr.	3.6
Pouteria malaccensis （Clarke）	3.3
Polyalthis glauca （Hassk.） Boerl.	3.3
Knema intermedia （Bl.） Warb.	3.0
Plot B	
Shorea teysmanniana Dyer ex Brandis	13.1
Ganua mottleyana Pierre ex Dub.	12.7
Gonistylus bankanus （Miq.） Kurz.	8.6
Tetractomia tetrandra （Roxb.） Merr.	7.6
Swintonia glauca Engl.	6.2
Stemonuros scorpioides Becc.	5.5
Tetramerista glabra Miq.	4.1
Shorea uliginosa Foxw.	4.1
Stemonuros secundiflorus Bl.	3.8
Aglaia argentia Bl.	3.6
Plot C	
Ganua mottleyana Pierre ex Dub.	26.8
Shorea teysmaniana Dyer ex Brandis	17.9
Tetramerista glabra Miq.	13.6
Swintonia glauca Engl.	6.2
Stemonuros secundiflorus Bl.	5.1
Aglaia argentia Bl.	4.3
Stemonuros scorpioides Becc.	2.9
Knema intermedia （Bl.） Warb.	2.7
Shorea uliginosa Foxw.	2.5
Tetractomia tetrandra （Roxb.） Merr.	2.4
Plot D	
Ganua mottleyana Pierre ex Dub.	28.7
Swintonia glauca Engl.	22.9
Palaquim burckii H. J. Lam	8.4
Parartocarpus forbesii （King） FM Jarrett	5.0
Xylopia malayana Hk. f. et Th	4.7
Stemonuros secundiflorus Bl.	4.2
Diospyros diepenhorsii Miq.	4.1
Gonistylus bankanus （Miq.） Kurz.	3.2
Shorea teysmaniana Dyer ex Brandis	3.0
Tetramerista glabra Miq.	2.7
Plot E	
Ganua mottleyana Pierre ex Dub.	24.7
Swintonia glauca Engl.	17.8
Stemonuros secundiflorus Bl.	5.9
Palaquim burckii H. J. Lam	5.8
Parartocarpus forbesii （King） FM Jarrett	5.7
Diospyros diepenhorsii Miq.	4.8
Aglaia argentia Bl.	4.4
Tetractomia tetrandra （Roxb.） Merr.	4.3
Alstonia angastiloba Miq.	3.4
Gluta aptera （*King*） Ding Hou	3.2
Plot F	
Ganua mottleyana Pierre ex Dub.	30.7
Swintonia glauca Engl.	12.4
Palaquim burckii H. J. Lam	9.6
Parartocarpus forbesii （King） FM Jarrett	6.6
Gonistylus bankanus （Miq.） Kurz.	4.5
Ilex pleiobrachiata Loes.	4.1
Xylopia malayana Hk. f. et Th	3.8
Shorea teysmaniana Dyer ex Brandis	3.5
Tetramerista glabra Miq.	3.3
Stemonuros secundiflorus Bl.	3.1
Plot G	
Swintonia glauca Engl.	21.2
Palaquim burckii H. J. Lam	20.4
Ganua mottleyana Pierre ex Dub.	14.4
Gonistylus bankanus （Miq.） Kurz.	7.7
Campnosperma coriaceum Ridl.	4.3
Shorea teysmaniana Dyer ex Brandis	4.0
Tetractomia tetrandra （Roxb.） Merr.	3.2
Lithocarpus blumeanus （Korth.） Rehd.	2.2
Parastemon urophyllum A. DC.	2.1
Shorea uliginosa Foxw.	1.9

Note: The plot A was located near rivers, and other plots were located at the intervals of 500 m.

Table 2　Indexes Calculated from Vegetation Census of Seven Forest Plots

Plots	A	B	C	D	E	F	G
[1] No. ind. (dbh≧ 1 cm)	173	322	243	270	303	338	292
[2] No. sp. (dbh≧ 1 cm)	59	54	40	46	47	48	45
[3] Div. index (ind. no.)	3.67	3.41	3.10	2.98	3.26	3.24	3.18
[4] Basal area (m^2/ha)	32.2	33.6	32.7	38.1	31.9	30.0	36.3
[5] No. sp. (dbh≧ 10 cm)	48	45	31	32	34	33	38
[6] Div. index (basal area)	3.32	3.12	2.48	2.40	2.67	2.58	2.63

[1] Number of individuals (dbh≧ 1 cm) found in subplots (20 × 20 m).

