Mitsuru Osaki · Nobuyuki Tsuji *Editors*

Tropical Peatland Ecosystems

Springer

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Dedicated to the memory of
Dr. Sehat Jaya, Dr. Herwint Simbolon,
and Dr. Muhammad Evri

Preface

The tropical peatland (including swamp and forests) found in the Indonesian and Malaysian archipelagos, the Amazon lowlands, and the Central African lowlands comprises some 42 Mha and is estimated to store approximately 148 Gt of carbon. Because of their inferior nature, these environments remained undeveloped, and relatively virgin forests still remain. Much of the recent increased interest in peatlands globally has resulted from their importance as carbon sinks and stores and their role in carbon cycling between the earth's surface and the atmosphere. There is considerable debate about whether or not peatlands are globally net absorbers or emitters of carbon and under what conditions they may sequester or release this environmentally important element.

High-carbon reservoir ecosystems such as (1) peatlands/wetlands ecosystems, (2) coastal ecosystems (mangrove/coral/sea grass), and (3) permafrost ecosystems have been highlighted by the Subsidiary Body for Scientific and Technological Advice (SBSTA) of the United Nations Framework Convention on Climate Change (UNFCCC). Tropical peatland is one of key ecosystems among the high-carbon reservoir ecosystems because of huge carbon and water storage and its effect on coastal ecosystems. The SBSTA encourages research and management (conservation and rehabilitation) of the high-carbon reservoir ecosystems because those systems are greatly affected by human and climate change impacts. Consequently, if the ecosystems are destroyed, huge carbon emission changes in the water balance will result, having a serious negative impact on global environments, especially with regard to climate change.

Thus, peatland ecosystems consist of the carbon–water complex, which is affected easily by the impact of human and climate change. Throughout much research of tropical peatland, the problems that result from development of tropical peatland are found to stem mainly from a lack of understanding of the complexities of this ecosystem and the fragility of the relationship between peat and forest and also between carbon and water. In its natural state, tropical peatland is a vast carbon sink and store. Once the carbon allocation to the system is discontinued by forest removal and the peat is drained, however, the air-exposed surface peat oxidizes and loses previously allocated carbon rapidly to the atmosphere, which results in progressive subsidence of the peat surface and contributes to climate change. Thus, it is essential that future land use of tropical peatland should take fully into account the principles and practices of sustainable development and incorporate the "wise use" approach. The wise use of peatland involves several elements, foremost among which is the identification of the benefits and values that they can provide and the adverse environmental and human consequences resulting from their disturbance.

At Hokkaido University, Japan, located on the edge of the Ishikari peatland, peatland science has been studied as a key topic for more than 100 years. Hokkaido University has applied inclusive research methods into tropical peatland, especially in Central Kalimantan, Indonesia, by the "Core University Project, 1997–2006" with LIPI funded by JSPS and the SATREPS project entitled "Wild Fire and Carbon Management in Peat-Forest in Indonesia, 2008–2014," with several Indonesian institutes funded by the Japan Science and Technology Agency (JST) – Japan International Cooperation Agency (JICA). This book on tropical peatland ecosystems has been produced as a result of cooperative studies mainly among Hokkaido University and Indonesian institutes but with many other collaborators as well.

Sapporo, Japan Mitsuru Osaki, Ph.D.
1 January 2015

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Part I
Introduction to Tropical Peatland

Mitsuru Osaki and Nobuyuki Tsuji

Chapter 1
Tropical Peatland of the World

John Rieley and Susan Page

Abstract In the tropics peat occurs mostly in sub-coastal lowlands and is formed from rainforest trees and associated higher plants. There are regional differences in the plant species involved and there are also changes with increase in altitude with a tendency to lower growing and more low temperature tolerant plants. The best estimate of the area of tropical peatland is 441,025 km^2 which is about 11 % of the global peatland resource, although there is a wide range of estimate from 387,201 to 657, 430 km^2 depending upon whether or not all Histosols and shallow organic soils are included. Current inventories of peatland area, peat thickness and carbon stores leave much to be desired and their accuracy varies not only from region to region but also country to country. The largest area of tropical peatland and peat carbon store is in Southeast Asia with 56 % of the former and 77 % of the latter owing to the large extent of peatlands and the considerable thickness of peat (regularly exceeding 10 m) in this region. Following Southeast Asia, South America contains the next largest area (24 %) of peatland but a smaller proportion of the global tropical peatland carbon store because of the thinner peat deposits. Africa contributes 13 % of the global area and 8 % of the carbon store, while Central America and the Caribbean, Mainland Asia and Australia and the Pacific contribute only 5 %, 1 % and <1 %, respectively and only 3 % of the carbon store, collectively. Tropical peatlands are now being subjected to intensive land use change and conversion to forms of agriculture including commercial plantations. This is well advanced in Southeast Asia, especially Indonesia and Malaysia where most of the peatland area has already been deforested, drained and converted often using fire as a land clearance tool. Apart from losses of biodiversity there have been immense emissions of greenhouse gases and large losses of carbon from the peat store, contributing to climate change processes. Other regions are further behind in these environmentally damaging impacts on the tropical peatland resource.

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1.1 Introduction

Peatlands occupy about 3 % of the global land area (Immirzi et al. 1992; Page et al. 2011), mostly (~89 %) in the northern hemisphere, covering large parts of Russia, North America and Europe, where they have formed in low-relief, poorly draining environments under high precipitation-low temperature climatic regimes. There are also large areas of peatland in the tropics, mostly in Southeast Asia but also in mainland East Asia, the Caribbean and Central America, South America and Africa, where favourable regional environmental and topographic conditions have enabled peat to form under high precipitation-high temperature conditions (Andriesse 1988).

In temperate, boreal and sub-arctic regions peat is formed mainly from mosses, herbs, shrubs and small trees (Moore and Bellamy 1973; Rydin and Jeglum 2006). By contrast, tropical peat, especially in low altitude locations, is derived mostly from the remains of rainforest trees (branches, leaves, roots and trunks) (Rieley et al. 1996; Page et al. 1999, 2006) and has accumulated over thousands of years to form deposits up to 20 m thick (Anderson 1983). Some tropical peatlands, however, are also found at higher altitudes, where they support lower-growing vegetation with some resembling those of the temperate and boreal zones. The largest area of tropical peatland is located in the coastal lowlands of Southeast Asia, especially in Indonesia and Malaysia.

Peatlands across the tropical zone are subject to various forms of anthropogenic impacts, especially in Southeast Asia where the rate of conversion to industrial-scale plantation agriculture has been the most rapid (Miettinen and Liew 2010; Miettinen et al. 2011, 2012) and where there have also been widespread peat fires (Page et al. 2002). As a consequence, the peatlands of this region are a large source of carbon to the atmosphere. By contrast, African peatlands occupy a much smaller unit area than those of Southeast Asia and are not subject to the same level of exploitation and are probably still carbon sinks although there is some use of peat for fuel and agriculture. The least impacted tropical peatlands are those in Central and South America since they are in remote locations where levels of human impact are low, although there are increasing threats of disturbance from resource exploitation, (e.g. for agriculture, mining or oil) (Lähteenoja et al. 2012).

An accurate inventory of tropical peatland in all countries with this resource is essential to determine the global area and magnitude of the peat carbon pool. It is also needed to predict what may happen to tropical peat carbon sinks and stores as a result of land use change, fire and climate change and to estimate the likely magnitude of transfers of greenhouse gases (especially carbon dioxide and methane) to the environment as a consequence. This information is also necessary to improve global carbon-climate models and support initiatives to improve peatland management practices and policies for climate change mitigation and carbon accounting

(Page et al. 2011). While the threats to the Southeast Asian peatland resource and its continued existence as a carbon store are relatively well documented, the extent of impacts on the peatlands of Central and South America and Africa are yet to be investigated in detail and therefore their vulnerability to disturbance and role in regional carbon cycling remains poorly understood (Lähteenoja et al. 2009).

There have been several evaluations of the global area of peatlands but these differ widely owing to a lack of detailed information from many countries and differences in definitions of peat and survey methods (e.g. Moore and Bellamy 1973; Kivinen and Pakarinen 1980, 1981; Bord na Mona 1984; Armentano and Menges 1986; Andriesse 1988; Gorham 1991; Immirzi et al. 1992; Joosten and Clarke 2002; GPD 2004; Page et al. 2011). Inventory data have been collected and collated for different purposes using a variety of criteria (definitions of peat) and methods and mostly provide ranges of values, the upper and lower limits of which may have been obtained from different sources. For example, the detailed report prepared by Bord na Mona (1984) for the World Bank focuses on the potential of peat in developing countries for energy and considers only peat with a minimum thickness of 1 m. In contrast, the peatland area data published in Joosten and Clarke (2002) include Histosols irrespective of the thickness of the organic surface layer (Page et al. 2011). The latter provides a larger estimate of the global area of peatland than either Bord na Mona (1984), Immirzi et al. (1992) or Lappalainen (1996) (Table 1.1). Several studies have noted that the area of tropical peatland has been underestimated (Immirzi et al. 1992) and, until recently, (Page et al. 2011) it was impossible to determine its full extent.

Page et al. (2011) carried out a detailed assessment of data published on tropical peatlands in order to provide updated best estimates of area, peat thickness, peat volume and carbon content by country, region and globally and assess the contribution of tropical peatland to national, regional and global land cover inventories and soil carbon stocks. They considered only those countries that lie between the Tropics of Cancer and Capricorn (23.5°N and 23.5°S) and excluded the sub-tropics (e.g. Florida Everglades) but included high altitude peatlands, especially in Africa. They

Table 1.1 Original area of peatland in different regions of the world (km^2)

Region	Immirzi et al. (1992) (mean)[a]	Lappalainen (1996) (best estimate)	Joosten and Clarke (2002) (maximum)
North America	1,710,470	1,735,000	1,860,000
Asia	338,208	1,119,000	1,523,287
Europe	1,784,887	957,000	617,492
Africa	49,765	58,000	58,534
Central and South America	86,271	102,000	190,746
Australia and Oceania	230	14,000	8,009
Total	3,969,831	3,985,000	4,258,068

[a] Immirzi et al. include all of the former Soviet Union in Europe

defined peat as the surface layer of a soil, consisting mostly of partially decomposed vegetation, with at least 65 % organic matter content in a minimum thickness of 30 cm.

Page et al. (2011) encountered anomalies and inconsistencies in and between some country inventories and found that they were not always strictly comparable owing to different definitions of peat and the inclusion of non-peat organic soils (<30 cm). They tried to remove shallow Histosols from their assessment but this was not possible in every case.

The lack of information for some African, Central and South American and Caribbean countries with very small areas of peatland (1–10 km^2) makes virtually no difference to the overall calculation of regional and global tropical peatland areas and carbon stores owing to their likely small areas. Some countries in Central and South America, however, may have different areas of peatland than the single values available suggest, for example, the 90 km^2 in El Salvador and 50,000 km^2 in Peru and these may distort the inventory data.

1.2 Area of Tropical Peatland by Region and Country

The total area of tropical peatland lies within the range 387,201 and 657,430 km^2, with a best estimate of 441,025 km^2, which is 10–16 % of the global peatland area (Page et al. 2011) (Table 1.2). The peatlands of Southeast Asia represent between 6 % and 8 %, South America 3 %, Africa 1 % and Central America <1 % of the global resource by area. The Southeast Asia region contains the largest area of tropical peatland (247,778 km^2, 56 % of the total area), followed by South America (107,486 km^2; 24 %), Africa (55,860 km^2; 13 %), Central America and the Caribbean (23,374 km^2; 5 %), Asia (mainland) (6337 km^2; 1 %) and the Pacific region (190 km^2; <1 %) (Table 1.2; Page et al. 2011).

In Africa, Zambia contains 12,201 km^2 (3 %) of the tropical peatland area, followed by Sudan with 9068 km^2 (2 %) and Uganda 7300 km^2 (2 %) with about 5 % in Angola, Botswana, Congo, Democratic Republic of Congo and Kenya, collectively, and less than 1 % in the remaining 17 African countries in

Table 1.2 Area of tropical peatland in different geographical regions (Based on Page et al. 2011)

Region	Area (best estimate) (km^2)	Area (range) (km^2)
Asia (southeast)	247,778 (56 %)	236,647–336,115
South America	107,486 (24 %)	95,335–143,936
Africa	55,860 (13 %)	29,464–135,043
Central America and Caribbean	23,374 (5 %)	20,761–31,210
Asia (mainland)	6,337 (1 %)	4,804–10,936
Australia and Pacific Islands	190 (0 %)	190
Total	441,025	387,201–657,430

the tropical zone (Table 1.3; Page et al. 2011). In South America the largest peatland area appears to be in Peru (50,000 km^2; 11 %), although this has not been confirmed, followed by Brazil (25,000 km^2; 6 %), Venezuela (10,000 km^2; 2 %) and Guyana (8139 km^2; 2 %) with only about 3 % in Bolivia, Chile (tropical peatland component), Columbia, Ecuador, French Guyana and Surinam, collectively (Table 1.3; Page et al. 2011). Panama has the largest area of peatland in Central America and the Caribbean with 7870 km^2 (2 %); Cuba, Honduras and Nicaragua have only 3 % of the tropical peatland area between them and the remaining eight countries in this region together contribute less than 1 % (Table 1.3). Only about 1 % of the tropical peatland area occurs in mainland South Asia, mostly in tropical China; very small areas occur in Bangladesh, India and Sri Lanka (Table 1.3). Peatlands in Australia and some Pacific islands are also of very limited extent (ca. 0.05 %) (Table 1.3).

Even in Southeast Asia, where the peatlands of Indonesia and Malaysia have been studied relatively well, there is still a lack of knowledge of the exact extent of peatlands. In West Papua (Irian Jaya), for example, there are at least 70,000 km^2 of thick peat deposits that have received very little study (Rieley et al. 1996). This is also the case in Papua New Guinea, where the difference between non-peat and peat-forming wetlands is ill defined. Page et al. (2011) estimate a peatland area of approximately 11,000 km^2 in Papua New Guinea (Table 1.3), whilst Joosten and Clarke (2002) give a much higher value of 28,900 km^2. According to Wayi and Freyne (1992) this larger estimate includes Histosols and shallow organic soils. This uncertainty regarding the area of peatlands is not confined to Southeast Asia. For example, the best estimates of peatland area in Sudan and Zambia are 9068 and 12,201 km^2 (Table 1.3), respectively, whilst the extent of Histosols and non-peat organic soils is 33,270 and 15,645 km^2 (GPD 2004).

In other instances, the lack of precise information is because of limited field survey in remote locations. Ruokalainen et al. (2001) suggest that Amazonian peatlands could have a total area of 150,000 km^2 but they do not provide verifiable evidence for their assertions and these data should be treated with care until they are confirmed.

1.3 Southeast Asia

The peatlands of Southeast Asia lie within the inter-tropical convergence zone that experiences a wet tropical climate with annual rainfall generally in excess of 2500 mm. Seasonality of rainfall is not usually marked, but there is either a long ‘wet’ season of 9–10 months alternating with a shorter ‘dry’ season of 2 or 3 months duration, or two ‘monsoon’ seasons (October to March and April to August) interspersed by two short ‘dry’ periods (Rieley and Page 2005). Peatlands of this region occupy mostly low altitude coastal (less than 50 m above mean sea level) and sub-coastal situations and can extend inland for distances of more than 150 km along river valleys and across watersheds. The most extensive peatlands in

Table 1.3 Global, regional and national inventories of tropical peatland (best estimates of peatland area and peat thickness, volume and carbon content) (Based on Page et al. 2011)

			Peatland area best estimate		Peat thickness best estimate	Peat volume best estimate		Peat carbon best Estimate		
Region	Country	Peatland as % of land area	km^2	%	m	m^3 × 10 exp 6	%	Gt	%	Notes
Africa	Angola	0.2	2640	1	0.5	1320	0	0.067	0	Extensive deposits in the valley of the River Cuanza, southeast of Catate, about 50 km from Luanda
	Botswana	0.5	2625	1	1	2625	0	0.132	0	About half of the permanent swamp in Okavanga Delta contains peat-forming vegetation
	Burundi	1.3	325	0	8	2600	0	0.131	0	Extensive area of peatland in valley of Akanyaru River that forms border with Rwanda; also some small high altitude mires
	Cameroon	0.2	1077	0	0.5	539	0	0.027	0	Potential peatland areas include the Toubouri Depression and swamp forests of Nyong and Dja Rivers
	Congo	1.8	6219	1	7.5	46,643	3	2.351	3	reports of peat up to 30 m thick in floddplain of Congo River; also reports of peatland in the Malebo Pool and Bilanko Forest
	Democratic Republic of Congo	0.1	2800	1	4	11,200	1	0.564	1	Peatlands are located in mountainous areas of Bukavu west of Lake Kivu
	Gabon	0.02	548	0	0.5	274	0	0.014	0	Peatland areas include swamps and flood plain of Ogoonue River and the shallow lakes Onangue and Manje
	Ghana	0.03	62	0	0.5	31	0	0.002	0	Possible peat swamps in southwest Ghana and White Volta flood plain
	Guinea	0.8	1952	0	0.5	976	0	0.049	0	Three types of peat have been identified: 1) mangrove formed by *Rhizophora spp*, 2) *Raphia sassandrensis* and 3) *Raphia gracilis*

	Ivory Coast	2.3	725	0	1.5	1088	0	0.055	0	There is some peatland in the delta of the River Agneb
	Kenya	0.4	2440	1	0.5	1220	0	0.061	0	Most peatland is around lakes in Rift Valley and on Mount Kenya, Abrrdares and Mount Elgon
	Liberia	1.2	120	0	0.5	60	0	0.003	0	Mostly valley bottom swamps dominated by *Raphia* spp with shallow peat
	Madagascar	0.3	1920	0	2.5	4800	0	0.242	0	Histosols around Lake Alatza in northeast may be associated with peat as may those at Lakes Alaotra, Itasy and Kinkony; coastal mangrove may also be associated with peat
	Malawi	0.5	492	0	1	492	0	0.025	0	Upland peat occurs on the Nyika Plateau in the north and Mulangs to the south
	Mauritania	0.01	60	0	0.5	30	0	0.002	0	Only a small area of peatlands in flood plain and delta of Senegeal River and around Lake Rkiz
	Mauritius	0.05	1	0	0.5	1	0	0	0	
	Mozambique	0.07	575	0	1.5	863	0	0.043	0	Some peatland occurs along Indian Ocean coast associated with depressions between coastal dunes
	Nigeria	0.2	1840	0	5	9200	1	0.464	1	May be some peat in extensive mangrove swamp of Niger Delta and in freshwater swamp forest
	Reunion	0.04	1	0	1	1	0	0	0	
	Rwanda	3.4	830	0	11	9130	1	0.46	1	See Burundi
	Senegal	0.02	36	0	3.5	126	0	0.006	0	Peat deposits are found in the Niayes Region in dune depressions

(continued)

Table 1.3 (continued)

Region	Country	Peatland as % of land area	Peatland area best estimate		Peat thickness best estimate	Peat volume best estimate		Peat carbon best Estimate		Notes
			km^2	%	m	m^3 × 10 exp 6	%	Gt	%	
	Sierra Leone	<0.01	3	0	0.5	2	0	0	0	Mention is made of forested peatland, open peatland and mangroves but location is not specified
	Sudan	0.4	9068	2	1	9068	1	0.457	1	The Sudd is one of the largest wetland areas in world but information on peatland there is unclear
	Uganda	3.7	7300	2	4	29,200	2	1.472	2	There are large areas of freshwater swamp dominated by Cyperus papyrus around Lake Victoria, in Kigezi District and between Lakes Albert, Victoria and Kyoga; Sphagnum dominates peatland in the Ruwenzori Highlands
	Zambia	1.6	12,201	3	0.5	6101	0	0.307	0	Extensive permanent swamp complexes around Lake Bangweulu in the north and Lukanga Swamp in centre of country
Subtotal			**55,860**	**13**		**137,590**	**8**	**6.934**	**8**	
Asia (South-east)	Brunei	17.3	909	0	7	6363	0	0.321	0	Most peatland occurs at low altitude near to sea level but small areas are found in higher land areas; much peatland is being converted to oil palm and paper pulp tree plantations
	Indonesia	11.4	206,950	47	5.5	1,138,225	65	57.367	65	Occurs mostly as extensive domes of woody peat, supporting rain forest trees

	Malaysia	7.9	25,889	6	7	181,223	10	9.134	10	Extensive deposits in coastal areas of Peninsular Malaysia. Sarawak and Sabah; much peatland is being converted to oil palm and sago plantations
	Myanmar (Burma)	0.2	1228	0	1.5	1842	0	0.093	0	Absence of information
	Papua New Guinea	2.4	10,986	3	2.5	27,465	2	1.384	2	Large area in highland zone much of which converted to agriculture, e.g. Wahli Valley
	Philippines	0.2	645	0	5.3	3419	0	0.172	0	Apart from Leyte Province little is known
	Thailand	0.1	638	0	1	638	0	0.032	0	The largest area of peatland occurs in Narathiwat Province
	Vietnam	0.2	533	0	0.5	267	0	0.013	0	Peatland is concentrated in the Tongkin lowland in the northeast and in the Mekong Delta
Subtotal			**247,778**	**56**		**1,359,442**	**77**	**68.516**	**77**	
Asia (other)	Bangladesh	0.3	375	0	1.5	563	0	0.028	0	Major peatland resources occur in the Ganges Delta with lesser deposts in the Sylhet Basin in the northeast
	China	0.1	5312	1	1	5312	0	0.268	0	Only about 10 % of China’s peatland is located in the tropical zone, mostly along the lower reaches of the Yangtse River and on Hainan Island
	India	0.02	490	0	4	1960	0	0.099	0	Only the south of the country is in the tropical zone; the Sunderbans has a large area of mangrove swamp some of which has formed peat

(continued)

Table 1.3 (continued)

Region	Country	Peatland as % of land area	Peatland area best estimate		Peat thickness best estimate	Peat volume best estimate		Peat carbon best Estimate		Notes
			km^2	%	m	m^3 × 10 exp 6	%	Gt	%	
	Sri Lanka	0.3	160	0	4	640	0	0.032	0	Peatlands are mostly at or near the west coast; Muthurajawela Swamp lies north of Colombo with another at Kotte to the southeast; peatland also occurs on interior mountains
Subtotal			**6337**	**1**		**8475**	**0**	**0.427**	**0**	
Central America and Caribbean	Belize	3.2	735	0	0.5	368	0	0.019	0	Mostly mangrove peat
	Costa Rica	0.7	370	0	1	370	0	0.019	0	Mostly located on coasatal plain that extends from Puerto Limon in Costa Rica to the Chiriqui Lagoon in Panama
	Cuba	3.4	3643	1	1.8	6557	0	0.33	0	Peat is coastal, minerotrophic and mostly mangrove
	El Salvador	0.4	90	0	0.5	45	0	0.002	0	Absence of information
	Haiti	4.3	1188	0	0.5	594	0	0.03	0	Some peat associated with coastal lagoons, mangrove swamps and marshed; little information
	Honduras	4.1	4530	1	0.5	2265	0	0.114	0	Absence of information
	Jamaica	1.2	128	0	5	640	0	0.032	0	Several small peat deposits but largest are the Negril Morass and Black River Morass

	Mexico	0.1	1000	0	0.5	500	0	0.025	0	Small peat deposits in the volvanic mountains and also associated with coastal dunes in the Gulf of Mexico and Yucatan Peninsula
	Nicaragua	3.1	3710	1	0.5	1855	0	0.093	0	Absence of information
	Panama	10.6	7870	2	6	47,220	3	2.38	3	See Costa Rica
	Puerto Rico	1.3	100	0	0.5	50	0	0.003	0	Some mangrove peat in the coastal lowlands
	Trinidad and Tobago	0.2	10	0	1.3	13	0	0.001	0	Absence of information
Subtotal			**23,374**	**5**		**60,477**	**3**	**3.048**	**3**	
Pacific	Australia	<0.01	150	0	0.5	75	0	0.004	0	Mostly swamp forestr and mangrove along coasts of Queensland and Northern Territory
	Fiji	0.2	40	0	1.5	60	0	0.003	0	Mainly along southeast coast of Viti Levu and along the Rewa River
Subtotal			**190**	**0**		**135**	**0**	**0.007**	**0**	
South America	Bolivia	0.1	507	0	0.5	254	0	0.013	0	Only small area of peatland between Toloco and Chuquiaguilloo, Murillo Province and along the Caluyi River and Paco Khita Lagoon
	Brazil	0.3	25,000	6	2	50,000	3	2.52	3	Mostly along the northeast and southeast coasts
	Chile	0.1	1047	0	0.5	524	0	0.026	0	Absence of information
	Colombia	0.5	5043	1	0.5	2522	0	0.127	0	*Mauritia* palm dominated swamps in the Atrato River valley and on the Pacific Coast
	Ecuador	2	5000	1	1	5000	0	0.252	0	Absence of information

(continued)

Table 1.3 (continued)

Region	Country	Peatland as % of land area	Peatland area best estimate		Peat thickness best estimate	Peat volume best estimate		Peat carbon best Estimate		Notes
			km^2	%	m	m^3 × 10 exp 6	%	Gt	%	
	French Guiana	1.9	1620	0	0.5	810	0	0.041	0	Extensive marsh and swamp forest along the coastal plain
	Guyana	4.1	8139	2	0.5	4070	0	0.205	0	Extensive marsh and swamp forest along the coastal plain
	Peru	3.9	50,000	11	1.75	87,500	5	4.41	5	Probably largest peatland area in South America at headwaters of Amazon and mountain bogs in Andes
	Surinam	0.7	1130	0	1	1130	0	0.057	0	Extensive marsh and swamp forest along the coastal plain
	Venezuela	1.1	10,000	2	4	40,000	2	2.016	2	Mainly in coastal swamps, mostly in Orinoco River delta and in river valleys
Subtotal			**107,486**	**24**		**191,810**	**11**	**9.667**	**11**	
Total			**441,025**	**100**		**1,757,929**	**100**	**88.599**	**100**	

this region occur along the coasts of East Sumatra, Kalimantan (Central, East, South and West Kalimantan provinces), West Papua and Sarawak, Malaysia (Rieley et al. 1996) (Table 1.3).

Within Southeast Asia, Indonesia has the largest area (206,950 km^2, 47 % of the total), followed by Malaysia (25,889 km^2; 6 %) and Papua New Guinea (10,986 km^2; 3 %) with other countries in this region containing much smaller amounts (1 % collectively in Brunei, Myanmar, the Philippines, Thailand and Vietnam) (Table 1.3).

1.3.1 Brunei

Most of Brunei's peatland occurs at low altitude, near to the coast, from sea level to about 50 m above. Small areas are found also in highland areas, where they are associated with Kerangas (heath forest) (Hunting Technical Services Ltd 1969; Anderson and Marsden 1988). Peatland makes up 19 % of the land area of Brunei but, since it is a small country, it makes a relatively small contribution to the global total (Page et al. 2011). Notably, the peatlands are still covered mostly with peat swamp forest.

1.3.2 Indonesia

Indonesia contains 47 % of the global area of tropical peatland (Page et al. 2011) mostly as extensive domes of woody peat, supporting peat swamp forest that covers vast areas of lowland landscape between major rivers. Large areas of tropical peatland in Indonesia, however, have been converted to agriculture, initially under the Indonesian Government's transmigration programme (re-settlement of people from densely populated areas in Java, Bali and Madura) but now for commercial oil palm and paper pulp tree plantations, especially in Sumatra and Kalimantan (Hooijer et al. 2006). This has led to widespread deforestation and drainage.

1.3.3 Malaysia

Six per cent of the global area of tropical peatland is in Malaysia (Page et al. 2011) with extensive deposits occurring as a discontinuous series along the poorly drained coastal areas of Peninsular Malaysia, Sarawak and Sabah. These peatlands are similar to those of Indonesia, forming deep domed peat deposits, covered with forest trees and dominating vast areas of landscape. The peat swamp forests have been exploited for their timber and many have been converted to agriculture, formerly for pineapple and other seasonal crops but much of the remaining peatland is now being converted to oil palm and sago plantations.

1.3.4 Myanmar (Burma)

Kivinen and Pakarinen (1980) estimated the peatland area of Myanmar to be 500 km^2, a value that is also used by Markov et al. (1988). Peat thickness is said to be shallow (1–2 m). An area of 3410 km^2 of Histosols has been projected from the Interpreted World Soil Map (Van Engelen and Huting 2002).

1.3.5 Papua New Guinea

Three percent of the global area of tropical peatland is in Papua New Guinea (Page et al. 2011). There are approximately 28,900 km^2 of organic soils (Histosols) equal to about 6.2 % of the land area (Wayi and Freyne 1992) but only some 11,000 km^2 are thought to be peatland. Peatland is found at altitudes from sea level to 3000 m in the mountains (Hope 2007). Some peat occurs in the Wahli Valley, part of which has been drained and cultivated (Bord na Mona 1984). Utilization for agriculture dates back some 900 years (Golson 1977). Most mires are 5–10 m in thickness with their formation spanning more than 30,000 years. The vegetation of lowland peatlands is dominated by swamp forest that gives way to sedges and grasses in the swampy valley bottoms of mountain mires. Above 3000 m peatlands are blanket bogs dominated by sedges, heathers and ferns (Hope 2007).