[2] Number of tree species (dbh≧ 1 cm) found in subplots (20 × 20 m).

[3] Diversity index, N'. $N' = \Sigma_i (n_i/N)\ln(n_i/N)$, where N is total number of individuals over 1 cm in dbh found in subplots (20 × 20 m), and n_i is number of individuals of species i.

[4] Total basal areas of trees (dbh≧ 10 cm) found in plots (40 × 60 m).

[5] Number of tree species (dbh≧ 10 cm) found in plots (40 × 60 m).

[6] Diversity index, N'. $N' = \Sigma_i (n_i/N)\ln(n_i/N)$, where N is total basal areas of trees (dbh≧ 10 cm) found in plots (40 × 60 m), and n_i is the basal area of species i.

Table 3　Measurements of Seven Forest Plots

Plots	A	B	C	D	E	F	G	r 2)
Canopy height (m)	46.0	38.6	42.9	41.4	36.0	33.5	36.0	− 3.4 *
Peat depth (m)	0.4	4.2	4.8	5.3	5.8	6.3	8.5	2.1 **
pH	3.3	3.5	3.5	3.4	3.5	3.6	3.4	NS
EC (ms/m)	15.5	11.0	14.3	9.7	10.7	9.0	9.3	− 1.9 *
ORP (mV)	288	284	164	331	298	293	238	NS
Cl^- (mg/l)	3.3	0.7	1.2	1.8	1.2	1.2	1.1	NS
NH_4^+ (mg/l)	1.3	1.2	1.6	1.5	1.2	1.5	0.9	NS
NO_2^- (mg/l)	0.01	0.02	0.01	0.02	0.01	0.02	0.01	NS
NO_3^- (mg/l)	0.14	0.10	0.07	0.10	0.09	0.10	0.07	NS
Phosphoric P (mg/l)	0.12	0.16	0.09	0.09	0.10	< 0.1	0.11	NS
SO_4^{2-} (mg/l)	< 5	< 5	< 5	< 5	< 5	< 5	< 5	
Water table (cm) 1)	27.1	37.1	39.1	40.1	30.1	24.2	28.1	NS
	(10.9)	(10.9)	(7.0)	(11.0)	(10.2)	(5.5)	(10.4)	

1) Average of levels of underground water in March among ten points per plot and SE in brackets.

2) Coefficient of regression analysis between distance from the riverbank (km) and measurements. NS : coefficient was not significant. $^*p < 0.05$　$^{**}p < 0.01$

tended to decrease in plots far from the river (Table 2).

Canopy height also decreased as distance from the river increased: it was 46 m in the plot nearest the river and 34 m in the plot ca. 2.5 km from the river (Table 3). The difference in water quality was remarkable only in EC (Table 3), which fell as we moved farther from the river, indicating low cation contents. The peat became thicker as we moved farther from the river (Table 3), as reported in a number of studies [Anderson 1964; Supiandi 1988a; 1988b; 1998; Supiandi and Furukawa 1986; Furukawa 1992]. Other measurements (pH, ORP, contents of Cl^-, NH_4^+, NO_2^-, NO_3^-, phosphoric P, and water table level were not significantly related with distance from the riverbank (Table 3).

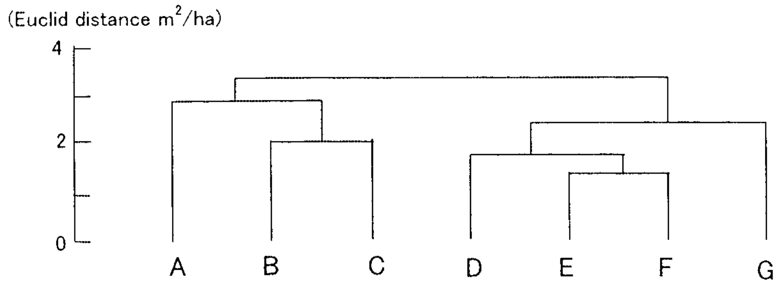

Fig. 2 A Result of a Cluster Analysis of Seven Forest Plots of Peat Swamp Forests at Different Distances from the River, Based on Euclidean Distances Calculated from Basal Areas, and Connected by the UPGMA Method

As a result of a cluster analysis (based on Euclidean distances calculated from basal areas and connected by the UPGMA method), three clusters were recognizable (Fig. 2). The plot nearest the river (A) was a cluster by itself, the next two plots (B and C) formed another cluster, and the four plots farthest from the river (D, E, F, and G) formed the third cluster. Within the third cluster, the farthest plot (G) was relatively distanced from the other three plots.

In conclusion, three types of forests are recognizable. The forest in the plot nearest the river is identical to mixed peat swamp forests. As pointed out in previous studies, mixed peat swamp forests grow in peat shallow enough to allow plant roots to reach mineral soils.

In the next zone, the peat was deeper and the plant roots did not reach mineral soils. However, the canopy was still high and the water was cation-rich. We call this the *méranti paya* forest. Here, "*méranti*" is a generic Malay term indicating the species *Shorea*, Section Mutica; and "*méranti paya*" means "*méranti* found in swamps." According to the review by Yamada [1991], some Sumatran peat swamp species of *méranti* are also found in peat swamps of the Malay Peninsula and Kalimantan. Thus, *méranti paya* forests are considered to be found also in these areas. Anderson [1976] confuses *méranti paya* forests with mixed peat swamp forests, but these must be clearly distinguished from each other, because *méranti paya* forests occur in the same habitats as *alan batu/alan bunga* forests, in which plant roots do not reach mineral soils (Tables 4 and 5).

Forests with lower canopy heights were found in the areas farthest from rivers. Anderson [*ibid.*] called them *padang* forests. If we follow the terminology that Anderson used in Sarawak and Brunei, the forests found in areas farthest from rivers in Sumatra should be called *padang suntai* forests. Here, "*suntai*" is the Malay name for *Palaquium burckii*, a species characterizing the vegetation. According to Anderson [*ibid.*], *suntai* is also dominated in Kalimantan in the same habitats as Sumatra. This is the forest type that replaces the *padang alan/padang médang* forests in Sarawak and Brunei (Table 6). In

Table 4　Vegetation Zoning of Sumatran Peat Swamp Forests

Vegetation Types	EC（ms/m）	Peat Depth	Dominant Genera
Mixed peat swamp forests	＞15	＜2 m	*Koompasia, Durio*
Méranti paya forests	11－15	2－5 m	*Shorea, Swintonia*
Padang suntai forests	8－11	＞5 m	*Palaquium, Swintonia*

Table 5　Environmental Conditions of Various Vegetation Types in Sumatran Lowland Plains

Vegetation	pH	Salinity	Soil
Mangrove forest	neutral	high	mud
Freshwater swamp forest	neutral	low	mud
Peat swamp forest	acid	low	peat
mixed peat swamp f.			shallow peat
méranti paya f.			moderately deep peat
padang suntai f.			deepest peat

Table 6　Correspondences of Forest Types between Two Regions within Western Malay Archipelago, Which Differ in Flora

	Sarawak, Brunei	Sumatra, Kalimantan, Malay Peninsular
Tidal zone		
belt 1	mangrove f.	mangrove f.
belt 2	mixed peat swamp f.	mixed peat swamp f.
Central zone		
belt 1	mixed peat swamp f.	mixed peat swamp f.
belt 2	*alan batu/alan bunga* f.	*méranti paya* f.
belt 3	*padang alan/padang médang* f.	*padang suntai* f.
belt 4	*padang kerntum* f.	*padang kerntum* f.
Flooding zone	freshwater swamp f.	freshwater swamp f.

KWS, peat depth was 5 m at the boundary between *méranti paya* forests and *padang suntai* (Table 4).