1.3.6 Philippines

There is very little information published on the peat resources of the Philippines although the Bureau of Energy Development of the Ministry of Energy estimated a total peat area of only 60 km^2 with an average thickness of 5.3 m. An assessment published by Oravainen et al. (1992) showed the potential of 70 km^2 of peatland in Leyte Province for agricultural development of which much has already been cleared and drained (Aberico 1981). The area was never used, however, because it flooded during the rainy season. Satellite image maps (1: 250,000) and their corresponding interpretation as plotted in a land cover map (of the same scale) were prepared by the Swedish Space Corporation (SSC 1988) and these show the distribution of swamps and marshes from which the area of peatland can be estimated.

1.3.7 Thailand

Whilst peatlands occur throughout Thailand their extent is small compared to Indonesia and Malaysia (Niyomdham et al. 1996; Urapeepatanapong and Pitayakajornwute 1996). Their character is diverse, however, reflecting variations in the peat depositional environment and their chemical and physical characteristics. Until the mapping surveys carried out by the Soil Survey Division of the Land Development Department, little attention was paid to peatlands in Thailand and few systematic studies were carried out because peat soils were not considered to be agriculturally productive and required expensive reclamation. The largest area of peatland occurs in Narathiwat Province in the south of the country where a Royal Initiative Project based at the Pikunthong Development Centre promoted research on their ecology and development.

1.3.8 Vietnam

Peatlands are concentrated in the Tongkin lowland, in the north-east and in the Mekong River delta, and they are mostly minerotrophic. The peat of coastal mangroves is quite shallow but, in some areas, the thickness is up to 2 m. The largest reed swamp dominated by *Phragmites karka* covers an area 130 km long by 30–40 km wide, on the eastern and northern parts of the Mekong Delta.

1.4 Africa

While various types of swamps are abundant in Africa, true peatlands are comparatively rare and few have been surveyed in detail (Bord na Mona 1984; Page et al. 2011) (Table 1.3). Even where peat has accumulated it often contains a high level of inorganic material derived from aeolian dust and waterborne silt and clay. With evaporation exceeding rainfall below 2000 m altitude, peat formation occurs largely in wet highland and mountain areas in Kenya, Rwanda, Burundi, Uganda, Congo and Malawi. Some peatland also occurs in the coastal deltas of west and southeast Africa. Precise information on the extent (area and thickness) of tropical peat deposits in Africa is not yet available (Page et al. 2011).

1.4.1 Angola

According to Bord na Mona (1984) and Shier (1985) there are extensive peat deposits in the valley of the River Cuanza, southeast of Catate, about 50 km from Luanda. In some areas the peat is a surface deposit while elsewhere it may be covered by up to 10 m of alluvium.

1.4.2 Botswana

The most important wetland area in Botswana is the Okavango Delta, a seasonal swamp of up to 16,000 km^2 of which over 3000 km^2 is permanent swamp and about half this latter area contains peat producing vegetation, especially *Phragmites* sp. and *Cyperus papyrus*. Kivinen and Pakarinen (1981) mention the presence of peatland in Botswana but do not provide an estimate of the area. Peatland could cover 2500–3000 km^2 with thickness of peat up to 4 m.

1.4.3 Burundi and Rwanda

The first studies of the peatlands of Burundi and Rwanda were conducted by the Belgian botanist Paul Deuse between 1958 and 1964 (Deuse 1966). A detailed inventory of peat deposits in Burundi was carried out in 1974 by Ruston Technical Services International for UNIDO that estimated around 14,000 ha (Ruston 1980). This includes an extensive area of peatland along the valley of the Akanyaru River which forms the border between these two countries. The possibility of using peat from this deposit to generate steam, power and reduction gases for the Musongati nickel project was assessed (Kalmari and Leino 1985), but was not implemented. The UNIDO survey also investigated Busoro Bog, 80 km south of Kigali, in the Akanyaru River basin of Rwanda, a ‘drowned valley bog’ with peat up to 10 m thick that is covered by a metre of water during the rainy season. In addition, there are numerous small high altitude mires near the Nile/Democratic Republic of Congo watershed (Pajunen 1985, 1996). A later survey of selected peatland areas, conducted by Bord na Mona in 1978 (Bord na Mona 1984) demonstrated that some *Papyrus* marshes previously thought to contain considerable amounts of peat consisted of a floating vegetation mat about 0.5 m thick, with only a thin layer of approximately 0.7 m of peat on the bottom.

1.4.4 Cameroon

Bord na Mona (1984) and Shier (1985) make a brief mention of the occurrence of Histosols associated with Orthic Ferrasols in Cameroon, some of which are peat forming. Other potential peatland areas include the Toubouri depression and swamp forests of the Nyong and Dja Rivers (Howard-Williams and Thompson 1985). Some floodplains and probable peatlands are shared with Chad, Niger and Nigeria.

1.4.5 Congo (Brazzaville)

There are reports of large areas of Histosols with peat up to 30 m thick in the floodplain of the Congo River (Markov et al. 1988; Shier 1985). Howard-Williams and Thompson (1985) refer to a potential area of peatland in the Malebo Pool (Congo and Democratic Republic of Congo), a shallow riverine lake of about 300 km^2. Elenga (1992) described peat swamps from the Bilanko Forest (700 m altitude), 80 km NNE of Brazzaville, with up to 4 m of peat.

1.4.6 Democratic Republic of Congo (Zaire)

Peatlands are located in the Congo Basin that is shared with neighbouring Congo-Brazzaville (Lewis, pers comm) and also in mountainous areas of Bukavu in the east of the country, immediately west of Lake Kivu (GPD 2004). The latter is an extension of the Virunga volcanic range shared with Kigezi District of Uganda. Individual bogs are small (50–1000 ha), with peat thickness varying from 1 m to over 15 m in volcanic craters between 1600 and 2200 m altitude.

1.4.7 Gabon

Bord na Mona (1984) and Shier (1985) make a brief mention of the occurrence of Histosols associated with Orthic Ferrasols in Gabon but do not indicate their location. According to the interpreted World Soil Map (Van Engelen and Huting 2002 quoted in GPD 2004) there are 1951 km^2 of Histosols in Gabon. Possible peatland areas include the swamps and floodplain of the Ogoonué River and the shallow lakes Onangue and Manje (Howard-Williams and Thompson 1985).

1.4.8 Ghana

Markov et al. (1988) mention the possible presence of peat-accumulating swamps in southwest Ghana. Other peatlands might occur in the White Volta River floodplain, a large seasonal wetland of around 8500 km^2 in the wet season and 1000 km^2 in the dry season (Howard-Williams and Thompson 1985).

1.4.9 Guinea

In Guinea, Histosols are associated with 5250 km^2 of lagoonal deposits in which three types of peat have been identified: (1) saline mangrove peat formed by *Rhizophora mangle* and *R. racemosa* on present fluvial-marine deposits; (2) intermediate *Raphia sassandrensis* peat, formed on desalinated marine sediments and alluvium; and (3) continental *Raphia gracilis* peat formed on alluvial deposits in river valleys (Kawalec 1976; Bord na Mona 1984). All of these peats are fairly shallow, inundated regularly and have ash contents ranging from 30 to 53 %.

1.4.10 Ivory Coast

Kivinen and Pakarinen (1981) refer to the presence of peatland in Ivory Coast but do not provide an estimate of the area. Bord na Mona (1984) and Shier (1985), using information from the FAO/UNESCO (1971–1981) Soil Map of the World, mention an area of Histosols that they equate to 320 km^2 of mires. According to Markov et al. (1988), however, there are some 2000 km^2 of peatland in the delta of the River Agneb with thickness of 5–7 m and 50–70 % organic matter content.

1.4.11 Kenya

Kivinen and Pakarinen (1981) mention the presence of peatland in Kenya but do not provide an estimate of the area. Markov et al. (1988) suggest it is about 1000 km^2, principally around lakes in the Rift Valley and on Mount Kenya, Aberdares and parts of Mount Elgon bordering Uganda. Lappalainen (1996) proposes 1600 km^2 based on work by Coetzee (1967) and Hamilton (1982). Around lake margins the principal peat forming plants are *Cyperus papyrus* and *Phragmites* sp. that form semi-floating mats with shallow peat. In the mountains, the peatlands have similarities with boreal and temperate peatlands and are dominated by *Sphagnum* spp. and sedges (Rieley *pers obs*).

1.4.12 Liberia

According to Bord na Mona (1984) there is an estimated 400 km^2 of peatland in Liberia, mostly valley-bottom swamps dominated by *Raphia* spp. with shallow peat that rarely exceeds 0.5 m.

1.4.13 Madagascar

Shier (1985), referring to the FAO/UNESCO (1971–1981) soil map of the world, infers there are 1970 km^2 of Histosols around Lake Alatza in north-eastern Madagascar that he equates with peatland. Howard-Williams and Thompson (1985) give a smaller area of 1000 km^2 for the swamps surrounding Lake Alaotra but mention other potential areas of peatland of up to 200 km^2 surrounding Lakes Itasy and Kinkony and associated shallow lakes. According to GPD (2004), quoting various sources, peat can be found in coastal lagoons (mangrove), around low altitude lakes and in the mountains where small crater mires 3–5 km^2 in area have peat up to 10.5 m thick.

1.4.14 Malawi

The peat resources of Malawi have not been studied in detail but upland peat deposits are known to occur on the Nyika Plateau in the north and Mulange to the south (Thompson and Hamilton 1983). According to the FAO Soil Map of the World (FAO/UNESCO 1971–1981) there are 910 km^2 of lowland Histosols on recent alluvial deposits along the valley of the River Shire, southwest of the capital Lilongwe.

1.4.15 Mauritania

According to Howard-Williams and Thompson (1985) there is only a small area of peatland in Mauritania in the floodplain and delta of the Senegal River and in Lake Rkiz.

1.4.16 Mozambique

Kivinen and Pakarinen (1981) mention the presence of peatland in Mozambique but do not provide estimates of the area. Markov et al. (1988) refer to peatland along the Indian Ocean coast with peat up to 3 m thick. According to Bord na Mona (1984) and Shier (1985) there are extensive swamp, marshland and seasonally-flooded areas in river valleys, estuaries and along the coast. Specific formations, known as ‘Machongos’, associated with depressions between old coastal dunes, contain peat. Andriesse (1988) estimates the extent of organic soils to be 100 km^2 but, according to Grundling (pers com in GPD 2004), there could be between 1500 and 2500 km^2 of peatland in the coastal plain of Mozambique.

1.4.17 Nigeria

Little information is available on peatland in Nigeria but Lappalainen (1996) refers to an extensive mangrove area of 7000 km^2 in the Niger delta mentioned by Gosselink and Maltby (1990) and freshwater swamp forest described by Denny (1991). It is likely that peat is present within these areas but how much is unknown.

1.4.18 Reunion

There is a report of small areas of peatland with peat up to 3.5 m thick in an old crater at altitudes between 1400 and 2500 m above sea level (GPD 2004).

1.4.19 Senegal

Peat deposits are found in the Niayes region of Senegal, which stretches along the coast from Dakar to St. Louis, an area characterized by a series of stable dunes and depressions lying behind the shoreline (Korpijaakko 1985; Shier 1985; Korpijaakko and Korpijaakko 1996). Following a long period of rainfall deficit and a lowering of the water table, the shallow lakes which occupied many of these depressions have disappeared, revealing up to 10 m of peat deposited under lacustrine conditions. The Government of Senegal set up the Compagnie des Tourbières du Senegal to develop these peat deposits within their programme for diversification of the country's energy sources (Bord na Mona 1984).

1.4.20 Sierra Leone

Markov et al. (1988) refers to forested peatlands, open peatlands and mangroves but does not give any indication of their area. There is a lack of information on Sierra Leone's peatland resource and it is likely to be underestimated.

1.4.21 Sudan

In spite of being the largest country in Africa there is relatively little factual information available on the peatlands of this country. The swamps of the Upper Nile, called the Sudd, are one of the largest areas of wetland in the world (Howard-Williams and Thompson 1985). Kivinen and Pakarinen (1981) mention peatland in Sudan but do not give an indication of the area. Lappalainen and Zurek (1996a) state there is 1000 km^2 of 'mire area' in Sudan but do not provide any evidence to support this. According to the interpreted World Soil Map (Van Engelen and Huting 2002) there are 33,270 km^2 of Histosols. The situation is confusing and requires further study.

1.4.22 Uganda

Uganda has a large area of peatland (Page et al. 2011) much of it formed in freshwater swamp dominated by *Cyperus papyrus* around the north and west of Lake Victoria. In addition, there are considerable swamps in the mountainous and volcanic-crater district of Kigezi bordering the Western Rift Valley, and in the shallow valley country between Lakes Albert, Victoria and Kyoga. In parts of the Ruwenzori Highlands *Sphagnum* moss dominated peatlands occur that are rare in Africa as a whole.

1.4.23 Zambia

Histosols are estimated to occupy up to 11,000 km^2 in the extensive permanent swamp complexes around Lake Bangweulu in the north and in the Lukanga swamp in central Zambia. It is unclear how much is peatland or how thick the peat might be.

1.5 Caribbean and Central America

According to the FAO/UNESCO (1971–1981) Soil Map of the World, Histosols have a limited distribution in Central America and relatively little information has been published on peatlands in this region (Page et al. 2011) (Table 1.3). Cuba, Haiti, Honduras and Nicaragua are reputed to have substantial areas. They occur at high elevations on some of the volcanic mountains and in a narrow strip along the eastern coastline running south from Belize. The coastal deposits are mainly organic residues from mangrove forests. In the Caribbean lowlands a narrow coastal strip of wetlands with Histosols extends south from Belize, widening considerably along the east coast of Honduras, Nicaragua and Costa Rica and narrowing again in Panama. This coastal area is characterized by intermittent mangrove forest, especially in river estuaries, and by lagoons and sandbars with swamps running inland. The coastal swamps, and those along rivers and lakes, accumulate peat derived from species of *Cyperus*, *Typha*, *Phragmites* and *Scirpus*. These areas have not been utilised traditionally for agriculture owing to their high and frequently saline water. Coastal swamps are also a feature of the islands of the Caribbean, occupying extensive areas in Cuba, Jamaica, Puerto Rico and Trinidad and Tobago.

1.5.1 Belize

Preliminary estimates of the peat resources of Belize suggested the total peatland area to be 680 km^2 (Bord na Mona 1984) but this was increased later to 900 km^2 with the major proportion of the deposits less than 1 m thick (Shier 1985). More recent studies of ecosystem changes since the Holocene in mangrove peat deposits on several islands have found peat thickness of 8 m (Wooller et al. 2007; Monacci et al. 2009).

1.5.2 Costa Rica and Panama

The 150 km of Caribbean coastal plain extending southeast from Puerto Limón in Costa Rica to the large shallow embayment of Chiriqui Lagoon in Panama embraces the alluvial plains of numerous rivers. The interfluves form a series of barrier beaches behind which are found occasional small freshwater lagoons with extensive swamps overlying Quaternary and Recent alluvium (Phillips et al. 1997). A study of the Changuinola peatland, developed in a back-barrier setting on the Caribbean coast of Panama, which is partly submerged to a depth of 3 m under the sea following a major earthquake on 22 April 1991, provided peat thickness of up to 8 m. There are other extensive areas of peatland, especially in Panama but to date information about them is lacking.

1.5.3 Cuba

Cuba has significant peat deposits on the two main islands, the Island of Cuba and the Island of Youth (Casanova 1996). Cuban peat is coastal and minerotrophic and the vegetation is mostly mangroves or herbaceous plants. The most important peatland in Cuba is the Cienga de Zapata the bottom of which is below sea level and its boundaries are in contact with seawater.

1.5.4 El Salvador, Honduras and Nicaragua

Bord na Mona (1984) provides the following peat resource information: El Salvador 90 km^2; Honduras 4530 km^2; Nicaragua 3710 km^2. There appears to be an absence of information in the literature to support these data and further investigation is required.

1.5.5 Haiti

A 475 km^2 wetland area occurs on the delta and plain of the River Artibonite, consisting of coastal lagoons, mangrove swamps and marshes (Lappalainen and Zurek 1996b). Some are thought to contain peat.

1.5.6 Jamaica

There are several small peat deposits in St. Thomas, St. Catherine, Clarendon, Manchester and Westmoreland but the two largest areas are at Negril in Hanover District on the western tip of the island and Black River in the St. Elizabeth District on the southwest coast. Both of the latter were surveyed extensively in connection with a possible project to use peat fuel for electricity generation (Bord na Mona 1984). The Negril Morass, 23 km^2 in extent, is a coastal swamp in which thicknesses of up to 16 m have been reported. The Black River Lower Morass covers some 60 km^2 and contains a Holocene fluvial/estuarine sedimentary sequence. Associated peat swamps occur along tributary watercourses where peat thicknesses exceeding 10 m have been obtained.

1.5.7 Mexico

Precise information is not available on the area and distribution of peatlands in Mexico although, according to Joosten and Clarke (2002), there are some 1000 km^2. Small climatically-determined peat deposits are associated with Andosols at high elevation in the volcanic mountains of Mexico. Histosols occur with Fluvisols and Gleysols in the wide swampy area which lies immediately behind coastal dunes east of Coatzacoalcos in the Gulf of Mexico and on the Yucatan Peninsula. These consist of mangrove swamps and freshwater marshes that contain peat (Lappalainen and Zurek 1996b).

1.5.8 Puerto Rico

According to Bord na Mona (1984) there are 100 km^2 of organic soils in Puerto Rica that have been equated to 100 km^2 of peatland by Lappalainen and Zurek (1996b). Peat deposits are confined to the coastal lowlands where mangrove peat has accumulated along the saline fringe, with *Typha*, *Phragmites* and sedge peat in the inundated coastal swamps. Some of the peatland away from saline influence has been drained for sugar cane cultivation.

1.5.9 Trinidad and Tobago

There are no known peat deposits in Trinidad but there may be 10 km^2 in Tobago associated with freshwater swamps on the West coast, southeast of Port of Spain and at San Rafael in the centre of the island (Bord na Mona 1984). Some peatland has been converted to agriculture but a large proportion is influenced by saline conditions.

1.6 South America

Peatlands in tropical South America are predominantly lowland coastal (lagoonal, estuarine or deltaic) or associated with extensive inland river floodplains (Shier 1985; Lappalainen and Zurek 1996b). Information on the area of peatland in various South American countries is still becoming available and the inventory requires continued updating (Page et al. 2011; Table 1.3) Tropical coastal swamps in Guyana, Surinam and French Guiana on the north-east coast, and on the eastern coast of Brazil, consist of low-lying grass and sedge swamps behind an outer mangrove belt, with swamp forest on the more elevated areas. Peat deposits are found in the basins of major rivers wherever water tables remain sufficiently high throughout the year. Montane peat deposits are also found in parts of the Andes where climatic and topographical conditions support peat formation. In the northern ranges, peat occurs south of Quito in Ecuador and in Columbia, in a superhumid, cool climate. In central regions the subhumid climate of the Andean Altiplano favours peat formation in the intermontane basin around Lake Titicaca in Peru.

1.6.1 Bolivia

Bord na Mona (1984) estimate there is only 9 km^2 of peatland in Bolivia distributed between Toloco and Chuquiaguilloo but Joosten and Clarke suggest it is 20 km^2 while Page et al. (2011) believe it could be as much as 500 km^2. Peatlands are also found in Murillo Province with smaller deposits along the Caluyo River and the Paco Khota lagoon (Shier 1985). Little is known about their thickness.

1.6.2 Brazil

According to the National Department of Mineral Production of the Ministry of Mines and Energy there are 66 separate areas of peat deposits containing some 358 bogs. The most important peatland areas lie along the North-east and South-east coasts. Little is known about the peatlands of Brazil but their area is likely to be very large. Estimates range from 15,000 km^2 (Bord na Mona 1984) to 55,000 km^2 (Ruokalainen et al. 2001. The total may be much larger. Little is known about their thickness.

1.6.3 Chile

Chile is an extremely long country extending from about 18° to 55°S, only about 10 % of which is in the tropical zone. Bord na Mona estimates the total area to be 10,470 km^2 therefore only 1047 km^2 are considered to be tropical peatland.

1.6.4 Colombia

Histosols occupy 3390 km^2, primarily swamplands, in river valleys and on alluvial floodplains, and moorlands at higher altitudes (Bord na Mona 1984). Peat-containing floodplains occur in the Atrato River valley of northern Colombia where palm-dominated swamps occupy basins and flat land (Lappalainen and Zurek

1996b). On the Pacific coast, a 0.3–1.2 km wide wetland is located behind a 600 km long mangrove swamp. Schulman et al. (1999) suggest there could be 8000 km^2 of *Mauritia* swamps overlying peat up to 1 m thick.

1.6.5 Ecuador

Little is known about Ecuador's peatland but Ruokalainen et al. (2001) suggest it could be as much as 4000 km^2, mostly *Mauritia* swamps.

1.6.6 French Guiana, Guyana and Surinam

Extensive shallow marsh and swamp forest deposits occur on the northern coastal plain of these countries. Peat thickness of up to 9 m has been observed although the average thickness is less than 1 m (Shier 1985; Lappalainen and Zurek 1996b). Most of the coastal peatlands have been converted to agriculture or shrimp farming.

1.6.7 Peru

Peru lies entirely within the tropical zone and contains peat forming forests at the headwaters of the River Amazon and also mountain bogs in the Andes. Little is known about Peru's peatland but Ruokalainen et al. (2001) suggest it could be as much as 50,000 km^2. More investigation is required to verify this. Recent studies suggest that Peruvian Amazonian peatlands store around 6.2 Gt of carbon, which is about 7 % of the global tropical peatland carbon pool (Lähteenoja et al. 2009, 2013).

1.6.8 Venezuela

According to Bord na Mona (1984) peatland in Venezuela occurs mainly in coastal swamps and in river basins, with the largest concentration in the Orinoco River delta. A small proportion has been drained for agriculture (Shier 1985; Lappalainen and Zurek 1996b). The Orinoco Delta comprises 20,000 km^2 of fresh- to brackish-water wetlands of which approximately one quarter (5000 km^2) is underlain by peat 3–10 m thick (Aslan et al. 2003). Recent information shows there is also peat on the tepui summits (table mountains) of the Guayana Highlands of southern Venezuela that has accumulated during the Holocene (Zinck and Huber 2011). These are mostly between 2000 and 2500 m above sea level and peatland covers approximately 30 % of the tepui summits (about 1500 km^2). Peat occurs in depressions, on gentle slopes and in small valleys, forming a discontinuous mosaic cover from a few square metres to several hectares. Peat thickness varies from a few cm to 2 m.

1.7 Mainland South Asia

As in Africa, lowland peatland formation in Asia is governed by local hydrological conditions, with climatic influences becoming more important with increasing altitude. Peatlands are primarily limnic or geogenous, occurring in coastal basins and river floodplains and deltas Page et al. 2011). The vegetation is typically sedge, reed or inundated swamp forest, with occasional mangrove systems (Shier 1985).

1.7.1 Bangladesh

Major peatland resources occur in the Ganges Delta with further limited deposits in the Sylhet Basin in the northeast of the country. The Ganges peat deposits underlie a shallow layer of alluvial silt and are inundated regularly by summer monsoon floods. The peat is formed mostly from grasses, reeds, sedges and trees. According to Bord na Mona (1984) the area of peatland in Bangladesh is some 600 km^2, ranging from 0.3 to 4.0 m thick, with an average of 1.5 m. The peat is highly decomposed with high ash content.

1.7.2 China

Only about 10 % of China's large area of peatland occurs in the tropical zone, mostly along the lower reaches of the Yangtze River and on Hainan Island. According to Bord na Mona (1984) there is 34,770 km^2 of surface peatland in China and a further 6820 km^2 of subsurface peat making 41,590 km^2 in total. The tropical proportion of this could be in the region of 4159 km^2. There is no information on the thickness of peat in China.

1.7.3 India

Little is known about the distribution and area of peatland in India which extends from coastal areas surrounding the Bay of Bengal and the Arabian Sea to the foothills of the Himalayas. The northern part of the country is outside of the tropical zone but the southern part is included. According to the FAO/UNESCO Soil Map peatland in India covers 320 km^2 in total but Markov et al. (1988) believe it to be nearer to only 100 km^2, excluding mangrove peat. The Sunderbans, which belong jointly to Bangladesh and India contain 6000–10,000 km^2 of mangrove some of which may be associated with peat.

1.7.4 Sri Lanka

The peatlands of Sri Lanka are located mostly at or near the west coast (Shier 1985). Muthurajawela swamp, covering 22 km^2, lies to the north of Colombo, with a second deposit at Kotte to the southeast. Peatlands also occur in Nuwara Eliya, the mountains of the interior of the island, at an altitude of 2200–2400 m (Lappalainen 1996)

1.8 Australasia and Pacific

There is only a small area of tropical peatland in this region, mostly swamp forest and some mangrove, along the coasts of Queensland and Northern Territory of Australia (Lappalainen 1996; Page et al. 2011). Fiji has about 40 km^2 of peatland, mainly along the southeast coast of Viti Levu (Bord na Mona 1984; Shier 1985). The principal deposits are along the Rewa River, northeast of Suva and close to Nausori. There are also some very small areas of peatland on some Micronesian islands.

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Chapter 2
Changing Paradigms in the History of Tropical Peatland Research

Hans Joosten

Abstract The history of peatland research in Southeast Asia can be understood as a story of changing paradigms. Whereas already in 1778 the idea had been proposed that coal originates from peatlands and that during the Carboniferous a tropical climate had prevailed, peatland science maintained that in the tropics decomposition would proceed too rapidly to allow peat formation. The many reports of the contrary never reached nor convinced the mainstream scientific world. Only in 1909 with a publication of coal geologist Henri Potonié the existence of real peatlands was widely accepted. Potonié simultaneously underscored that tropical peatlands could only be groundwater fed. In 1933 Betje Polak convincingly argued that many Southeast Asian peatlands are in fact ombrogenous bogs, not geogenous fens.

Instrumental in these scientific revolutions was the long-term devotion and the ‘un-disciplinary’ background of both Potonié and Polak. The decades that passed between the emergence of evidence and its wide acceptance support the observation that new scientific truths do not triumph by conviction, but because their opponents eventually die. As the peatlands in Southeast Asia are currently dying faster than their researchers, a new sustainability paradigm is urgently needed.

Keywords Peat • Bog • Tropics • History • Paradigm

2.1 Introduction

> “Guicciardini says, that it is not known whether Asia, Africa, or America, contain any mosses, as no search has been made. Degner and Dr. Anderson deny that there are any in these regions. . . . The former argues upon this as a fact: “If, “says he, “forests are converted into moss, the greatest part of Moscovy, Tartary, America, and other woody uncultivated regions would have, ere now, undergone this change, which is not the case.”

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> "To this I reply, . . . , That in woody regions, moss is of little value; it is never in request as a fuel, as the abundance of wood supplies its place. No efforts are made to search for it as a soil or a manure. The former can be produced in abundance; the latter is less requisite. Mosses, therefore, may exist in these regions, though no notice be taken of them." (Rennie (1807): Essays on the natural history and origin of peat moss)

Scientific progress can be understood as a sequence of 'paradigms' (Kuhn 1962/1996). A paradigm represents the matrix of generalizations, beliefs, values, and examplars that are shared by mainstream scientists. Paradigms are not only 'disciplinary' in the sense that they unify a scientific discipline, they also 'discipline' by self-confirmation and education and by – consciously and unconsciously – suppressing views that do not fit in the prevailing paradigm. A paradigm may be replaced, when sufficient challenging observations/considerations have accumulated and in a 'scientific revolution' (Kuhn 1996) a new paradigm with wider explanatory power is established.

Also the history of peatland research in Southeast Asia is such a story of changing paradigms. In this paper I describe the people, ideas and events that accomplished the two main scientific revolutions: the mere acknowledgement of the existence of peat in the tropics and the recognition of ombrogenous peatlands.

Especially Dutch scientists were instrumental in both revolutions. The Netherlands combines the oldest major economic and scientific peatland tradition (De Zeeuw 1978, cf. Schoockius 1658, the worldwide first scientific book on peat and peatlands) with its past as colonialist of the prime tropical peatland country Indonesia. Most countries in Europe where peatland science did originate have no tropical colonist tradition, the United Kingdom and The Netherlands being the exception. Whereas English publications were widely read, the Dutch (and German) language of many relevant reports and publications impeded diffusion of the 'revolutionary' ideas they contained. And where translations into English were indeed made, severe mistakes confirmed rather than challenged the prevailing paradigm. In this paper I therefore present new English translations of various original Dutch and German language texts that demonstrate historical development and illustrate topicality.