Forests identical to the *padang kerntum* forests of Sarawak and Brunei are also found in Kalimantan [*ibid.*]. However, forests whose canopy heights are as low as those of the *padang kerntum* forests were not found in Sumatra, according to our field observation, interpretation of aerial photographs (*padang kerntum* forests are distinctive in their fine tree crowns), and interviews with local Malays. In the aerial photographs, we sometimes found forests with fine tree crowns near rivers. However, these are flooding forests dominated by *Syzygium*, whose crown sizes are considered to be limited because of heavy flooding. If *padang kerntum* forests exist, they should be found far from rivers. However, such forests were not found in aerial photographs of three main lowland plains on the Sumatran east coast: the Kampar, Inderagiri, and Batan Hari regions.

For simplification, we apply a single term, *padang* forests, to refer to *padang alan, padang médang, padang suntai,* and *padang kerntum* forests, if it is not necessary to distinguish between them.

Hydrological conditions no doubt have significant effects on vegetation, but the level of the water table was not significantly related with distance from the riverbank (Table 3). Thus, other factors determining vegetation types should be considered. In our hypothesis, the mechanisms by which forest zoning is formed are explained as follows.

When peat starts to accumulate, mixed peat swamp forests cover the shallow peat. Trees absorb nutrients from mineral soils under the peat, and litter containing nutrients is deposited as peat. Thus, minerals are stocked in living plants plus peat, while mixed peat swamp forests cover the shallow peat. When the peat becomes thicker than 2 m, tree roots no longer reach mineral soils. Thus, nutrients are circulated between living plants and the peat (a small amount is supplied from rainfall but not from mineral soils or river water). As the peat becomes thicker still, plant roots do not reach the lower parts of it, and nutrients contained there are excluded from circulation. Thus, as the peat thickens, the amount of circulating nutrients becomes smaller. As long as rich nutrients are circulated, the biomass is large, allowing *alan batu, alan bunga* or *méranti paya* forests to occur. After the peat becomes thick and the amount of circulated nutrients is reduced, the biomass decreases, and thus *padang kerntum* forests occur. As we move farther from rivers, peat depth increases, and we can observe this vegetation succession, starting from mixed peat swamp forests, passing through *alan batu/alan bunga* forests or *méranti paya* forests, and ending in *padang kerntum* forests. Pollen analysis carried out by Morley [1981] suggested that vegetation succession occurred as peat became thicker.

Furukawa [1992] suggested a different mechanism. *Padang* forests occur as a result of the flowing away of nutrients that had been stocked in the peat. It is possible for this to occur. However, as found in Anderson's several study sites and KWS, peat depth usually correlates clearly with vegetation type. Such correlation can be explained by our model only. In any case, the nutrient contents of living plants and peat at various depths, as well as nutrient flows, must be measured to test the above hypothesis, and this work is now in preparation.

IV Furukawa's Zoning and Vegetation

The vegetation zonation described above is typically observed mainly in areas far from the coast. In coastal areas, the shift in vegetation corresponding to distance from a river starts from mangrove forests, and mixed peat swamp forests appear behind mangroves. Inland peat has accumulated for over 6,000 years [Anderson 1961; Supiandi 1988a; Furukawa 1992], but the peat of coastal areas has accumulated only for a few thousands years or less [Supiandi 1988a; Furukawa 1992]. Peat is so young and so shallow in coastal areas that *alan batu/alan bunga* forests, *méranti paya* forests, and *padang* forests are not found there (Table 6).

Furukawa [1992] calls coastal peat swamp areas tidal zones and inland peat swamp areas central zones, while the edges of plains covered with freshwater swamp forests are called flood zones. This paper follows that terminology.

The relationship between vegetation and Furukawa's zoning is summarized as follows. Flood zones are covered mainly with freshwater swamp forests. Central zones feature sequential zonation of mixed peat swamp forests, *méranti paya* forests (or *alan batu/alan bunga* forests in Sarawak and Brunei), and *padang* forests (further subdivisions are sometimes possible). Tidal zones are covered by mangrove forests and mixed peat swamp forests. Anderson [1961] described vegetation zoning within a central zone only. However, the diversity of environments in lowland plains is understood better in the combination of large-scale zoning from the foot of hills toward the coast and small-scale zoning along the distance from rivers (Table 6).