2.2 The Age of Denial (1778–1909)

In 1778 the German theologian and speculative geologist Franz von Beroldingen (1740–1798) propounded the theory that coal "largely originates from the Plant Kingdom, and that it is originally nothing else than . . . at times topsoil, at times trees, but most commonly peatlands that have been flooded and covered by earth, that through the works of Nature eventually have transformed into coal." This theory gloriously spread in spite of his second preposition that – as had been deduced from fossils in coal – during the Carboniferous period a tropical climate had prevailed over the entire globe. Mainstream science, however, maintained that autochthonous peat deposits were not found in tropical countries. In order to escape from this contradiction some geologists assumed that coal did not derive from peatlands at all, while others sought a solution by supposing that coal formation could only take place in a cool climate (Wichmann 1910a, b).

The maxim that peatlands do not exist in tropical countries was supported by the most influential scientists of that time. The leading Dutch geologist and soil scientist Winand Staring stated in his 1856 benchmark book on the soils of The Netherlands explicitly "that in the tropics peat formation is impossible, because the plants decompose too rapidly"(Staring 1856), a statement that was not challenged in publications of the same rank, in spite of many reports supporting the opposite.

Already Anderson (1794) had declared: "I have seen genuine peat that was found on the island of Summatra; which is a proof that it is not confined to cold regions only". Peatlands from Djambi (Sumatra) had been described by Groote in 1820 (Wichmann 1909). Pijnappel (1860) had reported on Von Gaffron, who – while exploring Central Kalimantan for coal and gold – had noted extensive swamp forest fires that for months had raged the Kotaringin area over almost 700,000 ha during the drought of 1846. Schwaner (1852–1854) had pointed out the presence of large peatlands in the southern and eastern part of Borneo, whereas Michielsen had presented peat from the Sumatran village of Siak to the 1864 meeting of the Koninklijke Natuurkundige Vereeniging (Dutch Royal Scientific Society) (Bernelot Moens 1865). Various early reports exist on the occurrence of peats on Java. Bernelot Moens (1865) noticed in his description of peat from near Djoegelangan village: "The presence of a peat deposit at this location would … conflict with the general accepted view that between the Tropics no peat soils can be formed, except on high places in the mountains, e.g. on the high plains of the volcanos on Java, because in the lower, warmer regions, the change of plant materials into humic soil occurs so rapidly, that no time is available for peat formation". Bernelot Moens explained tropical peat formation by the fact that "whereas the turn-over in a tropical country is faster, the all the more powerful plant growth also guarantees a proportional production." Vlaanderen (1865) presented the chemical profile of peat (loss-on-ignition 25.9 %) occurring south of Djenoe (Central Java), whereas Edeling (1867) described gas eruptions from a peatland in the Ambarawa basin associated with earth quakes. And shortly after Koorders in 1895 (see below) had published his detailed observations on pristine peat swamps in East-Sumatra, Van Bijlert (1897) presented a detailed analysis of the peatland soils (called "pajas") in that area used for tobacco cultivation: "Closer to the sea the paja soil is so loose and rich in water that the main canals can be made with dredge machines. Big pieces of peat float up, as do pieces of wood stems. The latter, initially hard as stone, fall within a very short time apart to an extremely fine, grey-black powder under the influence of heat and desiccation."

Van Bijlert (1897) also warned for the risks of fire and the inevitable subsidence of drained peat soils: "Has the soil become somewhat accessible by drainage, a start is made to cut the trees and to remove the lower vegetation. The burning of the dried trees should progress carefully and not in too large piles, because in such case the peat layer may also be burned. If a drained paja accidently catches fire, the peat layer burns away to the water level or to the incombustible subsoil. The deep paja soils … are without exceptions located low, and can thus only be made suitable for cultivation by a very well-developed and well-maintained drainage system. Like all peat soils the peat volume decreases very much and the surface thus approaches the drainage level. In case the land has over long time … remained constantly rather dry, this subsidence is doubtlessly of importance. … In general the land will continuously subside as a result of drainage. … The black or dark coloured soil is very strongly heatened by the sun, the peatified plant remains that have originated from water plants, fall apart to an extremely fine substance and are being decomposed very rapidly because of the effect of the easily penetrating air and the large heat in combination with humidity. … Returning to the same land in a next year, one finds the land laying deeper than before".

In spite of these early and detailed reports, the seminal peatland bible of Früh and Schröter (1904) included a special chapter "On the absence of typical peatlands in subtropical and tropical climates". The chapter concluded, after a thorough discussion of the literature (which excluded most above mentioned papers) and own observations:

1. "As far as hitherto existing studies range, no substantial proper autochthonous peat exists in the lowlands of the tropics, but at most peaty soils, raw humus and shallow fibrous sods.
2. Peat formation in the tropics only starts in higher regions with the climate of the temperate and cold zones.
3. The allegedly encountered peat deposits in the alluvia of the large tropical rivers are predominantly allochthonous formations."

Until 1909 the paradigm persisted that in the tropics no peat can be formed, because in the warm climate decomposition would proceed too rapidly and intensively. The many reports of the contrary never reached nor convinced the mainstream scientific world.

2.3 The Coal Man and the Focus on Fens (1909)

> "The commitments that govern normal science specify not only what sorts of entities the universe does contain, but also, by implication, those that it does not." (Kuhn 1996: The structure of scientific revolutions, p. 7.)

Whereas the ample observations over decades should have challenged the paradigm of a peat-free tropics, the scientific revolution only came with the publication of a paper with the fascinating title "Die Tropen-Sumpfflachmoor-Natur der Moore des produktiven Carbons" (The tropical swamp fen character of the peatlands of the productive Carboniferous; Potonié 1909). This booklet linked the concept of tropical peat to the globally important industrial energy carrier 'coal'. Its author Henry Potonié (1857–1913), a botanist by training and Professor of Palaeobotany and Coal Geology at the Royal Mining Academy and University of Berlin, was at that time preparing a magnus opus on combustible deposits of recent biotic origin (Potonié 1906; 1908–1915). Because of his strong interest in the genesis of coal (Potonié 1905, 1907a), Potonié was well aware of the hypothesis of von Beroldingen (1788). He had over years requested tropical investigators to search for peat deposits and had on scientific meetings interrogated travellers on the presence of "real peatlands" (i.e. with a peat soil) in the tropics (Potonié 1907b). Finally on a meeting of the Botanical Society of the Province of Brandenburg in 1907 Potonié met Sijfert Hendrik Koorders. Koorders was a Dutch forester and botanist born in Bandung and based at Buitenzorg (Bogor), who happened to be on health grounds on a sojourn in Europe. The meeting of the Society on June 14, 1907 took place in the newly built Royal Botanical Museum in Dahlem (Berlin), where Koorders was just finishing his long-term research on parasitic fungi of the rubber tree *Ficus elastica* (Koorders 1907). At the meeting a presentation on the geography and flora of Siam lead to a discussion on tropical peat bogs, in which – evidently – Potonié and Koorders participated.

Koorders (1863–1919) had in 1891 as a young botanist participated in the IJzerman expedition that with over 250 persons had crossed an 800 km^2 large peatland at the northern bank of the Kampar River in East-Sumatra. In the expedition report Koorders describes how the group had struggled for 3 days through a swamp consisting of 30 m high trees with overground roots emerging from a soft, very acid, brown peat soil. At the two nights they had to bivouac in the 12 km wide swamp, Koorders had pushed a more than 6 m long pole in the soil without reaching the mineral substrate (Potonié 1907b).

The report of the expedition (IJzerman et al. 1895) had only been published in Dutch and had consequently failed to attract international attention. Potonié immediately recognized the importance of Koorders' observations. He invited Koorders to share his insights on the nature of the peatland and they co-authored a paper that still in the same year appeared in the Naturwissenschaftliches Wochenzeitschrift (20 October 1907), a popular weekly science magazine of which Potonié was one of two editors, and in the influential Oesterreichisches Moorzeitschrift (15 November 1907; Potonié 1907b). The paper held the first scientific illustrations of a tropical peatland (Figs. 2.1 and 2.2) and a detailed botanical characterization of the peat swamp forest. It described the numerous pneumatophores ("that severely complicate progressing") that hitherto were only known from mangroves, the mighty stilt roots and buttresses that may reach up to 3–4 m up the trunk, and the horizontal aerial roots that grow like brooms out of the stems. For a second peat swamp near Pangkalan-Dulei (4 day's marches northeast of the Kampar swamp forest), Koorders described a peatland with

Fig. 2.1 (Original caption in translation) High forest-flat mire close to the equator, in the hot plane of Inner Sumatra in the Dutch East-Indies. Original drawn by Koorders (Potonié 1907b). Horizontal stripes: water, grid: peaty soil, X: bivouac

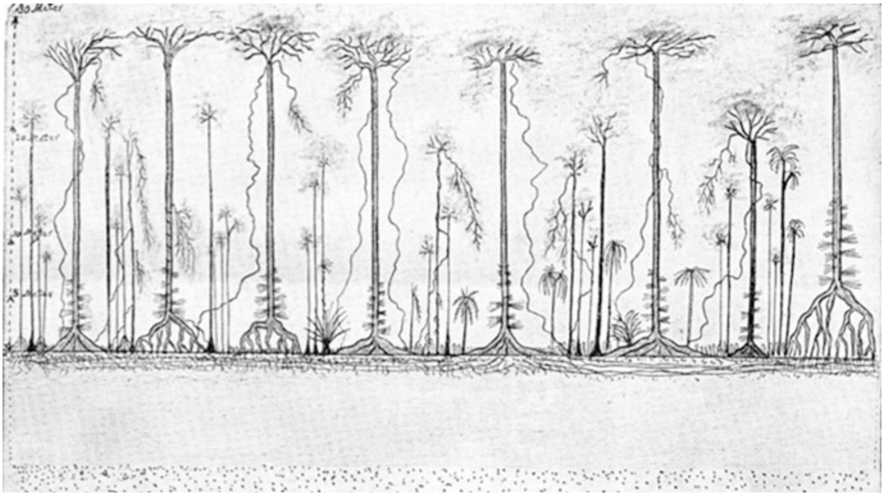

Fig. 2.2 (Original caption in translation): Part of Fig. 2.1 somewhat magnified to characterize the vegetation types of the peatland close to the bivouac of 20/21 March 1891. Original drawn by Koorders (Potonié 1907b)

a less dense forest cover with the trees – with low branched and twisted branches and dense crowns – only reaching heights of 5–12 m. Also the number of tree species was very low and no trees with large buttresses, high stilt roots or aerial roots were found.

To ascertain the presence of a real tropical peatland, Potonié and Koorders organized that controleur J.G. Larive – with huge efforts– in 1908 collected soil samples for analysis from the same spot of the Kampar peatland, where Koorders had pressed his pole into.

Meanwhile, independent from these developments but in support of the observations of Koorders, Wichmann (1909, 1910a, b) summarized most of the available literature in a detailed overview of the peatlands of Java, Sumatra (incl. the island of Bengkalis), Kalimantan, and New Guinea, using the presence of blackwaters as an important indicator. He especially described large extents of peatlands along the northeast coast of Sumatra. For the southwestern and southern parts of New Guinea, Wichmann cited the reports on the presence of peatlands of van Nouhuys and of Heldring who near Merauke had determined a peatland extent of 2240 km^2 (Wichmann 1909).

Whereas his German (1909) and Dutch (1910a) language papers had used the expression for 'peatlands' in general (German: 'Moore', Dutch: 'veenen'), his English language publication (Wichmann 1910b) restricted the subject to 'fens', i.e. minerotrophic/geogenous peatlands, both in the title ("The fens of the Indian Archipelago") and in the text. It is unclear whether this was done intentionally to adhere to the prevailing paradigm (cf. Potonié 1909) or whether it was a translation mistake of the etymologically similar Dutch word 'veen' into the English 'fen' which accidently supported that paradigm in international literature. Anyhow, Wichmann (1910b) concluded "The following brief survey may afford proof of the wide-spread distribution of fens in the Indian Archipelago, and, in spite of the very incomplete data, we may deduce from it that fens there occupy more than a million hectares." The fen peats he described from Java had ash contents of 27 %, 26 %, 36 and 49 %, respectively, so these must indeed have been derived from geogenous peatlands. Furthermore he interpreted the existence of most 'fens' in Sumatra as caused by the fact "that in consequence of the deposit of sludge etc. the river beds are constantly raised, so that the banks are also higher than the surrounding country. In the lowest portions of the depressions thus formed between the rivers, lakes and swamps were formed which gave rise to peat formation", which also would support a geogenous nature of the peatlands. In contrast, he also reported on fen formation in New Guinea, with peat with an ash content of only 4.58 %.

With the acknowledgement of the presence of peatlands in the tropics, immediately a new paradigm was vested, as had already been announced by Adolph Mayer in his 1901 textbook on soil science: "The truth is indeed that swamp mire soils (fen peatlands, laag veen in Dutch) are no rarity in the tropics, but that only the proper bogs thereat are absent."

"That is also my opinion", Potonié (1907b) added approvingly . . .

2.4 The Single Woman and the Emergence of Bogs (1933)

> "… a new theory, however special its range of application, is seldom or never just an increment to what is already known. Its assimilation requires the reconstruction of prior theory and the re-evaluation of prior fact, an intrinsically revolutionary process that is seldom completed by a single man and never overnight." (Kuhn 1996: The structure of scientific revolutions, p. 7.)

It was not so that the presence of ombrogenous bogs had remained completely unnoticed. Already Molengraaff had in 1892 observed raised bogs in the Madi mountains in Babas Hantu. In the Dutch publication of this expedition (Molengraaff 1900) he had described how the entire Madi high plateau was covered by "een echt tropisch hoogveen", i.e. a real tropical raised bog. The 1902 English edition, in contrast, did not differentiate explicitly between (ombrotrophic) bogs and (minerotrophic) fens, but translated the Dutch word "hooge veenen" (raised bogs) wrongly with "fens": "As we neared the bottom of the valley the patches of peat became more connected, and I soon realized that the whole of the valley, and probably the whole of the Madi plateau, was covered with marshy forest, standing in a thick layer of peat, originating from the half decayed remains of all kinds of trees, shrubs and mosses, a true tropical peatbog. In contrast to the fens of moderate zones, originating principally from a limited variety of shrubs and mosses, the tropical fens are principally composed of the remains of various trees" (Molengraaff 1902).

It was Dr Elisabeth Polak, Betje Polak as she was casually called, who finally in 1933 clearly pointed out the ombrogenous character of most Indonesian peatlands.

Betje Polak (1901–1980) had obtained her doctor's degree (with the highest honours) in 1929 (Polak 1929) and, with the appearance of her thesis, at once had made a name as a pre-eminent peat specialist. Her study was concerned with the nature of the peat deposits in the western Netherlands. At that time opinions widely diverged on their character and origin. In The Netherlands peatlands were traditionally differentiated in 'hoogveen' ('high peatland', located above sea level, solely fed by rain or fresh river water, where peat extraction could be practiced by digging after drainage) and 'laagveen' ('low peatland', below sea level, often flooded by the sea or by brackish rivers, with peat extraction taking place under undrained conditions by dredging, De Sitter 1796). As the extensive peat deposits in the western Netherlands were clearly lying below sea level and the peat was being dredged, the peatlands were in common parlance called 'laagveen' and most scientists assumed a subaquatic origin of this low-lying peat. A competitive theory questioned this interpretation by pointing at the botanical composition that was similar to peat deposited above the regional groundwater level ('hoogveen'). It was the detailed stratigraphical and palaeoecological study of Polak, which demonstrated that the succession of the low-lying peat had progressed from eutrophic fen peat via forest peat to older and younger *Sphagnum* peat, identical to the succession of the raised bogs on the higher Pleistocene sand soils of The Netherlands.

After the defence of her thesis Polak decided to leave The Netherlands, which suffered a severe economic crisis. With an award of the 'Buitenzorg Fund' she sailed in 1930 for the Netherlands Indies, the present Indonesia, to become temporarily attached to the Botanical Garden at Buitenzorg (Bogor), when its director went on holiday. After his return, she was in July 1931 appointed as a technician in the department of Physiological Chemistry at the Medical University in Batavia (Jakarta), a position probably created to enable her to continue her peat studies (Havinga and Muller 1981).

During these few years, Polak devoted immense energy to the study of tropical peatlands. The labels on the herbarium plants she collected show that in 1930 she visited West- and Central-Java, Northwest-, East- (e.g. Bengkalis) and South- (e.g. Palembang) Sumatra, and West-Borneo (e.g. Pontianak and Kapuas Lakes) (http://www.nationaalherbarium.nl/FMCollectors/p/PolakB.htm). These expeditions, which were out of tune with her somewhat un-athletic disposition, slow way of movement and lack of orientation ability (Havinga and Muller 1981), demonstrated her considerable initiative and courage. As a woman on her own, she travelled upriver accompanied with a native crew and penetrated – aided by local forest officers – the vast peat swamps on foot or by means of a 'peat-sled' (Havinga and Muller 1981).

On the 31st of March 1932 she resigned and returned to The Netherlands for private reasons. There she finished and published – next to some smaller papers on the subject (Polak 1933a, b) – her classical paper 'Ueber Torf und

Moor in Niederländisch Indien' (On peat and peatland in the Netherlands Indies, Polak 1933c) in which she concluded the ombrogenous character of the peat swamp forests. Her arguments for arriving at this conclusion included the following:

> "... the question can be asked with which already known peatland types the forested peatlands of Sumatra and Borneo can be compared. All researchers who described these formations have followed the viewpoint of Potonié and have asserted their 'Flachmoornatur' (fen character). Such mighty wood layers, such luxurious forest development, not hampered by external influences, do not exist in the temperate zones. Much more than with 'Tiefmoor' (Polak uses here a not existing German word/concept to cover the Dutch term 'laagveen' = fen, HJ), which always results from the terrestrialization of mineral rich open waters and whose peat is thus mainly composed of herbs, and whose surface lies deeper than or equal to the surroundings, a comparison with 'Hochmoor' (raised bog) suits. First the lens shape: the raised bog derives its name from the fact that its surface curves over the area like a small cupola. This is equally so for the Netherlands-Indian forested peatlands and for the European raised bogs. Secondly the high acidity typical for raised bogs. A third shared feature of the raised bog of the temperate zone and the forested peatland of the tropics is the oligotrophic character of the peatland water. Such formations are called 'ombrotrophic' mire formations by Von Post (1926) and they form thus an oligotrophic substrate for the vegetation. In Western-Europe the climax vegetation of such formations is a Sphagnetum, and one gets the impression, as if authors who described tropical peat deposits always had the Sphagnetum mire in mind. Widely spread is therefore the idea that raised bogs in the tropics only occur in mountains above 1200 m altitude, because it is there that *Sphagnum* is found, whereas in the lowlands only fens occur. (Schimper 1908; Potonié 1909; Von Faber 1927; Von Bülow 1929)
>
> However, even in the temperate zone the climax stage of an oligotrophic peatland does not necessarily have to be a Sphagnetum. This only applies to areas with an explicit oceanic climate such as the coastal area of North-western Europe; in more continental regions the raised bogs have a vegetation of Ericaceae and coniferous trees. Actually it should be self-evident that the oligotrophic peatland vegetation of the tropics should be uttermost different from that of Europe and one does not need to wonder that in these areas with the most luxurious plant cover we find the raised bog covered with a dense pristine forest and the peat consisting of the remnants of this forest. A feature of this wood peat is its poverty in inorganic constituents. The peat of Bila-estate had a loss-on-ignition of 1.35 %. In the 'Jaarboek voor Nijverheid en Handel' (1922) it is mentioned that the peat of the large forested peatlands chemically resembles the oligotrophic peat of Europe and that the small local peat formations more resemble the eutrophic peat. (cf. White 1924)
>
> Von Bülow (1929) regards raised bog formation in the tropics and the subtropics as utterly impossible. "In the realm of the Mediterranean, semi-arid or subtropical climate, no oligotrophic peatland formation has hitherto been observed. Self-evidently in the tropics even less." However, he fails to recognize, that equatorial regions with an oceanic climate have large quantities of precipitation, which is evenly distributed over the year. In the forest high air humidity prevails: desiccation of the soil and consequent oxidation of the organic constituents is not occurring. The relatively rapid decomposition is compensated by a very intensive production of plant remains. The soil water has a high acidity, is rich in dissolved humic acids, and has conserving properties.
>
> Von Bülow claims for the temperate zone that "Proper raised bogs are bound to the vicinity of the coast and the consequent smoothed climate", but the same conditions apply to the oceanic areas of the tropics. Also here the dominance of production over decay of plant remains is so large that similarly to Europe extensive regional peat accumulating conditions originate that are controlled by climate and the vicinity of the sea."

Another important issue she discusses is the zonation of vegetation types over the peat dome:

> "Is the peat swamp forest the climax vegetation, or is this eventually replaced by brushwood or a swamp with grasses and Cyperaceae? Observation of European raised bogs instigates various possibilities. The shape of the European raised bog and similarly of the tropical forested peatlands is a large biconvex lens that on one side is sunk in the ground and on the other side domes as a cupola over the land. The marginal rise in height is rapid, in the centre, however, the peatland is flat. Often the centre of European raised bogs has an open water area, one of more lakes, secondarily originated as a remnant of the precipitation that was not absorbed by peat and vegetation, or as a relic of the former lake that was the origin of the peatland. The same could apply for tropical forested peatlands. Although no systematic observations are available, one claims in the region of Bengkalis, that the centre of the forest consists of brushwood alternating with smaller and larger pools (footnote 1: Prof. Dr. R. Kolkwitz informed me in an oral communication that he had seen from the airplane large open areas in the swamp forests). . . . However, whatever may be, it is a fact that according to the results of the "Boschwesen" (forestry service, HJ) and also consistent with own observations the vegetation is zonally constituted."

Indeed some foresters of the Boschwesen were meanwhile measuring the depth of the peatlands and had noted the lens character of the peatland surface (Luytjes 1923; Boon 1935, 1936; Sewandono 1938), whereas Boon (1935) had made a systematic levelling of the surface (Van Doorn 1959).

"On the basis of own observations and in accordance with the literature" Polak (1933c) subdivided the peatlands in:

1. "regionally distributed ombrogenous coastal peatlands in the plains of Sumatra, Borneo, and probably New Guinea,
2. topogenous peatlands:
    (a) in the plains of Java and Sumatra
    (b) in the mountains of Java, Celebes, and Burus (Moluccas)."

Inspired by her preparatory work, peatland research in the Netherlands Indies continued vigorously. Schophuys (1936) described and mapped some 2000 km^2 of forested peatlands in the Barito catchment in Southeastern Kalimantan and confirmed their ombrogenous character. Boon (1936) described plans for the exploitation of forests in Bengkalis, Sewandono (1937) made an inventory of the peat swamp forests in the Panglon area on Sumatra's east coast, whereas Van der Veen (1938a, b) described peat soils under coffee plantations.

In 1939 Polak returned to Java (which almost certainly saved her life as almost her entire – Jewish – family was murdered by the Nazis in the following years) and found temporary employment as a soil scientist at the Institute for Soil Science at the General Agricultural Research Station in Bogor. There she had to change her focus to agricultural aspects (cf. Hardon and Polak 1941), but continued her study trips. In September 1939 she investigated Rawa Lakbok, a major fen area in West Java, in October Southeast Borneo in the vicinity of Martapoera and Bandjermasin, in 1940 again various areas in West-Java and Central Sumatra (incl. the 'Riouw Archipelago') and West-Borneo (http://www.nationaalherbarium.nl/FMCollectors/p/PolakB.htm). In 1941 she published in the journal Landbouw ('Agriculture') a review on peatland research in the Netherlands Indies with an extensive reference list, including many unpublished reports.

In the first year of the Japanese occupation (1942–1945) Polak managed to finish a manuscript about Rawa Lakbok based on field visits made in 1939 and 1941. The paper was on Japanese command translated into English and – without her approval – published when Polak was already interned in a concentration camp (Polak 1943). Her physical and mental health suffered severely in the camp and after the liberation she was granted recuperation leave (Havinga and Muller 1981). She stayed 3 months in the USA in the laboratory of the well-known peat specialist (and 1952 Nobel Prize receiver) Salman Waksman and in the Department of Agriculture in Florida, where she got further acquainted with (sub)tropical peatland agricultural research. Back in The Netherlands she prepared a review study on the suitability of Indonesian peat soils for agriculture (Polak 1948a).

In January 1948 Polak returned to Indonesia and got a permanent position as a soil scientist. From then on she engaged in research on the fertilization of peat soils with special attention to trace elements (Polak 1948b, 1950b; Havinga and Muller 1981). With respect to the more fundamental research, her attention moved to less acid peat deposits that were more suitable for cultivation than the coastal ombrogenous peats. In search of such deposits Polak travelled in 1949 to the upper reaches of the Kapuas river in Borneo, but almost no peat was found (Polak 1950a). On Java she continued to investigate Rawa Lakbok and published in 1949 a new version of the English 1943 paper (Polak 1949), with which she had been extremely dissatisfied. Her palaeobotanical investigations demonstrated the geogenous origin and eu/mesotrophic character of the Rawa Lakbok peatland. Furthermore the 1949 paper illustrated her ambition to improve the livelihoods of the local people in the poverty trap the peatlands constituted: “The population has given her uttermost forces to open up and meliorated the swamp as well as was possible with the available means. Because of the complex and unfavourable economic conditions, but certainly not in the least because of the difficulties experienced by the burden of excess water, the population has become deprived. In 1939 and 1941 many had to sell the self-reclaimed fields; others ended deep in debt. Signs of malnutrition and poverty were also clearly visible in the pre-war years (Photo 6 Poor Lakbok colonists). With effective technical improvements, however, the work that has been started with simple means but much effort can be continued and completed. Thereby the pioneers and immigrants of the Lakbok, which have migrated from the poorest regions to there to build up a livelihood, can get the reward they deserve for their hard labour and entrepreneurship.”

In May 1952 Polak was promoted principal scientific officer at the Institute for Soil Science and on August 1st, 1952, appointed Professor of Botany and Genetics at the Medical Faculty of the University of Jakarta.

Her 1952 publication “Veen en veenontginning in Indonesia” (Peat/peatland and peatland reclamation in Indonesia, Polak 1952) reflected her widened activities. In this paper she presented a first detailed map of the distribution of peatlands in Indonesia and estimated their total area on “roughly” 163,498.65 km^2. This number became the basis of all areal estimates of Indonesian peatlands, although nobody dared to repeat the exact figure in its incredible detail. Andriesse (1974) and Shell International (1982) thus came up with an area of 165,000 km^2, whereas Schneider (1980), Bord na Mona (1985), and Andriesse (1988) used the figure of 170,000 km^2. It lasted until 1981 until the Indonesian Soil Research Institute came up with an alternative figure of 270,230 km^2. This figure would also have resulted if Polak had applied the later definition of histosols (over 30 % organic matter in a cumulative layer of 40 cm or more) instead of the one she had used (more than 65 % of organic matter in the first 1 m or 0.5 m if under cultivation) (Driessen and Soepraptohardjo 1974, cf. Anonim 1969).

In June 1954 Polak went back to The Netherlands on long leave, but at the end of this period, in 1955, she decided not to return, because the prospects in Indonesia were too uncertain (Havinga and Muller 1981). She joined the Department of Regional Soil Science of the Agricultural University in Wageningen where she retired in 1966.

Her last public performance was in 1975 in Groningen, the city where peatland science had started more than 300 years before (Schoockius 1658). In reflecting her own research over the past half century, she used the Symposium on the Quaternary of Southeast Asia to warn against the enormous agricultural, pedological and ecological risks involved in the exploitation of the peatlands of Southeast Asia (Polak 1975):

> “In our time, exploitation and conservation of nature are opposed to each other. Exploitation of the extensive peat forests is difficult and expensive and cannot be very profitable. It should be recommended to leave the regional peat forests in their natural state or use them for timber-growing with the application of proper silvicultural techniques. These practices may not involve measures interfering with the natural environment.”

In 1980 she died after a long illness. Shortly after the final stage of peatland destruction in Southeast Asia set in . . . (Dommain et al. 2015).

2.5 Final Remarks

> “Any new interpretation of nature, whether a discovery or a theory, emerges first in the mind of one or a few individuals. It is they who first learn to see science and the world differently, and their ability to make the transition is facilitated by two circumstances that are not common to most other members of their profession. Invariably their attention has been intensely concentrated upon the crisis-provoking problems; usually, in addition, they are men so young or so new to the crisis-ridden field that practice has committed them less deeply than most of their contemporaries to the world view and rules determined by the old paradigm.” (Kuhn 1996: The structure of scientific revolutions, p. 144)

The story above confirms that the research history of tropical peatlands can be seen as scientific revolutions exchanging one paradigm for the other. It illustrates how prevailing ‘truths’ managed to survive over decades in spite of clear evidence to the contrary. Instrumental in the paradigm shifts was the long-term devotion of the key players to questions that would eventually undermine the prevailing paradigm: Potonié searching for the origin of coal, Polak addressing the fundamental differences between geogenous fens and ombrogenous bogs.

Typical is also the ‘un-disciplinary’ background of the major players: Potonié as a coal geologist, Polak as a young female palaeobotanist, both looking for and seeing things that contemporary soils scientists and botanists did not dare or failed to see.

Finally the long time span between the observation of the first contrary proof and the replacement of the established paradigm has to be noted. The decades that passed between the emergence of evidence and its acceptance in mainstream science supports the observation of Max Planck (1949) that “a new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die, and a new generation grows up that is familiar with it.”

Peatlands in Southeast Asia are currently dying faster than their researchers. Fascinating and hitherto little understood aspects of their ecology, like their sophisticated self-organisation and self-regulation (Dommain et al. 2010), can no longer be studied in their full expression, as peatlands are sacrificed to unsustainable drainage-based agriculture and forestry faster than science can follow (Dommain et al. 2015). Potonié would have needed these insights to understand the long-term stability of coal formation. Polak (1933c) touched upon them in her description of peat swamp vegetation zonation (cf. Anderson 1983; Bruenig 1990; Shepherd et al. 1997; Yamada 1997).

Throughout her life Betje Polak, the heroic pioneer of Indonesian peatland research, prepared the paradigm to come: how to reconcile the short-time demands of people with the long-term interests of society. It is urgent time that this sustainability paradigm is established.

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Chapter 3
Peatland in Indonesia

Mitsuru Osaki, Dedi Nursyamsi, Muhammad Noor, Wahyunto, and Hendrik Segah

Abstract Peatland area in Indonesia was about 14.91 million ha spread out in Sumatra 6.44 million ha (43 %), in Kalimantan 4.78 million ha (32 %), and in Papua islands 3.69 million ha (25 %). The important factors of peatland for agriculture are closely related to properties and character of soil, water, and GHGs emissions. The factors should be considered in arranging decision or policy and utilization for agriculture.

Utilization of peatlands for agriculture in Indonesia has a long historical foundation. Starting from success of indigenous peoples who looked peatland as a resource to produce traditionally food crops, fruits, and spices, then they have been growing into large plantations managed modernly to get a better income like palm oil plantation, however it is required to be sustainability for which water level, wild fire, and biodiversity must be managed appropriately. Greenhouse gases (GHGs) emissions issues, also, motivated government to limit peatland utilization because some of the emission was from peatland.

Keywords Peatland • Indonesia • Agriculture

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3.1 Introduction

Tropical peatland (including swamps and forests) are found on islands in the Indonesian and Malaysian Archipelagos, the Amazon lowlands, and Central Africa, they comprise some 42 Million ha, and are estimated to store approximately 148 Gt (1 Gt $= 10^{15}$ g) of carbon (S. Page et al. 2010). Much of the recent increased interest in peat globally has resulted from the importance of peatlands as carbon sinks and stores, and their role in carbon cycling between the earth surface and the atmosphere. Much detailed work has been carried out on carbon gas emissions from tropical peat in Southeast Asia in recent years and is contributing to knowledge of this topic. Because of their inferior nature, these environments remain undeveloped, are found in relatively virgin forests, are extremely fragile and very liable to disturbance. Peat-Forests in Indonesia still remain in large areas, however conservation and rehabilitation here is complicated because of (1) the great impact of Climate Changes including El Niño, La Nina, and ENSO, and (2) human impact such as plantations of oil palms, rubber, and pulp trees, and food production. This makes it necessary to establish strategies for peatland management in view points of (1) mitigation and adaptation of the impact of Climate Change, and (2) sustainable land management on Land Use, Land Use Change and Forestry (LULUCF). For this purpose, an analysis of a Human-Nature Harmonization System is especially the most basic issue in peatland.

The tropical peat swamp forest is important as not only for its wealth of diverse bio-resources but also its huge carbon pool (Tawaraya et al. 2003). Tropical peat swamp forests and deforested peatlands are important stores of carbon whose release in large quantities through burning can contribute significantly to climate change processes (Page et al. 2002). Furthermore, forest fires are an important cause of environmental alteration and land degradation or conversion through human activities. Indonesian forests have been affected by intense burning for plantation agriculture and exploitation practices for commercial logging since the 1970s. Interactions between land clearance activities and drought have caused massive uncontrolled fires that have burned on large areas of forest and agricultural land in the Kalimantan Island.

In 1997, a severe drought began in Southeast Asia. It was related directly to its contemporary El Niño-Southern Oscillation (ENSO) event (Schimel and Baker 2002; Wooster and Strub 2002; Slik 2004), and the 1997 disaster torched more than 2.7 million ha in Central Kalimantan (Aldhous 2004). Records of sea surface temperature anomalies for ENSO event from 1979 to 2002 also showed that the 1997/1998 and 2002 ENSO are among the strongest records set the conditions for widespread fires in South East Asia. Smoke by forest fires also harmed human health and environment. The similar problems caused by ENSO event occurred in 2002, when peat and vegetation fires broke out again in Central Kalimantan from July 2002 and lasted for several months (Siegert et al. 2004). Given that the peat is more than 12 m deep in places, it will burn again and again, each time drought returns (Aldhous 2004). It has become obvious that the incidence of more frequent

ENSO events, coupled with major land development projects that involve drainage of the surface peat, is leading to an increased risk of repeated fire events in tropical peatland areas (Siegert et al. 2004).

Much research of tropical peat has pointed out that the problems which arise with development of tropical peat stem mainly from a lack of understanding of the complexities of this ecosystem and the fragility of the relationship between peat and forest. In its natural state tropical peat is a vast carbon sink and store but once the carbon input is discontinued by forest removal and the peat is drained, the air exposed surface peat oxidizes and loses the carbon stored there, rapidly to the atmosphere, which results in progressive subsidence of the peat surface and contributes to climate change.

Utilization of peatlands for agriculture in Indonesia has a long historic foundation. Indigenous peoples, particularly in Kalimantan looked peatland as a land resources to produce food (rice, corn, sago, cassava), fruits (*durian*, *rambutan*, mango, etc.) and spices. In the history of swampland development, the success of local indigenous peoples in utilization of peatland inspired the government to open peatlands extensively. Controversy about use of peatland came after utilizing peatlands without appropriate and correct management.

An appearance of subsidence and degraded land in peatlands became a serious concern for domestic and international environmentalists and agriculturalist. Depletion of availability of land for agriculture and high rate of national population growth forced Indonesian government to prefer peatland as an alternative land resources which became important and essential land. In relation to GHG emissions issues from peatland, the government is targeting a reduction in GHG emissions by 26 % voluntary and up to 41 % with international collaboration until 2020, where about 9.5–13.0 % of the reduction is from peatland.

Peat soils which are in peatland area have specific properties that are different with other soils (mineral soils). Not all peatland can be used for agricultural crops, such as dome part of peat should not be opened because it will cause harmful environmental impacts (subsidence and greenhouse gas emissions). Only at selected sites, agricultural activities can be done. Peatlands which are suitable for farming have requirements such as (1) thickness of peat <100 cm, (2) sapric-hemic maturity, (3) thickness of peat about 20 cm at top layer since the peat mix with mineral soil, (4) mineral soil material contain organic matter <25 % after reclamation or drainage, and (5) water level <70 cm. Research results showed that productivity of rice in peat decreased with increasing soil thickness up to 100 cm (Noor et al. 1991; Noor 2001). Peatlands with thickness >100 cm had a very low level of mineralization as well as low level of soil fertility. Rice yield cultivated on thick peat soil continuously declined over time, so it was frequently abandoned. To maintain its productivity, appropriate and sustainable soil, water and plant managements are needed. This paper discus some perspectives about peatland potency and management for sustainable farming.

3.2 Peatlands Distribution in Indonesia

Indonesia, peatlands are distributed widely along the coastal areas of Kalimantan, Sumatra, and West Papua, approximately 30 % of which is in Kalimantan (Borneo in Indonesia territory). The peatlands and swamps are distributed in the lowland areas along the coastlines of Indonesia, and the influence of tides of rivers flowing through the peatlands reaches considerably distances inland. In general, Indonesia classifies peatlands based on hydrological and geological features into three: coastal peat (in areas affected by sea water), transitional peat (in brackish-water areas), and inland peat (in fresh water areas).

Peatland area in Indonesia was about 14.91 million ha spread out in Sumatra 6.44 million ha (43 %), 4.78 million ha in Kalimantan (32 %) and in Papua 3.69 million ha (25 %) (Ritung et al. 2012). Most or about 11 million ha of peatlands were in tidal swampland areas and the remaining land approximately 3.9 million ha were in swampland and beach area. Based on the thickness, about 5.24 million ha (35 %) included shallow peat (thickness 0.5–1 m), 3.91 million ha (26 %) medium peat (thickness 1–2 m), 2.76 million ha (19 %) deep peat (thickness 2–4 m), and 2.98 million ha (20 %) very deep peat (thickness >4 m) (Table 3.1, Figs. 3.1, 3.2, 3.3, 3.4, and 3.5). Several authors have previously stated that Indonesian peat land area was 14.9 million ha (Subagyo et al. 1990), 17.2 million ha (Euroconsult 1984), 18.4 million ha (Soekardi and Hidayat 1988), 19.90 million ha (Wahyunto et al. 2005, 2006), and 20.1 million ha (Radjagukguk 1993). Depreciation or depletion of peatland may occur every year due to fires, decomposition, subsidence, erosion, mining or intensive use.

In the past 10 years, the use and development of peatlands have been more extensive because of conversion of agricultural land into non-agriculture and increase of need for food and agricultural products for both domestic consumption and export opportunities. In this periods many peatlands were exploited for development of palm oil plantations. Approximately 2.0–2.5 million ha of peatlands were cultivated for palm oil in Indonesia. Peatland development, particularly for oil palm plantations, however, might be necessary to be considered over again associated with GHGs emissions reduction targets of 21–46 % by 2020, where 9–13 % of it was from peatlands (Noor 2012a).

Table 3.1 Peatland area in Indonesia

Island	Peatland area (ha)				Total (ha)
	Shallow (50–100 cm)	Medium (101–200 cm)	Deep (201–400 cm)	Very deep (>400 cm)	
Sumatera	1,767,303	1,707,827	1,242,959	1,718,560	6,436,649
Kalimantan	1,048,611	1,389,813	1,072,769	1,266,811	4,778,004
Papua	2,425,523	817,651	447,747	0	3,690,921
Total	5,241,437	3,915,291	2,763,475	2,985,371	14,905,574

Source: Ritung et al. (2012)

Fig. 3.1 Map of peatland in South East Asia. The map *illustrates* that most peatland are distributed on the islands of Sumatra and Borneo (Kalimantan, Sabah, Sarawak and Brunei) and in Peninsular Malaysia (Source: Whitmore 1995)

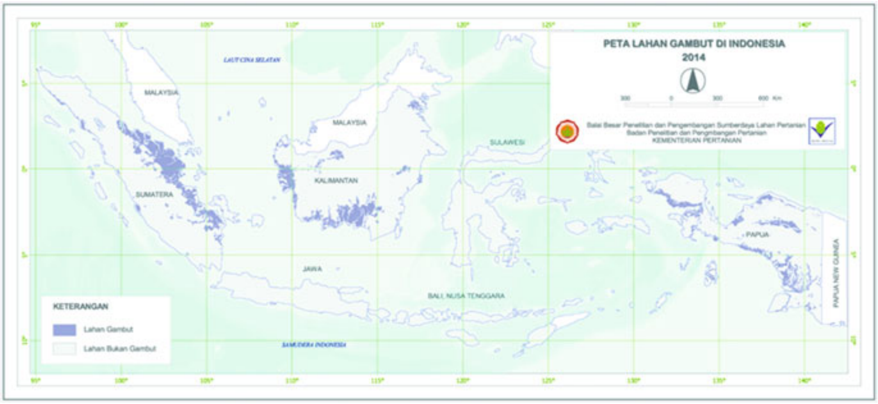

Fig. 3.2 Map of peatland in Indonesia

Peatland in Sumatra Island In Sumatra island, peatlands area was about 6,43 million ha that spread out such as shallow peat was about 1,77 million ha, medium peat was about 1,71 million ha, deep peat was about 1,24 million ha, and very deep peat was about 1,72 million ha. In Sumatra, peatland spread of 11 provinsi, the largest peatlands area in Sumatra was mainly in Riau (60.1 %) and Sumatra Selatan (19.6 %) (Table 3.2).

Peatland in Kalimantan Island In Kalimantan island, peatland area was about 4,78 million ha that spread out such as shallow peat was about 1,05 million ha, medium peat was about 1,39 million ha, deep peat was about 1,07 million ha, and very deep peat was about 1,27 million ha. In Kalimantan island, peatlands spread of four provinsi, the largest peatlands area in Kalimantan was mainly in Kalimantan Tengah (55.7 %) and Kalimantan Barat (35.2 %) (Table 3.3).

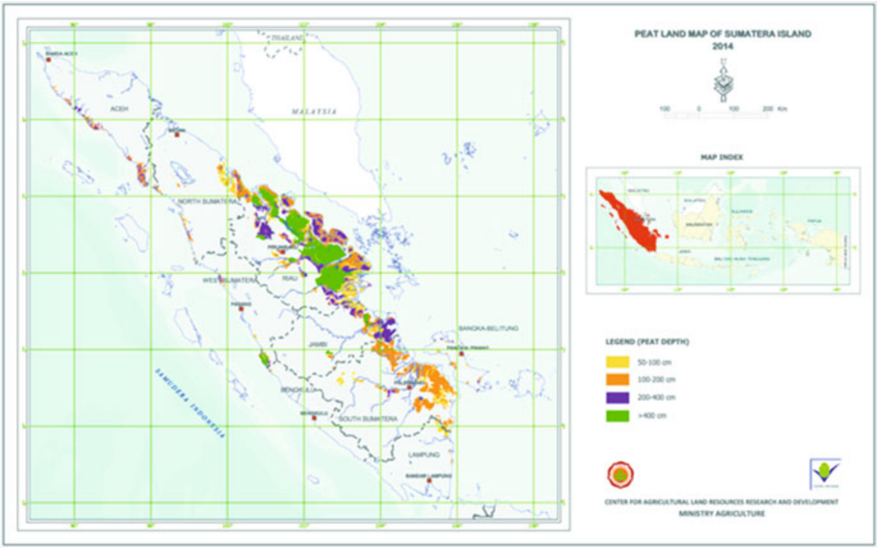

Fig. 3.3 Distribution of peatland in Sumatra Island

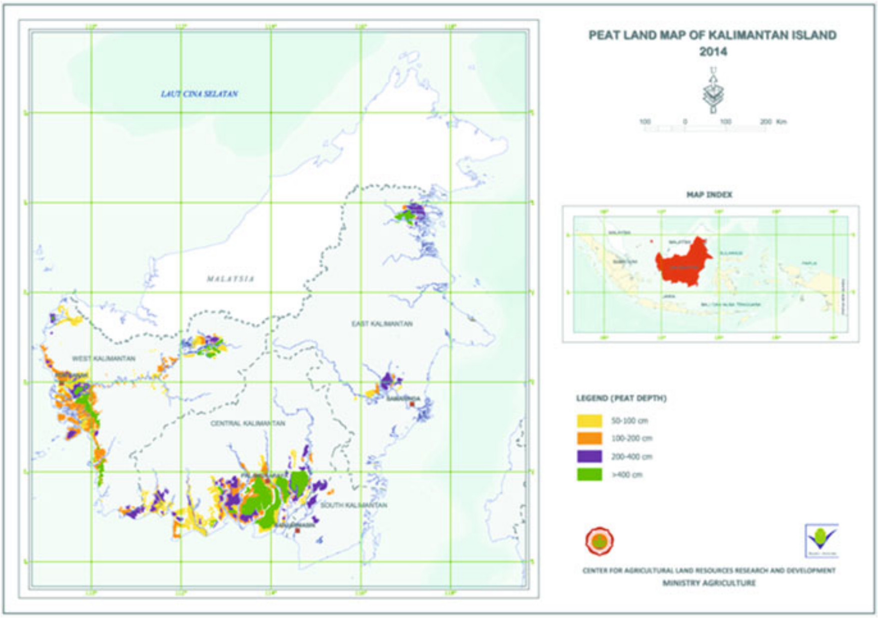

Fig. 3.4 Distribution of peatland in Kalimantan Island

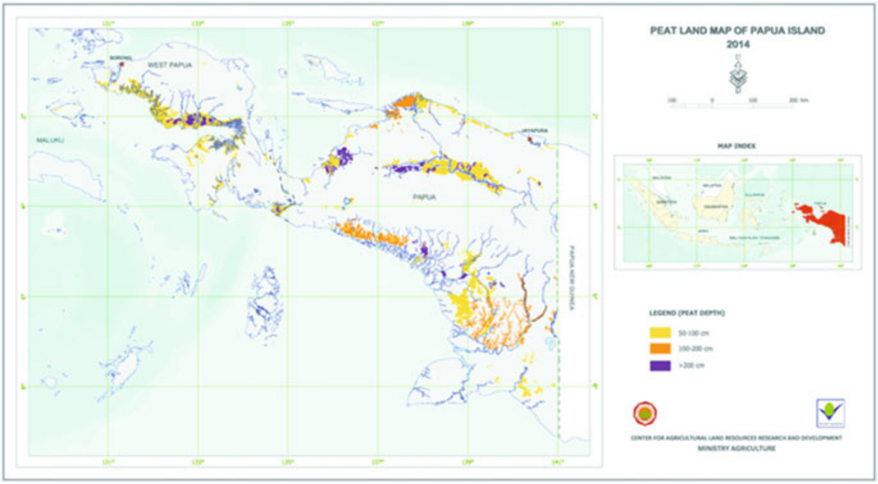

Fig. 3.5 Distribution of peatland in Papua Island

Table 3.2 Peatlands in Sumatra Island

	Peatland area (ha)				
Province	Shallow (50–100 cm)	Medium (101–200 cm)	Deep (201–400 cm)	Very deep (>400 cm)	Total (ha)
NAD	144,274	71,430	0	0	215,704
Sumatra Utara	209,335	36,4721	0	15,427	261,234
Sumatra Barat	11,454	24,370	14,533	50,329	100,687
Riau	509,209	908,553	838,538	1,611,114	3,867,413
Kep. Riau	103	8,083	0	0	8,186
Jambi	91,816	142,716	345,811	40,746	621,089
Bengkulu	3,856	802	2,451	944	8,052
Sumatra Selatan	705,357	515,400	41,627	0	1,262,385
Kep. Bangka	0	0	0	0	0
Belitung	42,568	0	0	0	42,568
Lampung	49,331	0	0	0	49,331
Total Sumatra	1,767,303	1,707,827	1,242,959	1,718,560	6,436,649

Source: Ritung et al. (2012)

Peatland in Papua Island Papua island have peatland area was about 3,69 million ha that spread out such as shallow peat was about 2,42 million ha, medium peat was about 0,82 million ha, and deep peat was about 0,45 million ha, and have not found very deep peat (Table 3.4).

Table 3.3 Peat land in Kalimantan Island

Province	Peatland area (ha)				Total (ha)
	Shallow (50–100 cm)	Medium (101–200 cm)	Deep (201–400 cm)	Very deep (>400 cm)	
Kalimantan Tengah	572,372	508,648	632,989	945,225	2,659,234
Kalimantan Barat	421,697	818,460	192,988	246,989	1,680,135
Kalimantan Selatan	10,185	21,124	74,962	0	106,271
Kalimantan Timur	44,357	41,582	171,830	74,597	332,365
Total Kalimantan	1,048,611	1,389,813	1,072.769	1,266,811	4,778,004

Source: Ritung et al. (2012)

Table 3.4 Peat land in Papua Island

Province	Peatland area (ha)				Total (ha)
	Shallow (50–100 cm)	Medium (101–200 cm)	Deep (201–400 cm)	Very deep (>400 cm)	
Papua	1,506,913	817,651	319,874	0	2,644,438
Papua Barat	918,610	0	127,873	0	1,046,483
Total Papua	2,425,523	817,651	477,747	0	3,690,921

Source: Ritung et al. (2012)

3.3 Peatland for Agricultural Land Use

Agriculture in developing peatland starting from local community efforts of local daily life in the peat. Farming on peat at first naturally highly dependent on natural friendliness sometimes work well and sometimes fail miserably, dependence on natural conditions is very high. Local communities in peatlands have no choice but to seek to empower the peatland his best to make ends meet. Agricultural expertise as a legacy from generation to generation, giving a boost to local communities local to clear the land and cultivate it, especially for foodstuffs such as rice, sago, cassava, maize and others. Indigenous knowledge is passed down from generation to generation a lesson learned for the next generation. Various local wisdom in perspective the growing use of peat in the local community though on a limited scale, but can be used as a good learning (Noor 2012b).

With the growing needs of life, the land use was only limited to the needs of one or two families with three or four children as the number of family members, knowledge and experience, including as the communication and information needs of land increased to more widespread. So in an effort to expand the area of agriculture and food security, the government held the opening of wetlands, including peatlands to support the resettlement program since 1969 and other programs such as Food

Self-Sufficiency; Food Diversification; Revitalization of Agriculture Fisheries and Forestry (RPPK), National Rice Production Enhancement (P2BN) and Plantation Revitalization. Background peatland clearance for agriculture by the government initially inspired by the success of local residents in the region both in Kalimantan and Sumatra. However, not all locations are open to work well even leaving the poor and very serious damage to land.

Utilization of peat is very diverse because of limited understanding and experience. Each tribe or ethnicity who live and have lived in peatlands and the perception of different ways to utilize the resources of peat as agricultural land, including tribal migrants from Java, Madura, Nusa Tenggara, Bali and others who have a habit of farming in upland looked different. For example, farmers looked Banjarese peatland suitable for growing paddy rice, but farmers generally Javanese as newcomers looking peatland suitable for growing crops and vegetables. Similarly other tribes of different views, such as Bugis found more appropriate peatlands planted rice paddy, pineapple and coconut as in Riau and East Kalimantan, Central Kalimantan Dayak found more suitable peat fields planted with rice, rubber, rattan, jelutung, nibung or sago and fruits such as durian or cempedak. Others again, with tribes living in Bali Kalimantan peatland looked suitable for fruits like pineapples, cempeda unlike in West Sulawesi they looked more suitable for citrus and chocolate. Chinese people in West Kalimantan peatland generally looked more appropriate for planting vegetables such as cabbage leaves, ku cai (a type of union), celery, and aloe vera. While the Malays in Riau peatlands looked fit planted pineapple, coconut, rubber or oil palm (Noor et al. 2008).

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Chapter 4
Peatland in Malaysia

Lulie Melling

Abstract Malaysia has approximately 2.6 Mha of peatlands, of which about 70 % (∼1.6 Mha) are in Sarawak. Tropical peatland forest is a unique dual ecosystem of both rainforest and peatland. Its topo-morphology is strongly influenced by the hydrological conditions, which then determine the vegetation structure, species composition, and peat type. The tropical peatland forests are divided into six (6) phasic communities with three (3) main forest types, namely the Mixed Peat Swamp forest (PC1), Alan forest (PC2 and PC3) and Padang Alan forest (PC4). Their formation and development controlling factors, characteristics, and classification are described in the following. Some insights into the conservation and sustainable use of peat in Malaysia are also provided. To date, tropical peatland in Malaysia is still a largely unknown ecosystem and one of the understudied environments in the world. Hydrology is the dominant factor affecting the formation and functioning of peatland ecosystems by influencing the forest type and flow of nutrients. Knowledge on the topo-hydrological characteristics of the peatlands is notably important for understanding the physical and chemical properties of the peat. An understanding of the variability of peat properties in tropical peatland that are highly influenced by its structure and species composition is critically needed to formulate the strategies for conservation and sustainable management of tropical peatland.

Keywords Tropical peatland • Ombrogenous peat • Biosequence

4.1 Introduction

Malaysian peatlands cover an area of about 2.6 Mha (Mutalib et al. 2002). Sarawak, one of two Malaysian states on the island of Borneo possesses the largest extent of peat, over 1.6 Mha. They represent about 70 % of all Malaysian peatlands (Fig. 4.1, Table 4.1). In contrast to temperate peatlands which is mainly covered by sedge and moss, tropical peatlands in low-elevation areas are forest-covered peatlands. High rainfall and high temperatures are also the main features that differentiate tropical

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Fig. 4.1 Distribution of lowland peatlands in Malaysia (Source: Department of Agriculture Malaysia 2002; Department of Irrigation and Drainage Sarawak 2014)

Table 4.1 Distribution of peat in Malaysia

State	Area (ha)
Sarawak	1,657,600
Johor	228,960
Pahang	219,561
Selangor	194,300
Perak	107,500
Terengganu	81,245
Sabah	86,000
Kelantan	7,400
Negeri Sembilan	6,300
Total	2,588,866

Source: Mutalib et al. (1991)

lowland peats from temperate-boreal ones (Zinck 2011). Earlier reports on peatlands in Malaysia were by Coulter (1950, 1957), Browne (1955), and Anderson (1958, 1961, 1964) and in the Annual Reports of the Forest Department (1957, 1962).

Almost all of lowland peat occurs in low-lying, poorly drained depressions or basins in coastal areas. In Sarawak, they are found in the administrative divisions of Kuching, Samarahan, Sri Aman, Sibu, Sarikei, Bintulu, Miri, and Limbang (Mutalib et al. 1991), and some at high altitudes such as on Mount Mulu (Whitmore 1984). In Peninsular Malaysia, peats are found in the coastal areas of West Johore, Kuantan and Pekan districts, the Rompin-Endau area, northwest Selangor and the Trans-Perak areas in the Perak Tengah and Perak Hilir districts. Peats are also found in Sabah; on the coastal areas of the Klias peninsula, the Krah Swamp in Kota Belud, the Sugut and Labuk estuaries, the and Kinabatangan floodplains (Mutalib et al. 1991).

4.2 Formation and Structure of Tropical Peatland

The ombrogenous (rainfed) peat particularly of Sarawak were formed in the few thousand years since the last glaciation of the Ice Age (Wilford 1960; Muller 1965; Morley 1981). Lowland tropical peatland in co-existence with swamp forests is a unique characteristic that contributes to the accumulation of thick surficial layers of peat. Tropical peat is generally heterogeneous, consisting of slightly or partially decomposed woody materials of the standing or preexisting forest. Well preserved tree trunks, branches and coarse roots are generally found within a matrix of dark brown amorphous organic material (Page et al. 2006). The peatlands were initially developed in depressions in marshy alluvial plains, where organic litter and debris accumulates rapidly, up to 4.5 mm/year (Anderson 1964) due to the permanently saturated and anaerobic conditions that greatly decreased the rate of biomass decomposition.

Bordered by the sea and rivers with greater peat accumulation towards the centre of the peatland, the peat is moulded into an inverted saucer-like shape, creating a prominent dome shape. The base of the peat is irregular giving a wide range in the peat depth. The depth of peat is generally shallower near the river mouths and increases inland. In general, deeper peat is found towards the centre of individual peat basins. However, this is not always the case as the deepest peat at 20.7 m depth was found in a Mixed Peat Swamp forest in Loagan Bunut National Park, Sarawak (Melling et al. 2006). On the seaward side of the swamps, the borders consist of mudflats or sandy beach deposits. On the landward side, there are sometimes very narrow levees or no levees at all. Along the rivers, levees of mineral soils form the boundaries (Anderson 1964; Whitmore 1984; Melling 2000; Melling and Hatano 2004). As shown in Fig. 4.2, even though the peat surface is relatively flat, it is highly uneven because of the hummocky microrelief. The highest point of the peat

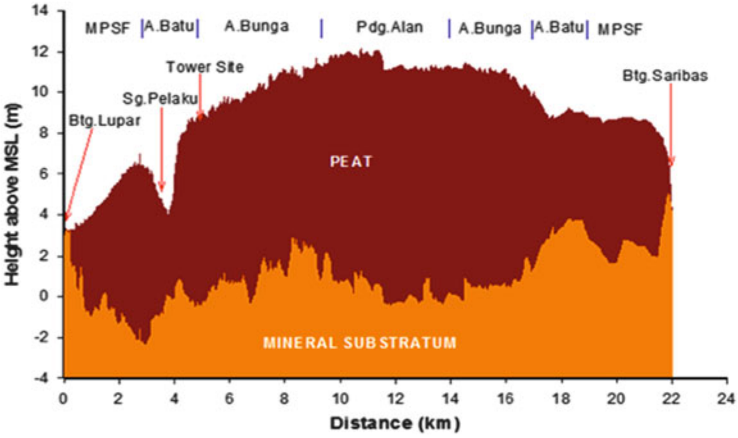

Fig. 4.2 Cross-section at Maludam National Park (Source: Melling and Hatano 2004)

dome is more than 10 m above mean sea level. The cross sectional profile shows that the peat depth ranges from 1 m to more than 10 m. Generally, the surface of the mineral substratum is above the mean sea level (Melling 2000; Melling and Hatano 2004; Melling et al. 2006). Knowledge on the topo-hydrological characteristics of the peatland is critically important for understanding the physical and chemical properties of the peat.

4.3 Peat Soil Classification

Initially, the three major regions in Malaysia, Peninsular Malaysia, Sarawak, and Sabah used different soil classification systems. As for Peninsular Malaysia, Coulter (1950) suggested the following classification according to inherent fertility status: *Eutrophic*, *Oligotrophic*, or *Mesotrophic* groups. Subsequently, Law and Selvadurai (1968) used other criteria based on carbon loss by ignition and peat depth. On the basis of carbon loss by ignition, organic soils were separated into organic clay (20–35 %), muck (35–65 %) and peat (>65 %). Classification based on peat thickness like shallow (50–100 cm), moderate (100–150 cm), deep (150–300 cm) and very deep (>300 cm) was proposed by Paramananthan et al. (1984). In Sarawak, the classification of organic soil was based on the thickness of the organic soil component, the nature of the substratum and ash content (Melling and Hatano 2004). The von Post humification scale was used to classify the degree of decomposition. Sabah used the FAO/UNESCO Legend (1990) of soil classification. Organic soils in Sabah were classified as Dystric or Eutric Histosols (Mutalib et al. 1991).