Lowland plains in Sabah, East Kalimantan, North and West Sumatra, and Central to East Java consist of flood zones only, so no peat swamp forests are found. Lowland plains in the Malay Peninsula, South Sumatra, and West Java consist of flood zones and tidal zones, so peat swamp forests are found, but only mixed peat swamp forests are spreading. Only the lowland plains in Sarawak and Brunei, Central-East Sumatra (Riau and Jambi), and West, Central, and South Kalimantan include all three zones, so peat swamp forests with clear vegetation zonation are found.

The occurrence of tidal and central zones depends on climate and on the balance between mountain size and plain size — that is, between the source and sink of mineral sediments. In seasonally dry climates, only flood zones occur, as in the case of Central to East Java. This is because seasonal fluctuation in rainfall causes frequent flooding. Even in aseasonal (or less seasonal) conditions, if plains are small compared to the mountains, again only flood zones will occur, as in Sabah, East Kalimantan, and North and West Sumatra. For all three zones to occur in a single environment, the plains must be relatively large (compared to the mountains) and the climate must be aseasonal.

Among the three types of zones, flood zones, where freshwater swamp forests occur, are the most suitable for cultivating rice. Lands covered with mixed peat swamp forests (mainly tidal zones) can be transformed into plantations of coconuts and rice fields after the water is drained off through channels. However, even within tidal zones, it is difficult to convert areas into farmland if they are too far from rivers [Furukawa 1992].

In central zones, areas suitable for agriculture are limited. Only small areas that are along rivers and covered with mixed peat swamp forests (within 100 m from riverbanks though usually much less) can be used in ways that tidal zones are used (but usually in more extensive ways, as reported in another paper). In central zones, huge areas covered with *méranti paya* forests (or *alan batu/alan bunga* forests) as well as *padang* forests are impossible to convert for agriculture, although these forests contain huge timber resources (except for the poorest *padang kerntum* forests).

The reason why it is difficult to exploit *méranti paya* forests can be summarized as follows. 1) The peat is extremely nutrient-poor. The lack of essential rare nutrients is especially difficult to overcome. In the case of rice, the lack of Cu as well as of a number of other minor nutrients is serious [Kyuma 1983]. 2) The root systems of tree crops are different from those of wild peat swamp trees, whose main roots spread widely and horizontally, and whose finer roots extend deeply into peat to act as anchors. Trees (including oil palm trees) planted in deep and purely organic peat easily fall before reaching productive sizes. 3) If water is drained through channels, deep and purely organic peat easily catches fire, and this fire is hard to extinguish. 4) In areas where *méranti paya* or *padang* forests occur, the beds of mineral soils are concave [Anderson 1964], and the levels of mineral soils are lower in peat than they are in river water. If water is drained, the levels of peat continue to fall quickly to the level of rivers as a result of shrinking, fire, and decomposition. In that case, drainage is no longer possible.

V Conclusion

The classification of the vegetation of peat swamps in Sumatra and Kalimantan by Anderson [1976] was too simple compared with the classification that he had earlier proposed for Sarawak and Brunei [Anderson 1961]. The present study revealed that the vegetation zonation of peat swamps in Sumatra corresponds to that of Sarawak and Brunei. Judging from the similarity of flora between Kalimantan and the Malay Peninsula, the patterns in those two regions may also be similar to each other. Vegetation zonation, as the distance from rivers increases, is a reflection of peat depth and EC. It is considered hypothetically that the amount of circulated nutrients determines vegetation types.

The determination not only of small-scale vegetation zonation as pointed out by Anderson, but also of the combination of small- and large-scale zonation, is useful for understanding the diversity of environments within lowland plains. The large-scale zonation proposed by Furukawa [1992] was helpful for this purpose. Among the various vegetation types, *méranti paya* and *padang* forests in central zones are the most difficult to exploit. How to use various habitats within lowland plains should be discussed in the second paper of this series.

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