Developing soil correlations among the three regions have been quite challenging due to differences in definitions and classifications. To rectify this, the Committee for the Standardisation of Soil Survey and Evaluation in Malaysia (COMSSSEM) under the Department of Agriculture, Malaysia in collaboration with the Sarawak Tropical Peat Research Laboratory Unit has developed a Malaysian Unified Classification System (2014) which is a modified version of Soil Taxonomy (Soil Survey 2010). This classification system adopts the local conditions and classifies the different types of peat based on wood content and peat depth (Tables 4.2 and 4.3).

Table 4.2 Classification based on the wood contents

Wood content			
Degree of woodiness		Size of wood	
Terminology	Wood volume (%)	Terminology	Wood diameter (cm)
Few	0–5	Fibre	<2
Common	>5–15	Small	2–5
Many	>15–35	Medium	5–10
Abundant	>35	Large	10–15
		Very large	>15

Source: Malaysian Unified Classification System (2014)

Table 4.3 Classification based on peat depth

Peat depth	
Organic soil material depth (cm)	Terminology
<50	Peaty phase
50–100	Very shallow
>100–200	Shallow
>200–300	Moderately deep
>300	Deep

Source: Malaysian Unified Classification System (2014)

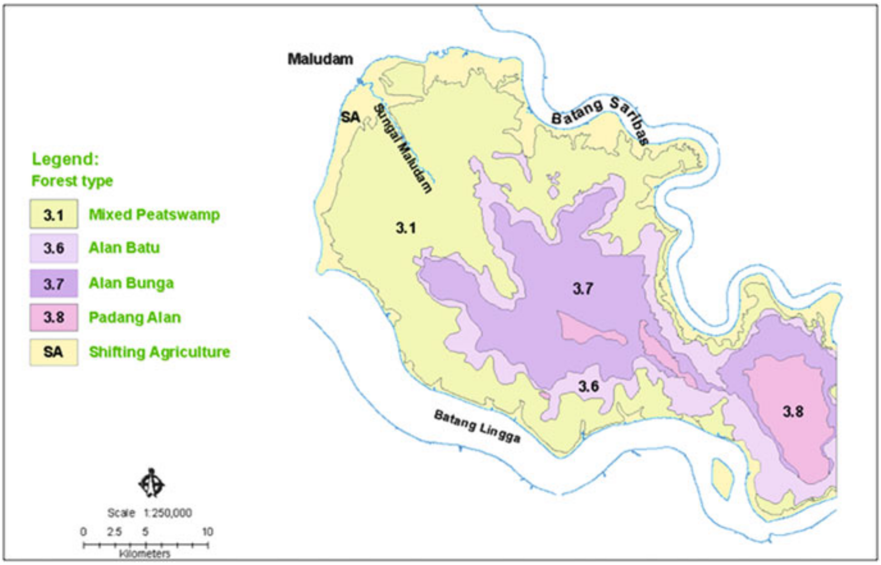

Fig. 4.3 Forest types of the Maludam National Park (Source: Melling et al. 2007)

4.4 Biosequence of the Peatlands

Tropical peatland forest is a unique dual ecosystem, characterised by both rainforest and peatland. It is highly influenced by the characteristics and nature of the peatland. Peatlands mostly have concentric forest zones differentiated by the different forest types. This phenomenon as compared to the other parts of Malaysia is quite distinct in Sarawak and this may be due to the extensiveness of each peat basins. In Sarawak, there are six types of concentrically zoned communities clearly distinguished from the margin to the centre of the tropical peatland forest as shown in Fig. 4.3 (Anderson 1961, 1963, 1964; Melling et al. 2007). Each community has characteristic species and structures in response to the topo-morphology of the peatlands and the fertility of the peat soils which is highly influenced by the hydrological condition. These six communities do not necessarily co-exist in every locality but the number of trees generally decreases across the catena (Anderson 1976). Due to the lower fertility towards the centre of the peatlands, vegetation decreases in canopy height, total biomass per unit area, and average girth of certain tree species while leaf thickness increases (Anderson 1963; Philips 1998). In the most mature swamps found furthest inland, the full sequence of these forest types is more developed. These species have pneumatophores, stilt roots, extensive buttresses, and sclerophyllous leaves as physiological adaptation to both waterlogged and water stress conditions. In waterlogged condition, pneumatophores are quite dominant. In water stress conditions when the low water table is coupled with high porosity resulting in lower capillary rise, the plants tend to have sclerophyllous leaves to prevent moisture loss.

The forest types, differentiated by species composition and structure of the vegetation are classified into different types called phasic communities (Anderson 1961; Melling et al. 2007) (Fig. 4.4 and Table 4.4). The less woody Mixed Peat Swamp forest (PC1) has the most decomposed peat profile, indicated by its higher bulk density. This forest type is usually found at the lower elevations where it receives water and nutrients from a larger area of upslope, and thus is richer in species composition than the other five communities. The Alan forest dominated by *Shorea albida* is the woodiest peat. Alan forest can be divided into two types, namely Alan Batu (PC2) and Alan Bunga (PC3) forests. The Alan Batu forest is mostly found in environments with major abiotic stresses. As physiological adaptation, the *Shorea albida* in Alan Batu forests has bigger buttresses that are almost invariably hollow and with very dense shell-walls (Melling et al. 2007). Due to the harsh environment, the roots of the *Shorea albida* in the Alan Batu forest are also more extensive compared to *Shorea albida* in Alan Bunga. The extensive root system creates vacant layers of about 20–30 cm in diameter within the top 100 cm of the peat profile (Yonebayashi et al. 1995; Melling 2000). The Padang forest (Padang Alan (PC4), Padang Selunsor (PC5) and Padang Keruntum (PC6) forests) is a dense pole-like forest that is accordingly named after its dominant tree species such as Alan, Paya, or Selunsor, whereby its biosequence is influenced by the surrounding hydrology. The pole-like nature of the trees also implies the lower fertility condition of the peat in this zone. The peat in this forest is not woody but very fibrous. Thus, the peat is very porous and has lower bulk density. This is probably due to the restricted lateral water movement, creating a more anaerobic peat soil surface (Melling et al. 2007). As for PC6, the vegetation is almost like that of savannas with shorter trees having extensive aerial roots. Due to the existence of these aerial roots, the peat in this forest tends to be more fibrous and corky in nature.

4.5 Peat Physical Characteristics

In its natural condition, the peat bulk density and porosity varies with the different forest types. The peat also varies in its profile morphology (Melling 2000; Melling et al. 2007). The bulk density of the three main forest types, namely Mixed Peat Swamp, Alan Batu, and Alan Bunga at Maludam National Park ranged from 0.10

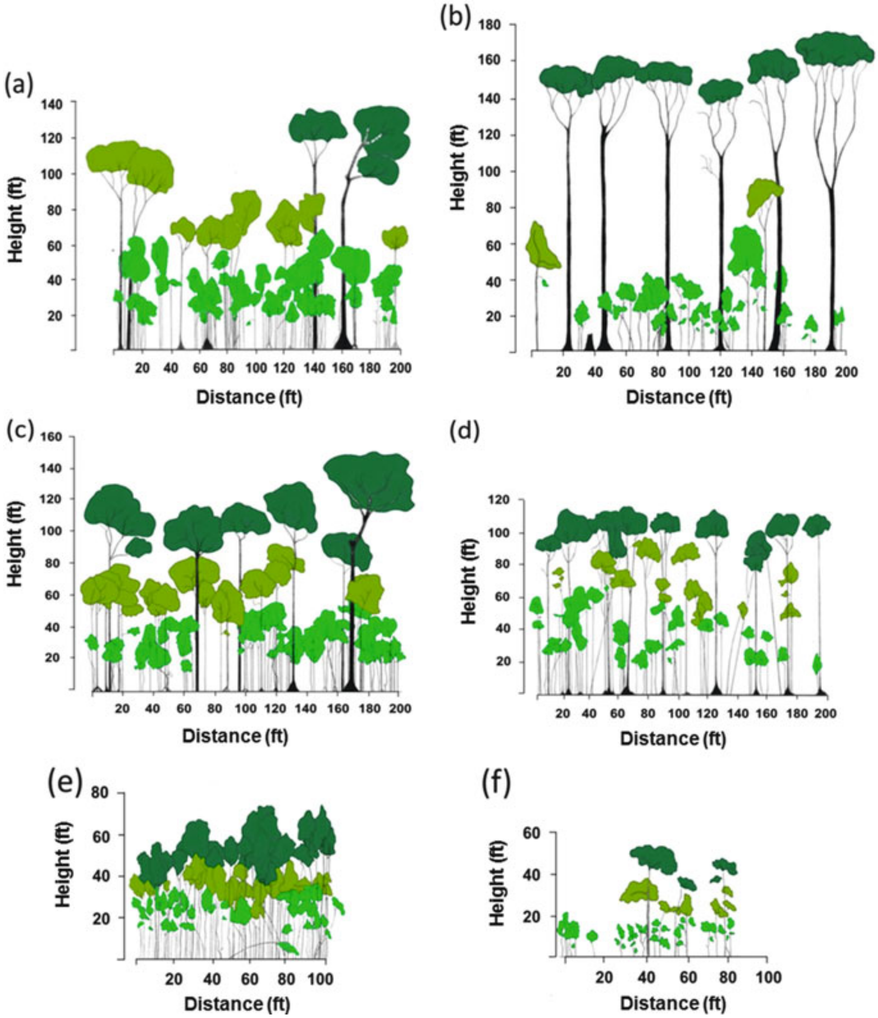

Fig. 4.4 The phasic communities (PC) of tropical peatlands in Sarawak; (**a**) Mixed Peat Swamp forest (PC1), (**b**) Alan Batu forest (PC2), (**c**) Alan Bunga forest (PC3), (**d**) Padang Alan forest (PC4), (**e**) Padang Selunsor forest (PC5), and (**f**) Padang Keruntum forest (PC6) (Source: Anderson 1961; Melling et al. 2007)

to 0.13 g cm^{-3} as shown in Table 4.5. Mixed Peat Swamp forest being more decomposed in nature, thus attributes to its higher bulk density as compared to the other forest types. Melling et al. (2008) reported a similar finding whereby the Mixed Peat Swamp forest in Loagan Bunut National Park recorded the highest bulk density with a value of 0.16 g cm^{-3} as compared to 0.12 g cm^{-3} of the Alan forest. The total porosity for Mixed Peat Swamps, Alan Batu, and Alan Bunga forests were more than 90 %. In another study by Melling et al. (2007) also in Loagan Bunut

Table 4.4 Principal characteristics of the phasic communities (PC) of forest in tropical peatlands in Sarawak

PC	Forest association	Principal characteristics
PC1	*Gonystylus-Dactylocladus-Neoscortechinia* association. Locally known as Mixed Peat Swamp forest	Principal species are *Gonystylus bancanus*, *Dactylocladus stenostachys*, *Copaifera palustris* and 4 species of *Shorea*. Initial phase of the tropical peatland forests. Found at peatland margins with structure and physiognomy similar to lowland dipterocarp rain forest on mineral soil. Structurally most complex and species rich phase. Uneven canopy in which its emergent species may attain a height of 40–50 m with a density of 120–150 tree species ha^{-1}. Epiphytes and climbers are abundant. *Shorea albida* is absent
PC2	*Shorea albida-Gonystylus-Stenonurus* association. Locally known as Alan Batu forest	Similar to PC1 but dominated by scattered very large trees (>3.5 m girth) of *Shorea albida*. It has an uneven and irregular canopy. The trees usually show evidence of being moribund, with staghead crowns and markedly hollow stems. The boles are heavily buttressed. Intermediate trees of *S. albida* are rare. *Stemonurus umbellatus* is an indicator species for this community
PC3	*Shorea albida* consociation. Locally known as Alan Bunga forest	Entirely dominated by *Shorea albida* with 70–100 trees ha^{-1}. It has an even upper canopy, which varies in height between about 45 and 60 m. The buttresses are much lower and narrower than in PC2. *Gonystylus bancanus is* extremely rare or absent. Middle storey is generally absent but a moderately dense understorey is dominated by a single species, either *Tetractomia holttumii*, *Cephalommappa paludicola* or *Ganua curtisii. Pandanus andersonii* forms dense thickets in the shrub layer. Herbs, climbers and epiphytes are rare
PC4	*Shorea albida-Litsea-Parastemon* association. Locally known as Padang Alan forest	Principal species are *Shorea albida*, *Calophyllum obliquinervum*, *Cratoxylum glaucum and Combretocarpus rotundatus*. Dense, even canopy forest at 30–40 m in height which is composed of relatively small-sized trees (<40–60 cm girth) that give the forest a pole-like and xerophytic appearance. These trees are very liable to wind damage. Herbs, terrestrial ferns, climbers, and epiphytes are rare or absent. Small, prostrate shrubs (*Euthemis minor* and *Ficus deltoidea* var. *motleyana*) are indicator species
PC5	*Tristania-Palaquium-Parastemon* association. Locally know as Padang Selunsor forest	Principal species are *Tristania obovata*, *Palaquium cochleariifolium*, *Dactylocladus stenostachys and Parastemon spicatum*. Narrow transitional forest between PC4 and PC6; dense, even and closed canopy with few with average heights of 15–20 m of high density (850–1,250 stems ha^{-1}). Herbaceous layer rare or absent
PC6	*Combretocarpus-Dactylocladus* association. Locally known as Padang Keruntum forest	Only one tree species, *Combretocarpus rotundatus*. Resembles an open savanna woodland with stunted, xeromorphic trees. The trees only exceed 1 m girth and seldom reach the maximum height of 13 m. Patchy shrub layer present. Pitcher plants (*Nepenthes* spp.) and epiphytic vegetation (*Myrmecodia tuberose* and *Lecanopteris sinuosa*) are indicator species

Source: Anderson (1961), Melling et al. (2007)

Table 4.5 Physical characteristics of Mixed Peat Swamp, Alan Batu and Alan Bunga forests in Maludam National Park

Properties	Mixed Peat Swamp	Alan Batu	Alan Bunga
Bulk density (g cm^{-3})	0.13	0.11	0.10
Water filled pore space (%)	74.0	74.1	75.1
Total porosity (%)	95.3	95.9	97.5

Source: Melling (2013)

National Park, the peat hydraulic conductivity under the Alan forest and Mixed Peat Swamp forest were 0.0378 cm/s and 0.0038 cm/s, respectively. Generally, due to its low permeability, the hydraulic conductivity of more decomposed Mixed Peat Swamp forest is lower than the other forest types (Melling and Katimon 2013). The soil profile description is important to understand more on the peat morphology in tropical peatland (Fig. 4.5).

4.6 Peat Chemical Characteristics

Peat type, peat thickness, humification level, topography and hydrology influence the chemical properties of the peat (Tie and Kueh 1979; Melling and Hatano 2004; Melling et al. 2006, 2007). The chemical characteristics of Maludam National Park are shown in Table 4.6.

As shown in Table 4.6, tropical lowland peats are generally acidic (pH 3.2–pH 3.8). Peat with extremely low pH (<3.2) is generally influenced by acid sulphate properties (Maltby et al. 1996) but the pH of peat water will be higher (pH 4.0–4.5) due to the dilution effect.

The highest Pyrophosphate Solubility Index (PSI) was recorded in Mixed Peat Swamps for both peat depths. Higher PSI indicated that the less woody Mixed Peat Swamp forests have higher humification rates than Alan Batu and Alan Bunga forests (Melling et al. 2007). Loss on ignition (LOI) in peat is very high ranging from 98.0 to 99.3 %. The ash content values of peat for all forest types were less than 10 %. This shows that peat has very low mineral content which is a cause of the low fertility. Low ash values also indicate that the peat is an ombrogenous type that receives water and nutrient input only through precipitation (rainfed).

The organic C content of peat in all forest types ranged from 52.3 to 58.2 % and is found to be slightly higher in the subsoil than at the surface. In the peat soil, N is largely found in organic form. Total N ranged from 1.4 to 1.9 % in all forest types in which higher N contents are recorded at the surface than in the subsoil. The C/N ratio in Mixed Peat Swamp forest was the highest, as compared to Alan Batu and Alan Bunga forest. In tropical peatland, the C/N ratio is high (ranging from 28.2 to 41.6 %) due to its woodiness. The C/N ratio is generally used as an indicator for the degree of decomposition (Broder et al. 2012). Generally, residues with low N content or high C/N ratios have slower decomposition rates. During the

(a)

Location : 2° 49' N 111° 54' E
Vegetation/Land use : Mixed Peat Swamp Forest (PC1)
Peat depth : 400 cm
Parent material : Woody Peat
Topography and terrain class : Flat; 1AO

Soil Classification :
a) USDA Soil Taxonomy – Eleventh Edition
(Soil Survey Staff, 2010)
Typic Haplofibrists

b) FAO/UNESCO Legend (FAO, 1990)
Dystric Histosols

Profile description

Depth (cm)	**Description**
0 - 15	Dark brown (7.5 YR 3/2); hemic; abundant very fine to fine roots; many medium roots; many fibres; few medium woods; clear smooth boundary.
15 – 30	Dark brown (7.5 YR 3/2); fibric; few very fine roots; many fine to medium roots; many medium woods; diffuse smooth boundary.
30 – 70	Dark reddish brown (5 YR 3/4); fibric; abundant fine to medium roots; many small to medium wood; common large woods.
70+	Dark reddish brown (2.5 YR 3/4); fibric; many to abundant fibres, many medium woods.

(b)

Location : 01^0 27' N , 111^0 08' E
Vegetation/Land use : Alan Batu Forest (PC2)
Peat depth : 960 cm
Parent material : Woody Peat
Topography and terrain class : Flat; 1AO

Soil Classification :
c) USDA Soil Taxonomy – Eleventh Edition
(Soil Survey Staff, 2010)
Typic Haplofibrists

d) FAO/UNESCO Legend (FAO, 1990)
Dystric Histosols

Profile description

Depth (cm)	**Description**
0-30	Dark reddish brown (5 YR 3/2); hemic; many fine to medium roots and few large roots; clear smooth boundary.
30-75	Very dark brown (7.5 YR 2.5/3); fibric; abundant fine to medium and large roots; many medium woods; many vacant space; clear wavy boundary.
75-125	Very dark brown (7.5 YR 2.5/2); fibric; many to abundant medium woods; many water channel.

Fig. 4.5 Soil profile description of (**a**) Mixed Peat Swamp (PC1) and (**b**) Alan Batu forest (PC2)

Table 4.6 Chemical characteristics of Mixed Peat Swamp, Alan Batu, and Alan Bunga forests in Maludam National Park

	Mixed Peat Swamp		Alan Batu		Alan Bunga	
Properties	0–25 cm	25–50 cm	0–25 cm	25–50 cm	0–25 cm	25–50 cm
Soil pH	3.5	3.4	3.7	3.7	3.5	3.6
Pyrophosphate Solubility Index, PSI	38.5	42.5	6.7	11.5	3.3	8.8
Loss on ignition (%)	98.0	99.1	98.4	99.2	99.3	98.2
Ash (%)	2.0	0.9	1.6	0.8	0.7	1.8
Total carbon (%)	57.0	58.2	53.6	54.9	52.3	54.5
Total nitrogen (%)	1.8	1.4	1.9	1.7	1.7	1.8
C/N ratio	31.7	41.6	28.2	32.3	30.7	30.3
Water soluble K (mg kg^{-1})	48.1	12.7	107.1	59.1	69.5	44.9
Water soluble Ca (mg kg^{-1})	32.9	27.9	41.1	41.3	46.8	51.0
Water soluble Mg (mg kg^{-1})	20.1	16.4	27.5	25.4	23.9	19.9
Water soluble Na (mg kg^{-1})	72.7	79.1	94.8	98.9	99.7	111.8
Water soluble Br (mg kg^{-1})	5.5	8.8	9.0	10.6	6.2	6.7
Water soluble NH$_4$ (mg kg^{-1})	82.0	31.1	72.1	39.6	31.2	24.6
Water soluble NO$_2$ (mg kg^{-1})	0.23	0.14	0.42	0.12	0.26	0.12
Water soluble NO$_3$ (mg kg^{-1})	63.3	34.7	69.6	39.2	24.9	19.2
Water soluble PO$_4$ (mg kg^{-1})	335.1	86.3	244.7	109.1	143.9	82.3
Water soluble SO$_4$ (mg kg^{-1})	25.5	17.4	13.0	11.0	6.3	10.0
Water soluble F (mg kg^{-1})	4.3	3.8	6.0	4.9	6.7	7.6
Water soluble Cl (mg kg^{-1})	51.4	66.9	115.0	92.0	107.2	74.5
Available P (mg kg^{-1})	218.3	60.1	168.9	97.5	119.8	60.6
Available Fe (mg kg^{-1})	226.8	205.3	190.8	191.1	114.1	107.5
Available Mn (mg kg^{-1})	22.2	14.6	28.4	19.3	11.1	10.1
Available Cu (mg kg^{-1})	0.3	0.1	0.4	0.2	0.4	0.2
Available Zn (mg kg^{-1})	5.8	6.1	17.5	14.5	8.6	8.2
Hot water B (mg kg^{-1})	1.7	2.0	1.7	1.8	1.9	1.4
CEC (cmol kg^{-1})	38.5	41.3	30.6	30.3	29.6	31.2
Exchangeable K (cmol kg^{-1})	0.5	0.2	1.0	0.7	0.8	0.6
Exchangeable Ca (cmol kg^{-1})	3.1	2.1	4.6	2.4	3.7	2.1
Exchangeable Mg (cmol kg^{-1})	4.4	3.7	6.2	5.2	5.1	4.0
Exchangeable Na (cmol kg^{-1})	0.4	0.5	0.4	0.5	0.4	0.5
Base saturation (%)	22.1	15.6	41.1	29.8	34.8	24.6
Total P (mg kg^{-1})	782.0	292.1	819.9	463.9	637.9	365.3
Total K (mg kg^{-1})	239.0	144.4	396.2	292.4	348.7	253.9
Total Ca (mg kg^{-1})	1228.5	1068.8	1499.1	991.5	1284.7	849.6
Total Mg (mg kg^{-1})	650.2	587.0	844.4	680.9	700.2	541.8
Total Fe (mg kg^{-1})	973.3	721.5	586.2	458.7	402.4	276.4
Total Mn (mg kg^{-1})	21.7	13.6	26.4	16.4	11.7	10.1
Total Cu (mg kg^{-1})	3.9	2.9	2.6	2.0	2.6	1.8
Total Zn (mg kg^{-1})	13.4	15.7	29.2	25.5	31.0	18.5
Total B (mg kg^{-1})	5.0	6.1	6.1	6.3	5.9	5.5

Source: Melling (2013)

decomposition process, the C/N ratio decreases, indicating that relatively more C than N is reduced in the process. The C/N ratio of deep tropical peat is higher than with temperate peat due to the high lignin content of the tree remains.

Cation Exchange Capacity (CEC) of peat is high, ranging from 29.6 to 41.3 cmol kg^{-1}. The cation Exchange Capacity (CEC) indicates the ability of peat soil in retaining or releasing nutrients. The high CEC in peat is not due to the presence of basic cations (K, Ca, Mg, and Na) but due to the dissociated carboxyl groups which release H^+ ions resulting in higher acidity in peat. In peat, there is a very limited supply of exchangeable cations, leading to lower base saturation (ranging from 15.6 to 41.1 %) in all forest types.

4.7 Sustainable Management of Tropical Peatlands

Malaysia aims to manage its tropical peatlands sustainably in an integrated manner to conserve resources and generate sustainable benefits for current and future generations. The goal can be attained by improving knowledge in the functions and characteristics of these peatlands, and developing and implementing strategic sustainable management. Various agencies were established, inter alia, to enforce and implement strategies for the sustainable management of peatland. Among these agencies are the Ministry of Resource Planning and Environment, Forest Department, Sarawak Forestry Corporation, Natural Resources and Environment Board, Sarawak Biodiversity Centre and Drainage and Irrigation Department (Sawal 2012). The tropical Peat Research Laboratory Unit was established in 2008 to conduct research and development on tropical peatland, and to disseminate scientific knowledge and provide advisory support pertaining to the management of tropical peatland. In support of resource conservation, the state of Sarawak has targeted approximately 1.24 Mha or 10 % of its land area covering a diverse type of habitats as Totally Protected Areas (TPAs). These TPAs comprises of national parks, wildlife sanctuaries and nature reserves (Khathijah et al. 2005). Moreover, the state of Sarawak plans to set aside 6.0 Mha as a Permanent Forest Estate (PFE) and other sensitive areas like water catchment areas (Sawal 2012). Two national parks in Sarawak are described below.

4.7.1 Maludam National Park, Sarawak

Maludam National Park, which represents the largest Totally Protected Peatland Forest in Sarawak was gazetted in May 2000. The Park covers an extensive area of 43,147 ha of TROPICAL PEATLAND FORESTs off the Maludam Peninsula in the Betong Division, which comprises the largest single TROPICAL PEATLAND FOREST dome in Northern Borneo. The area is divided into two parts by the Maludam River. The Park contains the only viable population in the world of the highly endangered Red Banded langurs (*Presbytis melalophos cruciger*), the endangered Proboscis monkey (*Nasalis larvatus*) and Silvered langurs (*Presbytis cristata*) (endemic to Borneo). Long-tailed macaques (*Macaca fascicularis*) are also very common here. Existence of more than 201 species of birds, 61 species of mammals, 6 species of amphibians, 11 species of reptiles, 28 species of freshwater fishes and 218 species of flora have also been documented. The birds of the Maludam area are very diverse with a few highly endangered species. Conspicuous birds include the Black Pied, and Rhinoceros hornbills (*Anthracoceros malayanus*, *A. albirostris and Buceros rhinoceros*), Common Blue-eared and Stork-billed kingfishers (*Alcedo atthis*, *A. meninting and Pelargopsis capensis*), Striated herons (*Butorides striatus*), Green imperial pigeons (*Ducula aenea*), and Greater Racket-tailed drongo (*Dicrurus paradiseus*). One of the most interesting findings was the sighting of the Masked Finfoot (*Heliopais pensonata*), a vagrant from continental Southeast Asia which has never before been sighted in Borneo island (Khathijah et al. 2005).

4.7.2 Loagan Bunut National Park

Loagan Bunut National Park, gazetted in 1990, covers an area of 10,736 ha between the Sg. Tinjar and Sg. Teru rivers, in the upper reaches of the Baram River basin in Sarawak. The park supports the only freshwater floodplain lake in Sarawak, an ox-bow lake, freshwater swamp forest, dryland forest, rivers, and riverine forests with resident populations of at least 6 mammal species (Mohd-Azlan et al. 2006), 12 bird species (Laman et al. 2006), 4 reptile species (Das and Jensen 2006) and 6 tree species (Tawan et al. 2006) which are categorised as globally threatened by the World Conservation and Monitoring Centre (WCMC). These include the endemic Grey Leaf Monkey (*Presbytis hosei*), Flat-headed Cat (*Felis planiceps*), Wrinkled Hornbill (*Aceros corrugatus*), Asian Black Hornbill (*Anthracoceros malayanus*) and a potentially viable Tomistoma (*Tomistoma schlegelii*) population (UNEP-WCMC 2014). The lake in Loagan Bunut National Park supports the water bird species, including the Oriental Darter (*Anhinga melanogaster*), Lesser Fish Eagle (*Ichthyophaga humilis*), Storm's Stork (*Ciconia stormi*) and Lesser Adjuntant Stork (*Leptoptilos javanicus*), which can also be categorized as the "flagship" species of Loagan Bunut National Park (Laman et al. 2006).

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Chapter 5
Peatland and Peatland Forest in Brunei Darussalam

Shigeo Kobayashi

Abstract Peatlands, stored with abundant organic matter, become a source of the greenhouse effect gases emissions such as carbon dioxide and methane generated by decomposition of organic matter since such lands have not been properly utilized. Rehabilitation of degraded peatlands has, nevertheless, hardly been attempted. This paper aims to clarify peatland properties of (1) peatland forest, (2) climate and water conditions, (3) physical properties, (4) chemical properties, (5) possibility of utilization of peat as organic compost, and (6) peat land-use changes in peatland of Brunei Darussalam. Natural peatland was distributed by mixed Dipterocarp forest, Alan (*Shorea albida*) Batu, Alan Bunga, Alan Padang, and Padang Paya. The typical peat of Brunei Darussalam was identified as the Oligotrophic Tropofibrists (Histsols-Fibrists) based on the physical and chemical properties of peat. Especially, carbon storage of the peat swamp forest ecosystems was indicated the maximum 1700 Ct/ha/m. Peat of Brunei Darussalam was also shown the possibility of organic compost, but the problems were pointed out its difficulties of natural regeneration after harvesting and the surface sink-age.

Keywords Alan (*Shorea albida*) forests • Physical properties of peat • Chemical properties of peat • Carbon storage • Compost utilization

5.1 Introduction

The Ramseur convention treaty on wetland conservation was concluded as an international treaty in 1971. According to this treaty, the wetland forests in the tropics have, however, been experiencing drastic land-use transformations for easy access and utilization, which, together with tropical forest decline, has also been a focal point of global environmental issues. Southeast Asia in particular has a very

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wide area of wetlands in which peatland forest, mangrove, and freshwater wetland forests are distributed in 22.2 million ha (Whitmore 1984; Kobayashi 1988; Yamada 1984; Page et al. 1999).

In tropical peatland, which most emit the greenhouse effect gases due to land use change, attempts have never been made to revitalize local society in favor of a land use which urges global-warming prevention (e.g., peatland forest rehabilitation). Therefore, this paper propose to adequately develop multi-purpose land use for agriculture (wet rice, coconut, etc.), forestry, fishery (shrimps and crabs) and the like, taking into consideration of conservation of very fragile tropical peatland ecosystem, and to build a sustainable management system.

This paper aims to clarify (1) climate condition of peatland/forest (indicating as peatland and peatland forest), (2) characteristics of peatland forest, (3) physical and chemical properties of peatland, (4) peatland use changes. This paper results obtained mainly from the permanent plots of peatland/forests at Alan Padang, A. Bunga and A. Batu (Alan: *Shorea albida*) forest in Belait, Seria and Sungai Mao, Brunei Darussalam.

5.2 Characteristics of Peatland Forest

Peatland/forest seems that the round water level is different between sites with a developed root system and sites with an underdeveloped root system (Kobayashi 1997b; Shimamura 2004). If a root system develops, the A_0 horizon is formed on the root above the peat horizon. Otherwise, A_0 accumulates directly on the peat horizon. Root systems with A_0 horizons show a high variation in water tension and become easily dry. An A_0 horizon in peat is generally not thick and the peat horizon is constantly saturated. Water tension in peatland creates severe habitat whereby the peat horizon is easily flooded and the root systems are easily dried out. It seems generally for severe habitat for seedling establishment. Tropical peatland forest is one of the most important area for the land utilization in insular Asia, although peatlands are widely distributed in Asia of 22.2 million ha compared with 5.2 million ha in America and 3.5 million ha in Africa (Kyuma et al. 1986). About 18.2 million ha of peat exist in insular Asia. On the other hand, peatland forests are distributed 90,884 ha in Brunei Darussalam. These forests dominantly consist of pure *Shorea albida* (Alan) stands classified into three forest types such as Alan Batu, Alan Bunga, Alan Padang (Anderson 1964; Stoneman 1997).

There are typical four forest types such as Mixed Dipterocarp forest, Tropical heath forest, Peatland forest, and tropical mountain forest where are occupied 95 % of area except mountain forest and others. The structures and soil profiles of each three major different forest types are the peatland forest, the heath forest and the mixed Dipterocarp forest in Brunei (Figs. 5.1 and 5.2).

The study site of mixed Dipterocarp forest was located in Andulau Forest Reserve about 5 km from Sungai Liang. Acrisols (red and yellow podzolic) soil composed of thin A0 and A horizon was distributed. The dominant species in this

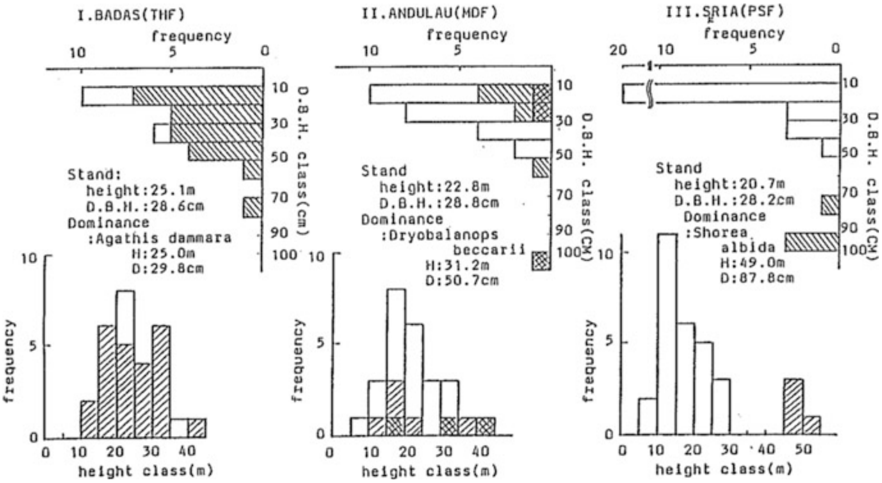

Fig. 5.1 Typical three types of forest structures in Brunei: (I) BADAS (THF): Tropical Heath Forest dominated by *Agathis dammara*, (II) ANDULAU (MDF): Mixed Dipterocarp Forest dominated by *Dryobalanos beccarii*, (III) SRIA (PSF): Peat Swamp Forest dominated by *Shorea albida* (Kobayashi 1988)

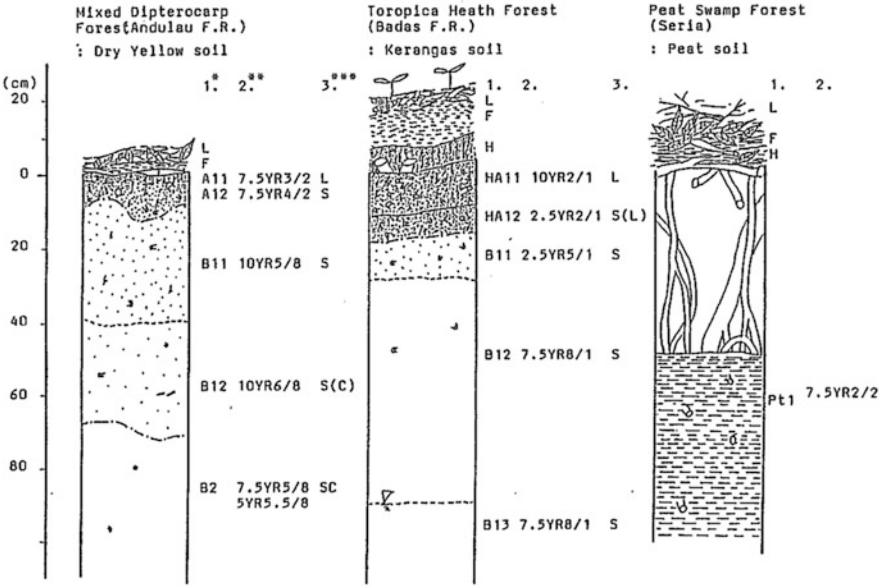

Fig. 5.2 Soil profiles of each forest type (Kobayashi 1988)

forest ware *Dryobalanops beccarii*, *Shorea beccariana* and *Shorea quadrinervis*. The stand was shown an average of 28.8 m in height, an average of 28.8 cm in D.B.H. and 50 % of trees belonged to *Dipterocarpacea*. The study site of tropical heath forest was located in Badas Forest Reserve about 10 km from Lumut. The soil was classified into Arenosols (Kerangas soil). Thick organic matter was accumulated and topsoil was mixed with undecomposed humus and white silica sand. This forest represented a pure stand of *Agathis dammara*. The average height of stand was 25.1 m and the D.B.H. was 28.6 cm. The dominant *Agathis dammara* comprised every size class and covers approximately 90 % of this site. The study site of peatland forest was located in Peat Swamp Forest Reserve 3 km from Seria. Peat swamp was characterized by peaty soil consisting of a thick peat horizon. Root systems were developing above the peat horizon near huge trees and height about 70 cm between the A0 horizon and peat horizon. This space was appeared to influence of the dominated *Shorea albida* regeneration. This peatland forest was mainly dominated by *Shorea albida* and characterized with an average of 22.7 m in height, an average of 28.2 cm in D.B.H. and about 100/ha in density. The comparison among these three forest types, the peatland forest dominated by *Shorea albida* and the heath forest dominated by *Agathis dammara* were less biodiversity caused by environmental condition instead of the rich biodiversity of tropical forests.

5.2.1 Structure of Peatland Forest

On specified different forests types were observed from outside of peat dome to center such as the mixed peatland forest dominated by *Dryobalanops rappa*, Alan Batu, Alan Bunga, Alan Padang and Padang Paya forests. Among of these forests, Alan forests occupied wide area and *S. albida* as monoculture stand is very peculiar in tropical rain forests associated with its phenological characteristics and site condition of peatland. Different Alan forest types are characterized on their heights and ground water levels. On the seedling establishment and regeneration process, although *S. albida* blossomed in February, 1986 in Brunei and Sarawak, the seedling population of *S. albida* almost disappeared from the forest floor 2 years after. The main factors of mortality were considered to be the shortage of light intensity (less than 700 lux) and the water condition of the habitat which becomes easily dry on days without rainfall on the root system and becomes flooded after continual rainfall on the peat horizon. It is also appeared on the point of demography that the energy allocation pattern to root weight of *S. albida* seedlings indicates less than 20 % compared with *Shorea laxa* and *Shorea angustifolia* more than 30 %. Peat land utilization must be taking into account of fragile ecosystem of *S. albida* forest on its regeneration process (Kobayashi 2000).

Shorea albida which established pure stand, had been harvesting like a clear cutting without plantation. The natural regeneration is the most difficult in this stand because of long period of *S. albida* flowering, lack of mother trees and the

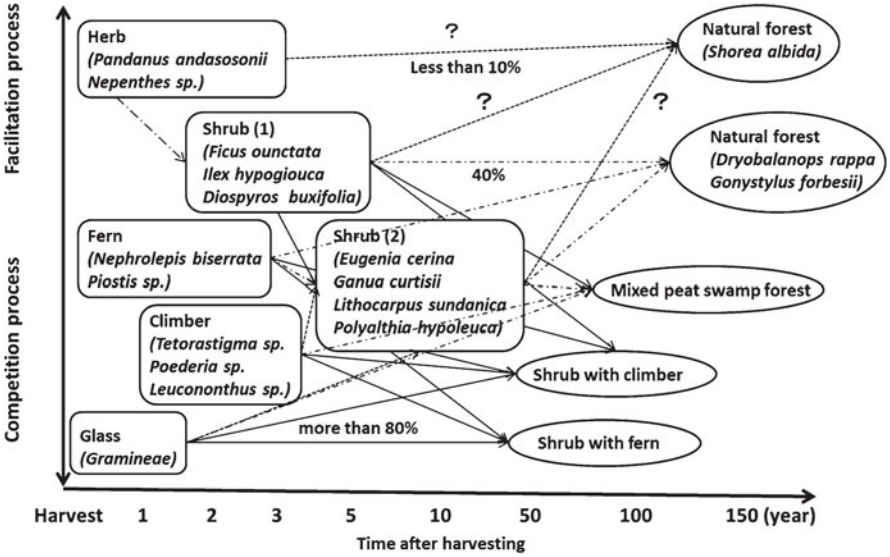

Fig. 5.3 Secondary succession after Shorea albida harvesting. The Parenthesis shows indicated species

extremely severe environment which were structure of peat profile, physical and chemical properties of peat (Matsune et al. 1994; Kuusipalo et al. 1996). Therefore, the clarification on the initial phase of vegetation recovery at the harvested site will be suggested as the feature forest rehabilitation activities at peat swamp areas. As the results of survey, vigorous vegetation recovery was recorded for 46 months after harvesting. Among of recovered species, *Pandanus andersonii* and *Nephrolepis biserrata* reproduced vigorously and established their dominances. The number of species increased according to the time lapse after harvesting. Sixty-seven species/100 m^2 were observed for 46 months after harvesting. However, an average of 30 species was surveyed in the natural Alan forest. Species composition was changing according to time. Natural regeneration of by original *Dipterocarp* species was very poor and only three species were observed such as *D. rappa*, *Shorea inaquilatealis* and *S. albida*. Nevertheless, the former dominant *S. albida* was recorded at only 1 plot among 16 plots (density: 3.1/ha). The *S. albida* forest will be taken over by different forest types. Therefore, initial vegetation recovery was classified into Shrub, Herb, Fern and Climber types (Fig. 5.3). Shrub and Herb types are considered the facilitation process and Fern and Climber types are the competition process during secondary succession according to species changes, although *S. albida* forest is not expected to re-establish (Kobayashi 2004). This perspective is recognized coupled with natural regeneration by Dipterocarp species and Ramin is very poor. The *S. albida* forest will be taken over different forest types which are expected low value resources.

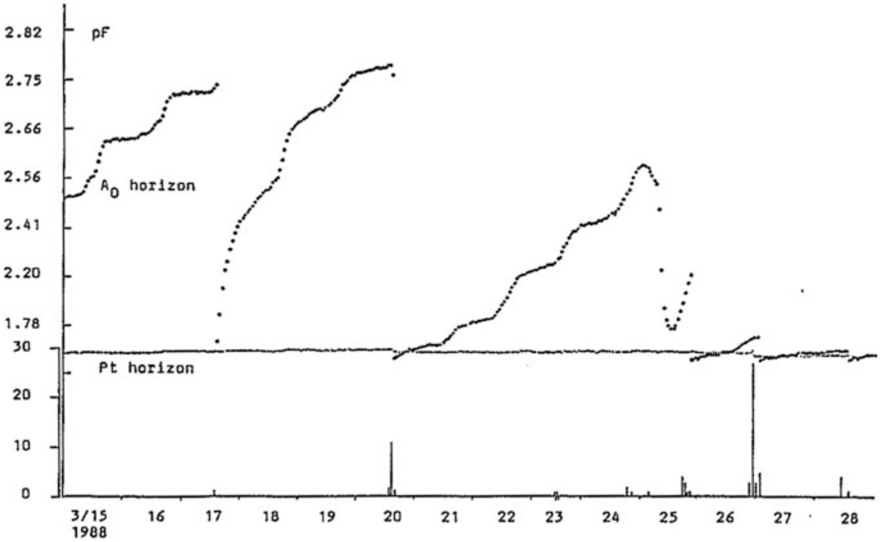

Fig. 5.4 Peat water condition related with horizon and rainfall. If no rain, surface will be dried (Kobayashi 1988)

5.2.2 Environment Conditions of Peatland

Peatland forest seems that the ground water level is different between sites with a developed root system and sites with an underdeveloped root system (Fig. 5.2). If a root system develops, the A_0 horizon is formed on the root above the peat horizon. Otherwise, A_0 accumulates directly on the peat horizon. Root systems with A_0 horizons show a high variation in water tension and become easily dry (Fig. 5.4). An A_0 horizon in peat is generally not thick and the peat horizon is constantly saturated (pF: about 1.5). Water tension in peat swamp creates severe habitat whereby the peat horizon is easily flooded and the root systems are easily dried out. It seems generally for severe habitat for seedling establishment (Burslem 1996; Gunatilleke et al. 1996). Each study recorded a maximum temperature of approximately 30 °C and a minimum temperature of 22 °C in same month when peat water tension was measured. The daily variation of each study site was synchronized. The daily range was less than 5 °C at each site. Tropical heath forest recorded comparatively high daily variations and peatland forest recorded the lowest average temperature for air temperature (Kobayashi 1997a; Takahashi and Yoneta 1997). Soil temperature remained constant at an average of approximately 26 °C for each site according to same month. The highest average of soil temperature was indicated in tropical heath forest and the lowest average of soil temperature was recorded in peatland forest. The daily variation of soil temperature in mixed *Dipterocarp* forest was comparatively higher than other types of forests. Soil temperature at peatland forest was relatively constant due to the thick A_0 horizon and saturated water condition.

5.3 Physical Properties of Peat

Physical properties of peat was analyzed and shown in Table 5.1. Peats were characterized to appear high hydraulic conductivity, low bulk density, high total porosity, and low specific gravity (Kobayashi et al. 1989). Hydraulic conductivity of peats decreased from Alan Padang to Alan Batu, but moisture content of fresh peats increased from Alan Padang to Alan Baru affected by ground water levels. Composition of solid, liquid and gaseous phases in peats indicated large differences depend on Alan forest types. Rate of gaseous phase indicated the largest in peat at Alan Padang, the smallest at Alan Batu. Rate of liquid phase indicated the smallest at Alan Padang and the largest at Alan Batu conversely. Gaseous and liquid phases were characterized each peats which were also affected ground water level. Therefore, these differences of gaseous and liquid phases were one of the characteristics of peats in Alan forests. Composition of fine and coarse porosities also indicated differences among peats at each Alan forest types. Their total porosity

Table 5.1 Physical properties of peats at Alan Padang, Alan Bunga and Alan Batu Forests (Kobayashi et al. 1989; Kobayashi 2012)

Plot	Alan Padang			Alan Bunga			Alan Butu		
Horizon	Pt1	Pt2	Pt3	Pt1	Pt2	Pt3	Pt1	Pt2	Pt3
Depth (cm)	0–12	2–34	34–	0–8	8–26	26–	0–5	5–24	24–
Hydroaulic conductivity (cc/min.)	977	1118	126	382	207	295	197	21	7
Bulk density (g/cc)	0.112	0.122	0.074	0.153	0.147	0.079	0.113	0.152	0.098
Porosity (%) coarse	56.2	56.0	64.4	55.3	29.7	47.3	30.6	15.6	34.6
Fine	29.5	35.7	29.0	33.6	58.6	45.9	59.4	73.2	57.3
Total	85.7	91.7	93.4	88.9	88.3	93.2	90.0	88.8	91.9
Water maximum (%)	58.5	59.8	57.4	52.5	80.2	74.0	78.7	87.9	94.3
Air minimum (%)	27.2	31.9	36.0	36.4	8.1	19.2	11.3	0.9	−2.4
Moisture content (%)	36.9	42.2	37.6	36.5	68.4	61.4	71.8	84.5	95.5
Specific gravity	1.50	1.53	1.49	1.53	1.47	1.55	1.51	1.45	1.40
Saturated water/dry peat (%)	566.8	490.4	784.3	347.9	555.8	951.8	715.2	582.0	972.2
Ground water level (cm)	74			56			24		

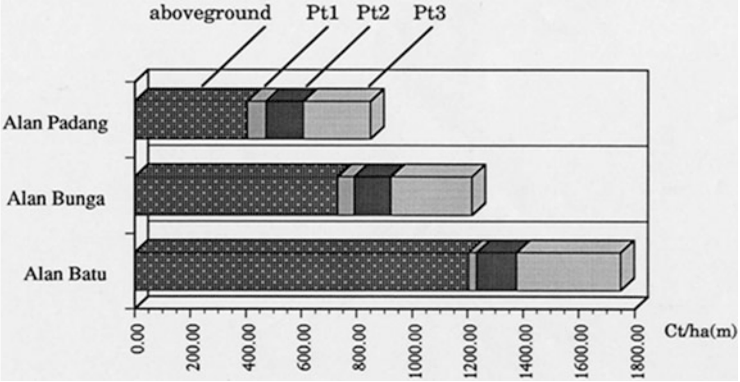

Fig. 5.5 Carbon storage of *Shorea albid*a forest ecosystem: the above-ground biomass was estimated and the under-ground carbon storage was estimated by depth of 1 m (Deepest peat was over 10 m)

were similar and more than 80 %, but the peat at Alan Padang showed much coarse porosity, the peat at Alan Batu had much fine porosity and the peat at Alan Bunga was medium.

The USDA Soil taxonomy (1990) classifieds fibric material using the criteria that its bulk density is less than 0.1 g/cc and that saturated water content based on dry peat weight is 850–3000 %. The bulk density of sapric material is more 0.2 g/cc while saturated water content was less than 450 %. Hemic material is classified by medium values of bulk density and saturated water content between Fibric. Although each horizon of peat at three Alan forest types was classified according to the above mentioned criterion, fibric materials were distributed within all Pt3 horizons. The peats of Alan forest were Tropofibrsts due to the key horizon of peat classification occurring on subsurface tiers (USDA Soil Taxonomy was changed in 2010, but Author used to apply the old Taxonomy because of the taxonomy must be synchronized the former taxonomy).

A problem exists concerning the utilization of peat which tends to sink down from the surface during dehydration and decomposition. Results from the experiment using the 400 cc cylinder showed the peat of Alan Batu underwent a 6.0 mm surface sinkage during a 40 % loss of water (Fig. 5.5). Other peats also displayed a surface sinkage but at different ratios. The volume of peats also decreased with thisprocess.

5.4 Chemical Properties of Peat

Chemical properties of peats did not indicate exceptional differences without for ash contents and cation exchangeable capacity at three Alan forests types (Table 5.2). Differences of ash contents and cation exchangeable capacity were related to different ratios of mineral soil and hemic substance. The characteristic aspects of

Table 5.2 Chemical properties of peat at Alan Padang, Alan Bunga and Alan Batu Forests (Kobayashi et al. 1989; Kobayashi 2012)

					Inorganic nitrogen			Exchangeable cation			
					NH_4	NO_3	C.E.C	Ca^{2+}	Mg^{2+}	K^+	Na^+
		pH		Ash (%)	mg/100 g dry soil		me/100 g dry soil	me/100 g dry soil			
Alan Pagang	Pt1	3.35	(3.30)	1.2	(9.52)	(0.00)	243	0.00	7.76	1.47	0.28
	Pt2	3.53	(3.29)	2.1	(7.47)	(0.14)	283	0.00	6.81	0.75	0.29
	Pt3	4.35	(3.20)	21.3	(8.57)	(0.00)	273	0.00	4.51	0.96	0.34
	Pt4	4.74	(3.58)	0.3	(5.55)	(0.00)	245	0.00	2.87	0.45	0.17
Alan Bunga	Pt1	3.32	(3.24)	1.6	(5.87)	(0.00)	316	0.76	8.56	1.22	0.42
	Pt2	3.47	(3.28)	1.7	(1.84)	(0.31)	361	0.00	5.57	0.71	0.33
	Pt3	3.56	(3.51)	1.0	(9.86)	(0.58)	250	0.00	5.13	0.52	0.41
	Pt4	3.50	(3.69)	0.6	(9.71)	(0.29)	266	0.00	3.29	0.40	0.33
Alan Butu	Pt1	3.25	(3.34)	2.9	(8.56)	(0.00)	301	2.27	7.86	1.05	0.44
	Pt2	3.35	(3.45)	6.6	(1.61)	(0.00)	225	0.00	3.00	0.38	0.28
	Pt3	3.29	(3.47)	0.8	(2.47)	(0.00)	309	0.00	2.60	0.29	0.27
Top soil of arboretum		4.66		90.8	(4.40)	(0.00)	87	0.00	4.33	1.09	0.00

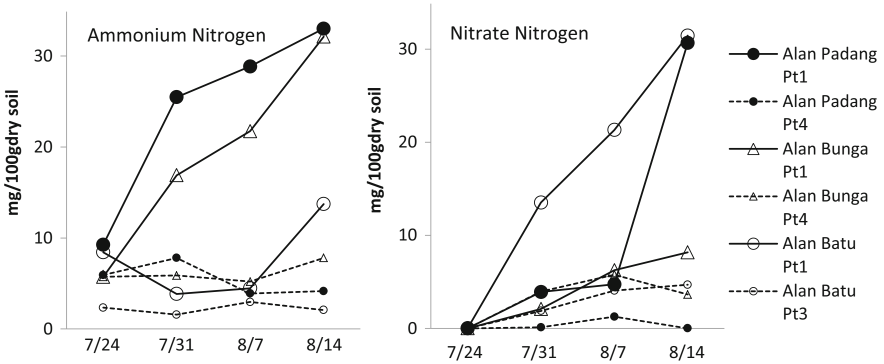

Fig. 5.6 Process of decomposition of peat under the analysis of ammonium nitrogen and nitro gate nitrogen (Kobayashi 1988, 2012)

Brunei peats revealed that the pH level dominated between 3.5 and 3.2 in fresh peats. It also indicated strong acidity with cation exchangeable capacity being more than 220 mm equivalent per 100 g dry peat while the exchangeable cations content was extremely low. Among exchangeable cations, the content of calcium and potassium in this study were low and the peats showed strong acidity. Therefore, peats of Alan forests were classified oligotrophic. Although peats indicated strong acidity, there was no evidence of sulfidic acidity, which was tested by SO_4 using Merckoquant test papers (Yonebayashi et al. 1997). Carbon stocks of Alan forest ecosystems were from 750 to 1700 Ct/ha/m at the center site to the marginal site of peat dome (Fig. 5.6). Aboveground carbon stocks of Alan forests were 300–1150 Ct/ha and underground carbon stocks of Alan forests were about 500 Ct/h/m which strongly affected depth of peat. If the depth of peat is 2.5 m, underground carbon stocks will be 1250 Ct/ha more than its aboveground carbon stocks.

The decomposition process of peat was examined by mineralization of nitrogen which showed different ratios and processes depending upon the horizons at Alan forest types. Generally, surface peats were easily decomposed and the deepest horizons sometimes indicated immobilization after 2 weeks in an incubation (Fig. 5.7). Ammonification was identified on surface peats of Alan Padang and Alan Bunga. Nitrification was also found on the peat surface of Alan Batu. It is therefore concluded that the decomposition ratio and process were affected by acidity, organic materials and water contents. In spite of different water contents and organic materials, peats displayed the possibility of decomposition and the future utilization of peats as compost. Nitrogen mineralization in peats showed different ratios and processes depending on the horizons and Alan forest types. Generally, surfaced peats were easily decomposed and the deepest horizons indicated immobilization after 2 weeks in the incubation. Ammonification was identified on surface peats of Alan Padang and Alan Bunga and nitrification was also found on the peat surface of Alan Batu. It is therefore concluded that the decomposition ratio and process

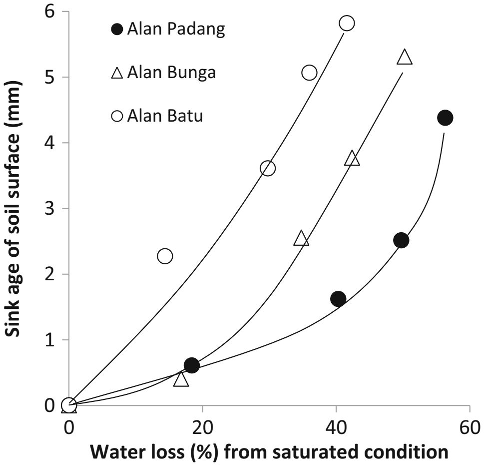

Fig. 5.7 Sink age of surface level of peat during the dehydration (Kobayashi et al. 1989; Kobayashi 2012)

affected by acidity, organic materials and water contents. Instead of different water contents and organic materials, peats displayed the possibility of decomposition and the future utilization of peats as compost.

5.5 Examination of Possibility of Utilization of Peat as Organic Compost

Tropical peat was studied for utilization of compost compared with common materials such as sawdust, litter and grass (Kobayashi 1994). The original peat of chemical properties indicates lower cation contents and a strong acidic pH value of 3.5. The water content is 500 % indicating the peat was oversaturated. It's necessary to be controlled and created the compost under 70 % of water content and pH7.0 of acidic condition for making the compost (Fujita 1987). When the lime was added to the peat to neutralize the pH and water content tried to be maintained 70 % at calorific fermentation was stimulated which was indicated to increase the temperature (Fig. 5.8). After treatment, the fermented was occurred, and chemical properties were changed (Table 5.3) after 68 days. Chemical properties of the compost before and after were changed that the amount of inorganic nitrogen and exchangeable cations increased in the peat compost through calorific fermentation. A final test of compost quality was conducted using the bioassay method and a fast growing plants, the tropical tomato (Table 5.4). Potting soil consisted of a 1:1 ratio of each material and topsoil. Grass and sawdust composts were sowed a sufficient growth of tomato seedlings two after sowing. Among of characteristics of tomato seedlings, increment of height and biomass displayed excellent growth occurred on grass and sawdust composts. According to these two composts, leaf litter and peat composts showed good tomato growth without topsoil. It will be necessary to

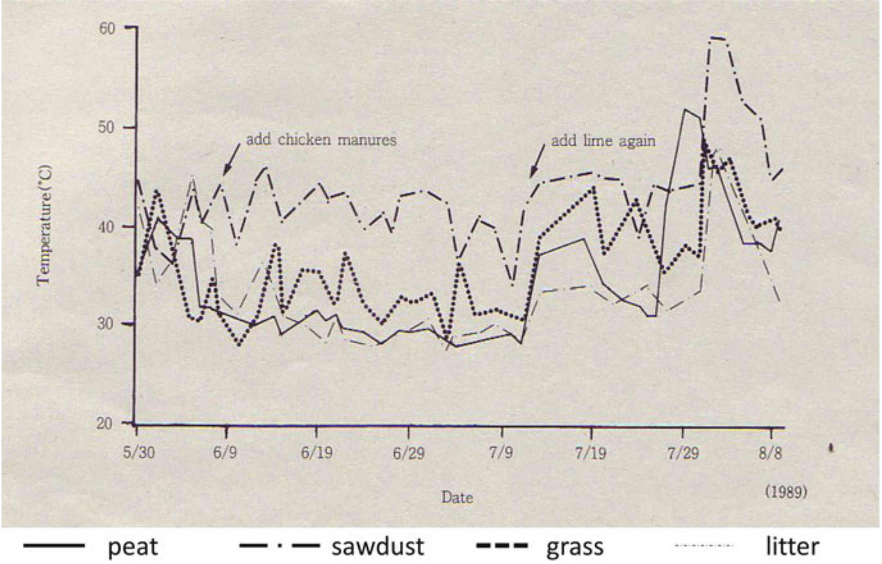

Fig. 5.8 Changes of temperature of compost in composts during pilling process (Kobayashi 1994)

check the matured peat compost for nutrients, because tomato showed third growth rate and peat did not ferment sufficiently in this study. There was no evidence of chlorosis in the tomato seedlings, because of leaf color was greenish (7.5 GY, 4/4.5–4/6). In addition, impediments to tomato growth such as root decay by post fermentation, did not occur.

Although, the peat had the potential to become compost, some problems were encountered therefore first of all, the *Shorea albida* forests have very unique structures and are scientifically important among tropical rain forests because only one species is dominated and consists of pure forest on the peat swamp. Secondly, drying and decomposition case, the peat will become to shrink and subside. Third, the structure of peat layers indicated complex layers alternating between peat and clay, the latter which usually contains Pyrite and transforms into sulfate after oxidation. Therefore, tropical peat must be carefully considered for use as compost.

5.6 Peatland Use Changes

It's rarely reported to clarify the unevenness environment of peatland forest on the process of litter decomposition (Shimamura 2004). Litter decomposition parameter (standard error) was 0.8910 (0.0410), 0.916(0.0603), 0.760(0.0394) in mound, flat and gap, respectively. It showed the highest value at flat area and the lowest at gap. We also clarified the environment changes according to land use changes from peat swamp forest to cultivation land, rubber plantation, coconut plantation and

Table 5.3 Changes of chemical properties after piling of compost (Kobayashi et al. 1989)

	Peat		Sawdust		Litter		Grass		Chicken	
	Before[a]	After[b]	Before	After	Before	After	Before	After	Manures	Topsoil
pH	3.56	6.82	4.95	8.34	5.39	7.64	6.64	7.53	7.31	4.66
Inorganic nitrogen										
MH_4-N	22.1	846.0	5.2	476.4	56.8	885.6	35.2	396.5	995.1	4.4
NO_3-N	1.1	466.2	0.0	37.3	0.0	148.4	0.0	165.6	56.9	0.0 (mg/100 g) dry-soil)
Total	23.2	1212.2	5.2	513.7	56.8	1034.0	35.2	562.1	1051.0	4.4
Cation exchangeable capacity	224	182	117	151	161	291	189	193	–	87 (me/100 g dry-soil)
Ca^{2+}	0.00	22.97	0.00	11.74	3.52	17.93	6.13	25.47	17.37	0.00
Mg^{2+}	1.70	5.22	1.32	3.75	3.46	4.06	3.55	4.94	21.74	4.33 (me/100 g dry-soil)
K^+	1.09	29.00	1.18	25.22	4.20	24.61	16.66	30.12	68.08	1.09
Na^+	0.00	7.51	0.00	5.36	0.52	6.15	3.89	6.49	16.22	0.00
Ash %	31.2	51.8	2.3	21.2	13.3	24.3	23.7	60.2	45.7	91.1

[a] Composting material air-dry

[b] Two months after piling, adding chicken manure and sulfate ammonium and lime

Table 5.4 Bio-assey of composts quality using tomato seedling after 2 weeks sowing (Kobayashi et al. 1989)

	Height	Stem fiameter	Leave no.	Biomass	Root weight*	Leafe color	Growth condition
Peat	7.6	1.3	4.4	12.5	1.2	7.5GY 4/4.5–4/6	Good
Sawdust	9.4	1.8	5.1	17.1	1.3	7.5YG 4/4.5–5/5.5	Very good
Litter	8.1	1.5	4.9	15	1.8	7.5YGY 4/4.5–4.5/5	Good
Grass	9.6	1.7	5.5	17.9	1.6	7.5YG 4/4.5–4.5/55	Very good
Topsoil	3	0.7	3.5	3.6	1	7.5YG 4/4.5–5/5	Bad
(unit)	cm	mm		mg	mg		

*dry weight (mg)

paddy. It showed lower air and underground temperatures and stronger acidity than agriculture fields. The environmental changes of land use changes from peatland forest indicated to accelerate the peat decomposition. Carbon decreasing rate by peat decomposition was estimated 0.053 Ct/ha/year from the peatland to coconut plantation (Kobayashi 2007).

After land use changes, surface temperature increased, moisture of peat became dry and mild acidic. Then the peat changed from fabric peat to mesic peat and to sapric peat. After changing, peat completely decomposed. Annual organic matter accumulation in peatland was 1.25 Ct/ha/year. We have also estimated the accumulation of peat and organic matter 5.7 t/ha/year. As the 50 % of peat and organic matter annual decomposition rate. We have gotten the less than 0.26 Ct/ha/year at Teluk Meranti and 0.15 Ct/ha/year under the conversion of land utilization from forest to Coconut plantation.

The tropical peatland/forest ecosystem will be contended the most organic matters where will be faced on the frontier of the development of land use change, even though it's the most carbon storage ecosystem (Kobayashi 2007; Gunawan 2012). Therefore, this peatland with the unique forest types must be taken account to conserve for future original forest and to global warming issues.

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Chapter 6
Peatland in Kalimantan

Mitsuru Osaki, Bambang Setiadi, Hidenori Takahashi, and Muhammad Evri

Abstract Peatland area in Indonesia was about 14.91 million ha spread out in Sumatra 6.44 million ha (43 %), in Kalimantan 4.78 million ha (32 %), and in Papua islands 3.69 million ha (25 %). In 1995, Mega Rice Project (MRP) in tropical peatland launched in Central Kalimantan, of which project failed because of knowledge gaps, especially on peatland hydrology, water management, peat subsidence, impacts of long term drainage, mechanization problems on peatland and socio-economic consequences.

This paper focuses on the peatland ecosystem affected by climate change, specifically the rainfall, relating with the position of the Intertropical convergence zone (ITCZ), which has a strong influence on the seasonal variations, and the seasonal patterns of rainfall variation in different parts of Indonesia. Further, to gain a better understanding of El Niño related phenomena, we provide details of the relationship among the Southern Oscillation index (SOI), the rainfalls during dry season in Central Kalimantan, and the lowest annual groundwater level in the tropical peatlands.

Kalimantan, Indonesia side of Borneo Island, has two big water storage system in peatland near costal area and humid forest of Hurt of Borneo at central mountain area. In Kalimantan, there are Main Three River Basins: the Kahayan, Mahakam, and Kapuas Rivers, which connect the Heart of Borneo with the Mountain Ranges in Borneo (*Water Tower*) and peatland downstream (*Water Pool*). As both Heart of Borneo (*Water Tower*) and peatland (*Water Pool*) interact mutually, both ecosystems destruction will induce the reduction of resilience and increase of vulnerability.

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Keywords Carbon-water interrelation • Dayak people • Mega Rice Project (MRP) • Water pool • Water tower

6.1 Introduction

Particulars of peatlands in Indonesia are estimated as 20.7 Mha of area (47 % of total tropical peatlands), 1138 Gm^3 of volume (65 % of the total tropical peatlands), 57.4 Gt of accumulated carbon (65 % of total tropical peatlands), and with an average 5.5 m thick peat layers (Page et al. 2011).

Kalimantan is the name given to the Indonesian portion of the large island of Borneo, the third largest island in the world after Greenland and New Guinea (MacKinnon et al. 1996).

Peatland area in Indonesia was about 14.91 million ha spread out in Sumatra 6.44 million ha (43 %), in Kalimantan 4.78 million ha (32 %), and in Papua islands 3.69 million ha (25 %). Thus, Kalimantan is one of key area for tropical peatland, which has been affected seriously on both human and climate change impacts.

6.2 Climate Conditions in Kalimantan

According to the Köppen classification system, the climate of a tropical rain forest (Class Af) is characterized by all 12 months having average precipitation of at least 60 mm. These climate zones are commonly distributed within 5–10° latitude of the equator. The climate in Indonesia is influenced by two monsoon periods, the Northeast "wet" Monsoon from November to February and the Southwest "dry" Monsoon from April to September. During the Northeast Monsoon, Australia and South-East Asia receive large amounts of rainfall, while the Southwest Monsoon normally brings relatively drier weather. The jet stream in this region splits into the southern subtropical jet and the polar jet streams. The subtropical arm directs northeasterly winds across south Asia, creating dry air streams which produce clear skies over India from the months of November to May. The Southwest Monsoon is drawn towards the Himalayas, creating winds blowing rain clouds towards India, which receive up to 10,000 mm of rain in some areas.

Intertropical Convergence Zone (ITCZ) Effect on Peatland In the Northern Hemisphere summer (July), the position of the ITCZ, which affects the tropical climate, stretches westward and northward from the Indian Ocean to approximately 30° north latitude, and reaches near the equator in the central Pacific Ocean, reaching the Himalayas and crossing southern China. In the Northern Hemisphere winter (January), it spreads to the south across Africa and reaches the Australian continent (Fig. 6.1). All of Indonesia lies in the annual fluctuation range of the ITCZ, and has a rainy season from October to April when the ITCZ passes across the country. However, the position of ITCZ is complicated due to the influence of the

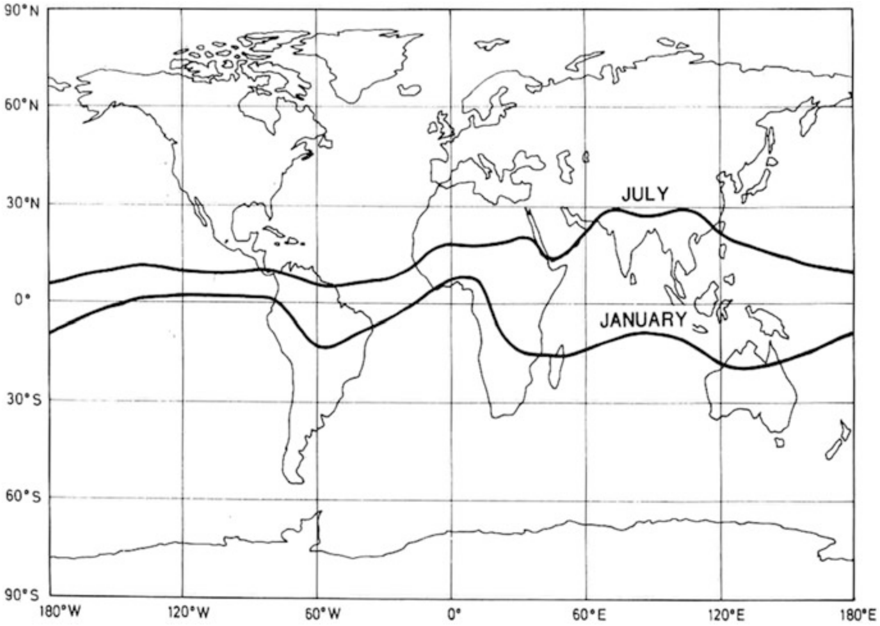


Fig. 6.1 Mean positions of the Intertropical Convergence Zone (ITCZ) in January and July (Henderson-Sellers and Robinson 1986)

land areas, from India to the Indochinese Peninsula, and different parts of Indonesia experience different intensities of rainy and dry seasons at different times of the year.

Figure 6.2 shows the seasonal fluctuations of rainfall at different locations in Indonesia based on data for the 10 years from 2001 to 2010 provided by the Indonesian Agency for Meteorology, Climatology and Geophysics. In Jakarta, Surabaya, Ujung Pandang, and Kupang, which are all located south of the equator, the monthly total amounts of rainfall is the lowest in July and August when the ITCZ is at the northern limit of its range. However, the monthly rainfall in July and August does not decrease extremely even when the ITCZ is at the equator or immediately to the north of the equator, and there is no distinguishable dry season at these locations. There are some areas including at Medan and Manado, where the average monthly rainfall decreases in January and February when the ITCZ is located to the south. Also, some areas such as at Pontianak, Pekanbaru, Padan, Palembang, and Palangka Raya, experience a mild dry season in February and March when there is some decrease in the rainfall, although it is a smaller decrease than in July and August.

According to the climate zones of Koepen, most parts of Indonesia excluding some parts of the mountainous regions have a Wet equatorial climate, *Af*, the mean temperatures in the coldest month are higher than 18 °C. At high altitudes, above 1500 m along the Kalimantan border between Indonesia and Malaysia, the climate is

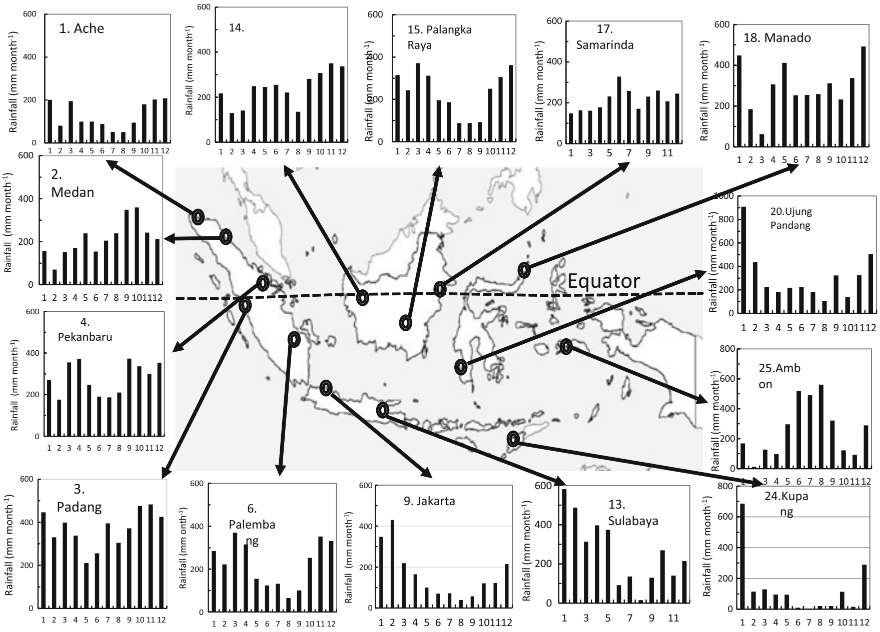


Fig. 6.2 Annual changes in monthly total amount of rainfall (mm), 10 year average from 2001 to 2010, in Indonesia (Data source: Rain data table of the Indonesian Agency for Meteorology, Climatology and Geophysics)

classified as Humid subtropical climate, Cfa. The eastern part of Jawa has relatively little rain, and some parts with Tropical savanna climate, *Aw*. Figure 6.3 plots climatic global peatland diagram that show the monthly mean temperature versus the total rainfall in Pontianak in west Kalimantan with this data for peatlands of various other parts of the world. Peatlands in Indonesia are clearly tropical, those in the Florida Peninsula in North America are subtropical, the wetlands in Kushiro and Sarobetsu are in cool temperate areas, and those in northern Siberia are cold temperate pleatlands.

Rainfall during the dry season and El Nino phenomena in Kalimantan Kalimantan can be divided broadly into five agroclimatic zones based on the mean monthly rainfall. About 43 % of the land area of Kalimantan is classified into zone A (wet season more than 9 months and dry less than 2 months), a large percentage of the peatland areas of Central Kalimantan are classified in zone C with 5–6 months wet and 2–3 months dry seasons. According to this classification, a month is considered “dry” when the mean monthly rainfall is less than 100 mm and “wet” when the mean monthly rainfall is more than 200 mm (MacKinnon et al. 1996). This is the zone where there is the combination of high temperatures (mean temperature of all months higher than 18 °C) and sufficient soil moisture for prolific vegetation growth. In South and Central Kalimantan rainfall generally increases northwards, inland from the coast.

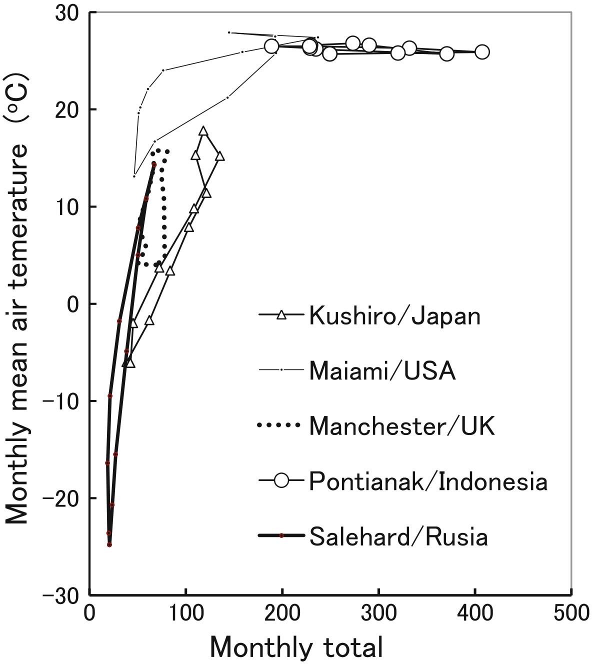
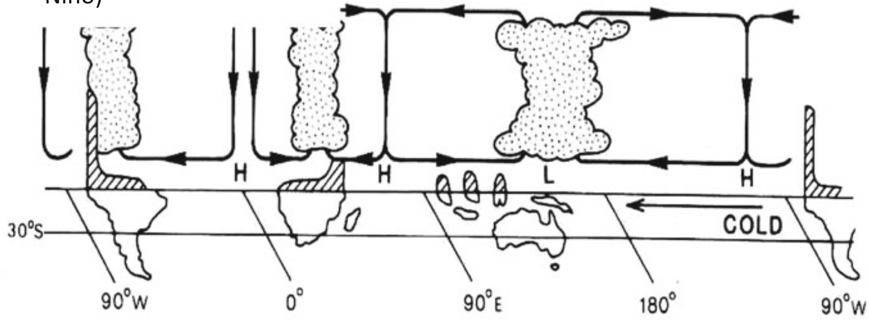


Fig. 6.3 Climatic global peatland diagram classified by monthly mean air temperature and monthly total rainfall

In the ocean upwelling area off the coasts of Peru, nutrient-rich cold water regularly rises to the surface, although the temperature of the surface is lower than the surroundings. However, every 3 or 4 years this upwelling flow weakens and warm seawater of the equatorial countercurrent flows into the area. Then the air layers warmed by this warm sea surface rises off the coast of Peru, and after flowing west across the South Pacific gives rise to a descending air current near Indonesia. Due to this descending air current Indonesia then suffers from a climate condition with little rain, resulting in a prolonged dry season (Fig. 6.4). This phenomenon is the so-called El Nino, and the intensity of the occurrence is determined by the Southern Oscillation index (SOI), which is computed from fluctuations in the surface air pressure difference between Tahiti in the South Pacific and Darwin, Australia. Anomalous dry seasons occurred frequently in this area due to the effect of ENSO events, such as in the years 1982, 1987, 1991, 1994, 1997, and 2002 (MacKinnon et al. 1996; Schimel and Baker 2002; Wooster and Strub 2002a, b; Aldhous 2004; Slik 2004), and there have been further ENSO events in 2006 and 2009.

Figure 6.5a plots the SOI for the 33 years from 1978 to 2010 versus the mean rainfall for the 5 months from June to October (Japan Meteorological Agency 2014) as it deviates from the total rainfall for the 5 months from June to October, the dry season in Palangka Raya, Central Kalimantan (Fig. 6.5a). The figure shows a clearly positive correlation between the SOI and the rainfall during dry season in Palangka Raya, with the coefficient of determination ($R^2 = 0.59$), indicating that El

(A) DEC-FEB (Non El Nino)



(B) DEC-FEB 1982-83 (El Nino)

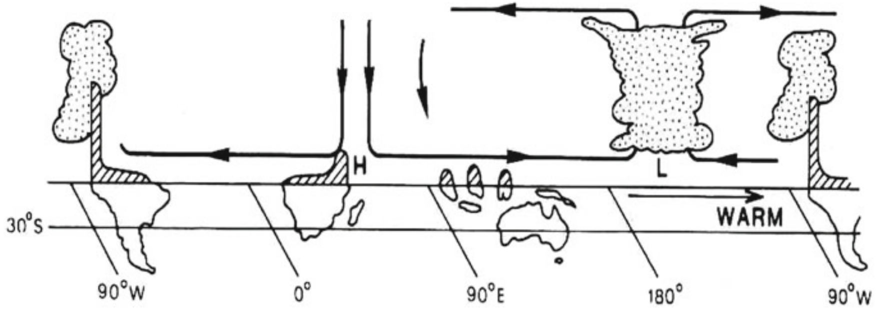


Fig. 6.4 Cross-sections of the walker circulation along the equator during non El Nino (**a**) and El Nino (**b**) events in 1982–1983 (Barry and Chorley 1989)

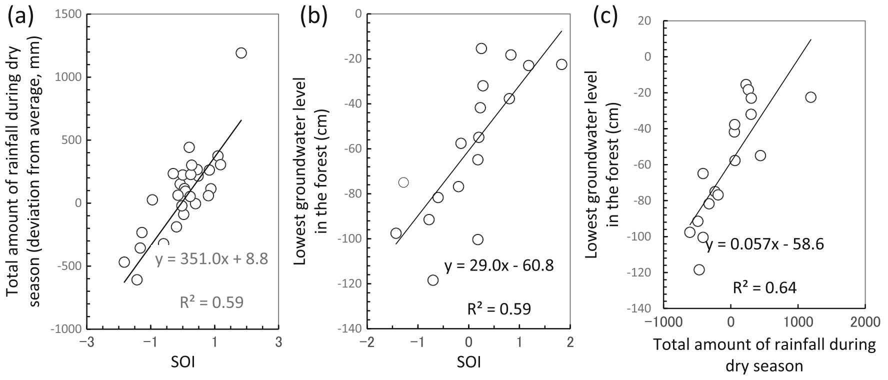


Fig. 6.5 Plot of (**a**) SOI versus the total amount of rainfall during the dry season at Palangka Raya, (**b**) SOI versus the lowest groundwater level in the tropical peatland/forest in Central Kalimantan, and (**c**) the total amount of rainfall during the dry season versus the lowest groundwater level in the tropical peatland/forest

Nino affects the rainfall during the dry season in Central Kalimantan. Figure 6.5b shows the annual lowest groundwater level in the tropical peat swamp forests in Central Kalimantan, recorded from 1993 (Takahashi and Yonetani 1997) and plotted against the SOI, this plot shows a significant correlation with the SOI, also with the coefficient of determination ($R^2 = 0.59$), and as shown in Fig. 6.5c there is a slightly higher correlation between the total rainfall during the dry season and the annual lowest groundwater level with the coefficient of determination ($R^2 = 0.64$).

The correlations among the SOI, the total rainfall during the dry season in Palangka Raya, and the annual lowest groundwater level in the tropical peat swamp forest strongly suggest that the rainfall during the dry season in Central Kalimantan decreases during El Nino events, and that this lowers the groundwater level of peatlands. The decrease in the groundwater level of the peatlands is a major cause of outbreaks of the peat fires in this area (Jaya et al. 2012).

6.3 Water Stock and Water Networks in Kalimantan

The water volume contained in the tropical peat in central Kalimantan is about 95 % when it is saturated at high groundwater levels, but it decreases to about 25 % and fire risks become high when droughts continue in the dry season in the drained areas (Takahashi, unpublished data). Assuming the potential retained water capacity as 95 %, the water retention capacity of Indonesian peat is about 1100 Gm^3, and this acts as a huge reservoir. For comparison the total reservoir capacity of dams in Japan is 20.4 Gm^3 (http://damnet.or.jp/cgi-bin/binranB/TPage.cgi?id=19). These data suggest that the water volume accumulated in tropical peat areas is huge, and changes in the water environment due to a terminal disturbance of this ecology will have a serious impact on global ecology and the environment. For this reason it is urgently important to conduct an analysis and modeling of the water flux of these areas because there is no adequate basic data at present.

The Heart of Borneo (HoB) Initiative is a conservation and sustainable development program aimed at conserving and managing the contiguous tropical forest in the island of Borneo (Fig. 6.6). The HoB covers approximately 200,000 km^2 of ecologically inter-connected rainforest in the provinces of Kalimantan (Indonesia), the states of Sabah and Sarawak (Malaysia), and Brunei Darussalam. The Heart of Borneo initiative has been developed and implemented to prevent unsustainable use of high economic value natural resources that are at serious risk by illegal and unsustainable activities from environmental and social aspects in the areas of jurisdiction of the three countries. An expression of commitment through a declaration entitled "*Three Countries*, *One Conservation Vision*" was announced in Bali on 12 February 2007.

The HoB program is a coordinating regional partnership providing equal responsibility and assigning roles among the three countries. The remaining tropical rainforest with high conservation value in the world is an important area for the global community and international institutional support is provided by priority

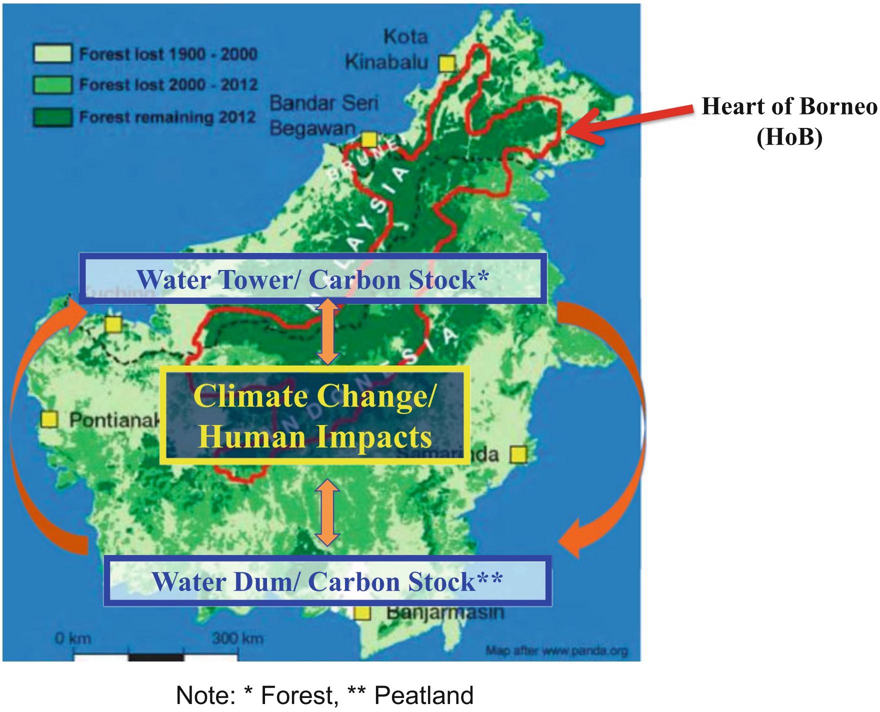


Fig. 6.6 Diagram of the carbon-water relationship in Kalimantan (the *red line* shows the Boundary of the Heart of Borneo (HoB))

programs such as: the Transboundary Management; Protected Areas Management; Sustainable Resources Management; Ecotourism Development; and Capacity Building.

In Kalimantan, there are Main Three River Basins: the Kahayan, Mahakam, and Kapuas Rivers, which connect the Heart of Borneo with the Mountain Ranges in Borneo (*Water Tower*) and peatland downstream (*Water Pool*) (Figs. 6.6 and 6.7). The Water Tower supplies water to the Water Pool through the water available in forests and rivers, and also the Water Pool supplies water by water cycling through rain. Thus, Human Impact and Biodiversity, and not only climate change also affect the Water Buffer and Water Cycle in the forest.

Kahayan River The Kahayan River, or the Great Dayak, is the largest river in Central Kalimantan, and the capital Palangka Raya of Central Kalimantan Province lies on this river, located close to the tropical peatland-forest area, and approximately 120 km from the Java Sea, at an elevation between 15 and 20 m above sea level (MacKinnon et al. 1996).

The inhabitants are mainly Dayaks, who practice slash-and-burn rice cultivation and pan for gold on the upper reaches of the river. The lower Kahayan flows through

Source: US National Park Service, Esri

Fig. 6.7 River network connecting the Heart of Borneo (HoB) and the Peatlands of Kalimantan (The three main rivers are: Kahayan, Mahakan and Kapuas rivers)

a rich and unusual environment of peat swamp forests, which has been severely degraded by an unsuccessful program to convert a large part of the area into rice paddies, and the degrading has been compounded by legal and illegal forestry. Central Kalimantan covers 153,800 km^2, with 82 % tropical rain forest and no more than 3 % agricultural land. The northern part of the province is mountainous, the central area has flat and fertile tropical forests and the southern area is swampy. The forests provide rattan, resin, and high-quality woods. The climate is hot and humid, typically around 30 °C throughout the year. Annual rainfall is between 2800 and 3400 mm.

The Kahayan River rises in the northern mountains, then meanders for 600 km southward through the plains to the Java Sea. Tidal effects are felt 50–80 km inland from the sea. A recent study found 28 species of fish in the river, 44 species in the Danau Sabuah Lake and 12 species in traditional fish ponds along the river. The riparian wetlands are the main spawning areas, however fishermen are recently reporting declining yields due to problems with the water quality. The lower reaches of the Kahayan River formerly flowed through a huge area of peat swamp forest, an unusual ecology that is home to many unique or rare species such as Orangutans, as well as to slow-growing but valuable trees. The peat swamp forest is a dual ecosystem, with diverse tropical trees standing on a 10–12 m layer of partly decayed and waterlogged plant material, which in turn covers relatively infertile soil. The peat swamp forests were being slowly cleared for small scale farming and plantations before 1997, but most of the original cover remained.

In 1996 the government initiated the Mega Rice Project (MRP), which aimed to convert 1 million ha of peat swamp forest to rice paddy. Between 1996 and 1998, more than 4000 km of drainage and irrigation channels were dug, and deforestation started in part through legal and illegal forestry and in part through burning. It turned out that the channels were draining the peat forests rather than irrigating them. Where the forests had often flooded up to 2 m deep in the rainy season, now the surface is dry at all times of the year. The government has therefore abandoned the MRP, but the drying peat is vulnerable to fires which continue to break out on a massive scale. Peat forest destruction is causing sulphuric acid pollution of the rivers. In the rainy seasons, the canals are discharging acidic water with a high ratio of pyritic sulphate into the Kahayan River up to 150 km upstream from the river mouth. This may be a factor contributing to lower fish catches.

Mahakam River The Mahakam River basin is considered to retain the biodiversity and health of the tropical Kalimantan riparian zone and logged over forest areas: it is evaluated as a reference to develop restoration practices that are adaptive to climate change. The Mahakam River rises at Cemaru in the mountains of Kalimantan, and flows about 650 km east-southeast to the Makassar Strait (MacKinnon et al. 1996). The Mahakam River is the largest river in East Kalimantan, with an approximately 77,100 km^2 catchment area. The Mahakam River flows meet the Kedang Pahu River, through the Mahakam lakes region, which is a flat tropical lowland area surrounded by peat land, and also connected with the Semayang and Melintang lakes downstream. There are about 76 lakes in the Mahakam river basin and about 30 are at the middle reaches of the Mahakam area, including the three main lakes. A wetland at the river mouth delta has been developing and holds Samarinda, the capital of Kalimantan Timur (East Borneo) province.

The Mahakam delta is a mixed fluvial-taidal delta. The delta covers about 1800 km^2, consisting of mangrove areas near the shore, Nypa swamps in the central areas, and lowland forest near the start of the delta. Recent fishery development in this area has converted a vast area of mangrove into shrimp ponds (tambak).

Kapuas River The Kapuas River is the largest river on the islands off South East Asia. The river rises in the Kapuas Hulu Mountains in the central part of the Kalimantan and flows 1143 km west-southwest, from 114° to 108° E., and reaches in a very large marshy delta west-southwest of Pontianak. The physical characteristics of the Kapuas River are flat, wide, and with many meanders. This majestic river is one of the important rivers that feed into the South China Sea, the largest marginal sea in the world.

About 350 km from the source, near the northern shore of the river, there is the Kapuas Lake group which is connected to the river by numerous channels. These lakes include the Bekuan (area 1268 ha), Belida (600 ha), Genali (2000 ha), Keleka Tangai (756 ha), Luar (5208 ha), Pengembung (1548 ha), Sambor (673 ha), Sekawi (672 ha), Sentarum (2324 ha), Sependan (604 ha), Seriang (1412) Sumbai (800 ha), Sumpa (664), and Tekenang (1564 ha) (MacKinnon et al. 1996). The delta is west-southwest of Pontianak, the capital of the province of West Kalimantan, which lies at the equator. The delta has five arms, of which the northernmost is the widest, the *Kapuas Besar* (Big Kapuas). The largest tributary is the Melawi River, which flows into the Kapuas River from the left near the city of Sintang, about 465 km from the mouth. Other major tributaries are the Landak, Kubu, Punggur, and Sekayam rivers (MacKinnon et al. 1996).

6.4 Peatland Eco-systems of Kalimantan

In Kalimantan, trees of the family Dipterocarpaceae dominate in terms of abundance, density and biomass (Appanah and Turnbull 1998). Slik et al. (2003) found that the ten most abundant tree families after Dipterocarpaceae were Euphorbiaceae, Myrtaceae, Sapotaceae, Lauraceae, Myristicaceae, Burseraceae, Anacardiaceae, Ebenaceae, Annonaceae, and Guttiferae.

Some commercial tree species from tropical peat-swamp forests can be utilized in reforestation programmes, for example: *Shorea balangeran*, *Dyera polyphyla*, *Gonystylus bancanus*, *Alsodophan* sp., *Alstonia pneumatophora*, *Calophyllum* spp., and others. Timber from the ecosystems here is used in building boats, furniture, and homes, as well as for firewood and for charcoal by the local population (Sosef et al. 1998). Some tree species are used for medical purposes because of their antimicrobial activity and the presence of other biologically active compounds such as coumarins, xanthones, and terpenoids. Recently, the *Calophyllum* species has received considerable attention from pharmacological interests because they contain compounds that strongly inhibit HIV (*human immunodeficiency virus*) reverse transcriptase (Reyes-Chilpa et al. 1997).

Tropical peat-swamp forest areas have diminished due to forest fires, overexploitation, and development of highways, industrial, and agricultural land, and also plantation estates (Phillips 1998). Today, degraded peat-swamp forests require extensive rehabilitation and an annual supply of high-quality seedlings. The major obstacle in the rehabilitation of peat-swamp forests is the slow growth and the high mortality of seedlings in the nurseries destined for reforestation.

About 258.650 higher plant species are recorded in the world and about 13–15 % of these are found in Indonesia (about 35.000–40.000 species). At least 5575 higher plant species were recorded in Kalimantan, 71 lichen species, 376 mosses, 235 fungi and other families (Widjaja et al. 2011).

From long term monitoring it has been recorded that the Kalampangan peat swamp forest before the onset of the wildfires was dominated by: *Combretocarpus rotundatus*, *Palaquium cochlorifolium*, *Callophyllum canum*, *Ctenolophon parvifolius*, and *Cratoxylum glaucum*, but the forest has degraded due to the building of man made canals and there were wildfires in December 1997 and September 2002. After the 2002 forest fire, the dominant species were: *Co. rotundatus*, *Cratoxylum arborescens*, *Palaquium gutta*, *Shorea teysmaniana* and *Syzygium ochneocarpum*. Of 1158 individual trees, 1102 were considered to have been established after the wildfires, while the remaining 56 individuals were pre-fire trees that survived the wildfires of December 1997, most belong to: *C. canum*, *Co. rotundatus*, *Dyera lowii*, *and P. gutta* species. In September 2002 wildfires burnt out all trees within the surveyed plot for the second time, leaving only two *Dyera lowii* trees still standing and producing new leaves in August 2004, and both these trees had also survived the first wildfires. In August 2004 or about 2 years after the second series of wildfires the floor of the peat land plot (after the second series of wildfires) was covered with plants on about 15.3 % of the area, on average by 12 species of herbs and seedlings, mainly ferns *Stenochlaena palustris* (Burm.f.) Bedd. and *Blechnum orientale*, which are found in 79 % and 73 % of the observed subplots, respectively.

The Mixed dipterocarps forest of Wanariset-Samboja in 1980 was dominated by *Pholidocarpus majadum* (Arecaceae), *Anthocephalus indicus* (Rubiaceae), *Shorea laevis*, *Shorea parvifolia*, and *Dipterocarpus cornutus* (Dipterocarpaceae), and since then the forests have degraded due to three series of wildfires. After experiencing the three series of wildfires, in August 2004, the forest was still dominated by *Pholidocarpus majadum* (Arecaceae), *Macaranga gigantea* (Euphorbiaceae), *Nauclea purfurascens* (Rubiaceae), *Dipterocarpus cornutus*, *Shorea parviflora* (Dipterocarpaceae), and *Mallotus paniculatus* (Euphorbiaceae). However, in number of individuals, the top five of the most frequently found species were pioneer secondary species of: *Macaranga gigantea* (Euphorbiaceae), *Mallotus paniculatus* (Euphorbiaceae), *Ficus uncinulata* (*Moraceae*), *Vernonia arborea* (Asteraceae), and *Macaranga pruinosa* (Euphorbiaceae) (Simbolon, *unpublished data*).

From a basic study of *ecosystem services* and the *biodiversity* survey it was recorded that 12 species of timber and 14 of medicinal plants were commonly used by the local population before the 1960s. A survey among Bawan villagers showed that: (1) since 2006 only six timber trees species and four medicinal plants were easily found in the forest. The populations of *Benuas* and *Meranti*, which were the main timber species during the 1960s had decreased. The tendency was similar for medicinal plants. (2) There was a pattern of decreasing timber production for the 40 years during the period from 1960 until 2006, due to forest degradation and land conversion to farming or plantation uses. (3) From 1968 until the 1980s, three private forest concessions were operating here with wood and rattan exploitation.

6.5 Traditional Peatland Utilization Practices in Kalimantan

The Dayak people have never used deep peat for agriculture; they have only utilized the shallow peat ("*petak luwau*") near the riverbanks, where there is mainly mineral soil. Therefore, the Dayak, whose livelihood depends on shifting cultivation and especially upland rice, have concentrated settlements in upstream areas of Central Kalimantan (Limin 1994, 1999; Limin et al. 2003, 2004). Consequently, the utilization of peatland for agriculture has been very limited, historically.

The "*handel*" based farming practices have been used by the local population in peatland and wetland areas. Dimensions of the "*handel*" canals are determined by farmers based on the volume of water to enter and flood the rice fields. By heeding natural condition, such as soil fertility as indicated by the kinds of plants growing, the farmers determine the feasibility of an area to support crop cultivation. They also factor in that the soil, water, and trees have the ability to contribute to the success of the cultivation. Therefore, at the end of the cultivation activities, the local population is grateful to the Lord, earth (including soil, water, and trees), and their ancestors.

The opening of forest area for rice fields ("*ladang*") is always determined by considering the season, especially the flooding level and the length of the dry season. The farmers follow a number of rules based on experience gained by their parents and ancestors. Generally, the procedures for establishing rice fields ("*ladang*") by Dayak people are as follows.

Season Determination Based on natural observations the Dayak farmers estimate when the following are likely to occur (1) a short dry season, (2) a long dry season, (3) absence of flooding, and (4) heavy floods. Based on this they use two criteria to choose a field's location, namely, (i) low land ("*petak pamatang*" or "*petak bahu danum*"), if a long dry season is predicted, and (ii) hill area ("*petak bukit*"), if a short dry season and heavy flooding are predicted.

Several natural signs that indicate the kind of growing season likely to occur in the following year include: (1) Moon and star positions when these can be observed, (2) Roots of trees (mangrove tree) and mushrooms e.g. "*kulat danum*" which grow near or beside the river, and (3) Behavior of certain animals, e.g. "*rihun*" (*Hexagenia bilineata*, Say), ants i.e. "*semut gatal*" or "*sansaman*" (*Dolichoderus bituberculatus* Mayr), and birds i.e. elang (*Spizaetus nanus*).

Choice of Location Farmers discuss among themselves to determine the location, because at least there need to be two families as neighbors in one place where they establish their rice fields ("*ladang*"). This strategy must be followed, because the main constraint on rice production will be natural pests, e.g. pigs, deer, monkeys, rats, and birds. To confirm the choice of location there is an important natural sign of luck called "*nantuani dahiang*". The farmers determine the success of their rice fields ("*ladang*") by: (1) dreams before and after visiting the location and (2) the sound of eagles when they leave and arrive at the location. Land fertility can be determined by the color of the top layer of soil by digging of soil using a knife (“*manejeb petak*”). If the topsoil is black (fertile) for around 10–20 cm, the area can be used for rice fields (“*ladang*”). The vegetation type is another indicator of soil fertility, e.g., the presence of “*kalapapa*” (*Euodia* sp.), and “*kalanduyung*” (*Mallotus* sp.).

Land Clearing and Land Preparation Land clearing and land preparation can be divided into four stages. Shrubs or small trees are first cut down, so burning will be clean. Tree branches and twigs are chopped up and used as biomass. In the burning stage, the farmers burn all of the biomass (grass, leaves, branches, and twigs), except for large timber. The success of the burning stage determines the success of the rice production. Using traditional burning methods, the fire does not spread outside the rice fields (“*ladang*”). To ensure this the farmers make a transect along the border of the rice field (“*ladang*”) and many people join in the burning activities. Generally, the biomass is never all burnt away. Therefore, the farmers must collect the residual biomass material (“*mangakal*”) and put in a pile (“*pehun*”). This heap of biomass is disposed of by burning of the heaps (“*mamehun*”).

Planting (“*manugal*”) and Land Management The Dayak always plant rice directly with seeds, especially in dry areas. Seeds are planted in holes made by sticks, 5–7 cm in diameter. The holes must be closed with soil or ash after the seed is placed in it.

Intensive weeding is carried out, commonly in the second and third year of the rice field (“*ladang*”). In the first year, weeding is not necessary, especially for rice fields (“*ladang*”) just put into use from cleared primary forest. Weeds in the first growing year are very few owing to the previous burning of the rice fields (“*ladang*”). In the second year, weeds become very high and grow fast. Therefore, after the first or second year, farmers abandon the rice field (“*ladang*”), and move to a new area.

Traditionally, pest and disease protection involves the use of an extract of “tuba” and “*saing*”, applied using a bamboo sprayer. “Tuba” (*Vatica albiramis*) and “*saing*” are local names of plants from which a paralyzing drug is obtained.

Harvesting Generally, harvest activities are conducted in three stages. First, in the young rice harvest stage (“*nyumput parei*”) the Dayak make “*behas maru*” and “*kenta*” (looks like chips) from young rice. The maturity of the rice grain in this stage is less than 10 %, as indicated by its green color. The amount of rice harvested for “*behas maru*” is very limited, and provides food for only 1 or 2 days.

Next, the real harvest is carried out if all rice grains on 50 % of the stalks are mature, indicated by their yellow color. Finally, there is the remaining harvest (“*mamata*”), because some of the rice had not matured earlier. This activity also includes rice produced by new shoots.

Post-harvest All of the rice harvested is put in one place in buildings, close to the roof. The drying process is carried out every day by opening the roof, only closing it when it rains and at night. The rice grains are dry enough when they are easily released from the ear-stalks, and the release process is named “*mengirik*”. Before the rice is placed in the rice barn ("*lumbung*") the drying process should be carried out till the grains become firm, and unhulled paddy is separated from the ear-stalks using a huller ("*kipas*") and winnowing basket ("*penampi*"). The rice barn may be in the rice field ("*ladang*") or in the houses in the village.

Festival for Celebrating and Blessing the Harvest The last activity in the rice growing ("*ladang*") practices is the celebration and blessing of the harvest ("*pakanan batu*"). This festival signifies the appreciation of the blessings of the Lord, support of the land, and functioning of equipment. The name of the celebration comes from "*batu*", a rock for sharpening the knives ("*parang*"), and "*beliung*" *and* "*gentu*", equipment used for preparing and working in the rice fields ("*ladang*") from the beginning of cultivation.

The celebration is held after finishing all the activities for the farming in the rice field ("*ladang*"). The Dayak express thanks to the Lord, nature (land and water), and their ancestors. They believe that successful farming practices of the rice fields ("*ladang*") must involve the three components above.

Utilization of Previous Rice Fields ("*ladang*") Usually the Dayak use previously farmed rice fields ("*ladang*") for growing other annual crops, e.g. rubber, rattan, and fruits such as cempedak (*Artocarpus chempeden*), durian (*Durio zibethinus*), and rambutan (*Nephelium* sp.). Planting the particular crop depends on future plans for the area. If the farmers want to open an area for rice fields ("*ladang*") in some years, other crops are restricted to only certain places or planted in widely spaced rows. The purpose of planting in widely spaced rows is to leave space to grow rice between the rows of plants. However, if there are no plans to use an area for rice fields ("*ladang*") in the future, all crops may be planted throughout an area. In this way, many Dayak have plantation gardens (rubber, rattan, and fruits) that were established by their grandfathers and even earlier. This is a strategy to maintain the carrying capacity of the land and to claim land ownership.

The re-utilization of formerly used rice fields ("*ladang*") does not take place after fixed periods of time; rather, rice fields are re-utilized only after there is sufficient vegetation to produce enough fertilizer when burned.

Local Knowledge of Peat Utilization The utilization of peatland by the Dayak people is limited to shallow peat. Shallow peat used for growing rice by the local population in upstream areas is called "*petak luwau*", while in coastal areas it is referred to as "*lahan pasang surut*".

The characteristics of the shallow upstream peat ("*petak luwau*") are as follows: (1) Peat thickness: 20–50 cm, (2) Decomposition condition: hemic to sapric, (3) Bottom material: clay, (4) Location: near river banks or between two hills, (5) Previous vegetation: dominated by grass, (6) Water supply: rainfall and river flooding, and (7) Soil condition after planting: muddy. Rice fields in "*petak luwau*" were farmed as follows by the local population: (1) Clearing land in the first year by cutting small trees and grass. After the first year for growing rice, all of the field becomes covered with grass, one kind with very sharp blades leaving itchy spots with the local name "*garigit*", teki (*Cyperus rotundus*) and also "*kumpai*" (*Ortoxylum ridicum*), (2) burning when the biomass is totally dry, (3) removing the biomass left and re-burning at specific places or places along the border to other farmers to ensure retention of water, (4) not tilling, since it is sufficient to cut the grass and burn, (5) planting rice plants grown in a nursery for 2–3 months, rather than planting seeds directly, (6) marking the border between farmers by digging small and shallow canals to either drain water from the field or collect water as necessary, (7) getting water needed for irrigating the rice fields from the river without a connecting canal from the river to the field, since the water needed comes from river flood water, (8) using the same planting schedule as for the rice field in the "*ladang*" farming, i.e. October to March, and (9) these areas must be unaffected by sea water tidal fluctuations. According to farmers with experience of "*petak luwau*", rice production depends on the hydrological conditions. If, in the generative growth phase, the rice field is not flooded for a long time, rice yields will be high. Productivity of the local rice variety is 1.75–3.00 t/ha (Limin 1994) and for the superior rice variety, 2.4–5.6 t/ha (Noor 2001).

Shallow Peat in Coastal Areas ("*lahan pasang surut*") The utilization of peatland was common using "*handel*" farming. A "*Handel*" is a small canal excavated from a big river to the interior or dome area of a coastal peatland. The size of canals limited to a width of 2–3 m, depth 0.5–1.0 m, and length 1000–2000 m. The characteristics of this land area are as follows: (1) it is influenced by sea water tidal movements pushing river water into the rice field and flooding it daily, (2) the rice field is located up to 2000 m from the river bank, (3) the maximum peat thickness is 1.0–2.0 m, (4) the material underlying the peat is clay, (5) the decomposition status is mostly sapric, (6) nutrients are provided constantly by the twice daily tidal movements, and (7) the soil condition after planting becomes muddy. Productivity of the local rice variety is 1.90–4.00 t/ha from one source and 2.0–2.8 t/ha from another, while the superior rice variety yields 3.4–5.5 t/ha (Noor 2001).

Canal Technology Establishment of the canal system in coastal areas by the Government of Republic of Indonesia is linked to the settlement of people arriving through transmigration. An area of the Basarang Canal, called "*Anjir Basarang*", still produces rice at a high productivity (around 4–5 t/ha), and many Dayak from upstream areas moved to this area to make rice fields there. The farmers are still making "*handel*" along the "*Anjir Basarang*". Extending "*handel*" into a larger canal ("*Polder*", "*Garpu*", "*Sisir*" and "*Kolam*") for the new transmigration settlement has led to a significant decrease in rice production. After that decrease, the Dayak returned to their original villages.

6.6 History of Peatland Development in Kalimantan

The traditional "*handel*" farming has been used by the local population in peatland and wetland, and is a superior farming method for peatland farming. However, the Development Sector of Government interpreted the reasons for the success of the local population in managing their farmlands with the "*handel*" system wrongly, leading to unfortunate results. The Development Sector of the Government attempted to apply this to much larger areas drained and irrigated by means of oversized canals. The history of development of the canal system by the Development Sector of Government can be summarized as follows: (1) "*Handel*" farming (traditional ways), (2) "*Anjir*" (1880–1936 by Dutch Colonial Authorities), (3) "Polder" system (1950 by Schophyus/Dutch Expert), (4) "*Garpu*" (fork) (UGM)/"*Sisir*" (comb) system (IPB and ITB) (1969–1982), (5) "*Kolam*" (pond) system (1980s), and (6) Giant canal system (1996, Mega Rice Project).

Upto the 1960s, development of the coastal areas in central Kalimantan started from the south Kalimantan state (capital Bandjarmasin), which is located in the east of Kalimantan on the Barito river, and advanced toward the west. In this project, two types of canals, Anjir and Handil played important roles, the former connecting rivers, and the latter as narrow waterways connecting to the Anjir canals. The construction of these canals was started by the local population (mainly Banjarese) when Kalimantan was a colony of the Netherlands. Currently, Anjir consists of six canals (16–35 km long) connecting to the Barito, the Kapuasu, and the Kahayan rivers, and their tributary streams, but there is no connection on the west, the right bank of the Kahayan river. Anjir canals are now large canals allowing passage of large barges, and playing an important role in the local shipping services although it was originally excavated to develop the economy of the surrounding area, and its waterways were as narrow as 2 m. The Handil canals serve as secondary waterways with 2 m in average width and 1.5 m in depth, excavated at right-angles to the Anjir Canals at intervals of about 500 m. The lengths of the Handil canals range from 5 to 11 km. The Handil canals are currently used mainly for drainage of farmland, and each waterway of the Handil canals has its own governing body for its operating practices run by the local population. These canals were originally excavated as traffic routes for settlement and cultivation. Because many of the areas with Handil canals are developed in the alluvial soil zone, they serve as a grain growing area of Kalimantan (especially for south Kalimantan and the adjacent central Kalimantan) (Osaki and Inoue 2000).

Since the 1970s, Indonesia has implemented an immigration policy (transmigrasi) aiming to increase food production, to achieve food self-sufficiency, and to alleviate the crowded population on Java and Bali Islands. There has been migration from Java and Bali Islands to the coastal areas of central Kalimantan. The settlers migrated to areas with trunk waterways (canals) connected to rivers, but these have proved a dead end inland without connections between rivers, unlike the case of the Anjir. Many of these new settlements are located in the shallow peatlands, where the peat layers have already disappeared from most of the farmland, and sulfuric acidic soil appeared from the subsoil, making it difficult to cultivate rice (Osaki and Iwakuma 2008).

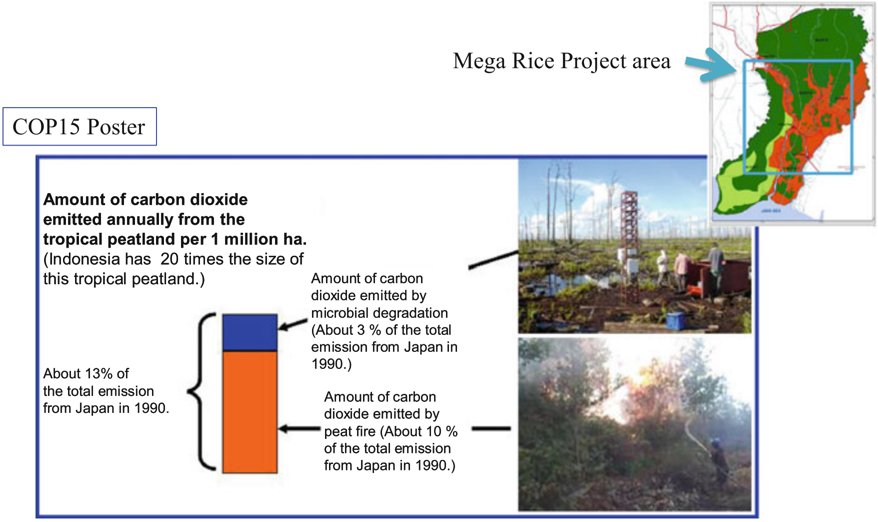
Further, in 1995 it was decided that a large scale development project (a 1 million-ha peatland development project) would be carried out overlapping the same area. The former President Republic of Indonesia, President Suharto launched the Mega Rice Project by Presidential Decree no. 85 of 1995. The purpose of this project was to turn 1 million ha of swamps in central Kalimantan into paddy fields at one stroke to improve the rice self-sufficiency of Indonesia as well as to attract new settlers. In this project, the Department of Public Works, Department of Agriculture, and Department of Immigration managed the project planning and construction of basic irrigation facilities, land reclamation, and immigration relations, respectively.

The target region was from the south 2° 15′ south latitude, and encompassed the Kapuas, the Barito, and the Pulaupetak rivers, which connect the Kapuas and the Barito (east side), and the Sebangau rivers (west side). However, the project excluded some areas including the area surrounding Kuala Kapuas, where intensive development has already been completed. The target area was divided into four blocks, A–D, bordering on each river. The actual total project area was 1,134,000 ha, and about a half of the target area is peatlands with a peat thickness over 40 cm. The classification of the land include primary forest (25 %), forests to be cleared (40 %), denuded land such as moors (25 %), and land that have been cultivated (10 %). The project was launched by a presidential order issued in 1995, the work was initiated by 1996, and the excavation work of the trunk waterways and settlement in some parts were largely completed in 1997. However, the entire project has been put on hold from May, 1998 since Indonesia faced economic difficulties. In Block A, the project progressed with the construction of the trunk waterways and the land reclamation, and 13,500 households settled in three settlements in the block between October, 1996 and March, 1998.

The project failed because of knowledge gaps, especially on ecosystem function, peatland hydrology, water management, peat subsidence, impacts of long term drainage, mechanization problems on peatland and socio-economic consequences. The failure of the project can be attributed to: (1) Problems of ecology and natural resource functions (idle land, decreasing food production, over drainage, forest and peat fires and flooding), (2) Problems of infrastructure (irrigation network not optimal, insufficiency of settlement infrastructure), and (3) Problems of socio-cultural suitability and support (high risk of failure owing to lack of harvesting technology and absence of product markets, insecurity, reorientation of transmigration jobs, lack of capability of people in peat soil management.) In more detail, the 1 million-ha peatland development project suffers from the following issues:

Deforestation Excavation for trunk waterways in 1 million ha of swamps made it easier to enter the inland forests that were not previously accessible, and accelerated large-scale deforestation. Specifically in the area between the Kahayan and the Sebangou rivers, which had been entirely undeveloped, there has been removal of large amounts of lumber along the banks of the Sebangau river.

Wild Fires in Peatland-Forests Due to the unusual droughts in 1997–1998 and the excessive drainage by the trunk waterways, wildfires broke out covering vast areas, destroying a wide range of peatlands and forests. The ignition loss (rate of decrease in weight of dry samples when heated at 700–800 °C) of tropical peat in the low, flat inland areas reaches values as large as about 98 %, showing that this peatland is composed of mostly carbon compounds, organic matter. As the volume density of tropical peat is approximately 0.1 g cm^{-3}, and the carbon content of the



Mega Rice Project area

COP15 Poster

Amount of carbon dioxide emitted annually from the tropical peatland per 1 million ha.
(Indonesia has 20 times the size of this tropical peatland.)

About 13% of the total emission from Japan in 1990.

Amount of carbon dioxide emitted by microbial degradation (About 3 % of the total emission from Japan in 1990.)

Amount of carbon dioxide emitted by peat fire (About 10 % of the total emission from Japan in 1990.)

Fig. 6.8 CO_2 emission in Mega Rice Project area estimated in 2009 (presented at COP15 of Copenhagen in 2009). Recent (2013) estimation on C emission (MtC/Mha/year) in MRP: (a) By fire: 30.5 (fire)/312 (Japan C in 1990) = 0.098 = 10 %. (b) By microorganisms: 12 (peat degradation)/312 (Japan C in 1990) = 0.038 = 4 %

peat is approximately 50 %, 1 m^3 of swamp holds about 100 kg carbon. Assuming 10,000 ha peatland of 10 cm thickness has been burnt, this amounts to 0.5 Mt carbon emitted to the atmosphere. Page et al. (2002) reported that the area affected by peat fires occurring in the region of the Mega Rice Project in central Kalimantan in 1997 is 470,000 ha, and estimated that 150–180 Mt carbon was released.

Using the data from long term measurements by Hokkaido University, we calculated the annual average CO_2 emission from 1 million ha of the farmland of the Mega Rice Project and found that it significantly exceeded the carbon reduction targets of Japan, and that it was equivalent to 3 % (by biodegradation) and 10 % (by peat fire) compared with the annual total emissions of Japan in 1990 (Fig. 6.8). Further, as the overall area of tropical peatland in Indonesia is about 20 times this area, it was reported that extremely vast amounts of carbon were emitted by the development of the tropical peatlands (White Paper on Science and Technology 2010).

Appearance of Poor Soil Peatlands in tropical regions including Indonesia have faced the problem of appearance of poor soils. If peat layers disappear due to increased drainage and use for agriculture, quartz sand (mainly from Inland peat) which has lost nourishing substances and is a strongly sulfuric acid soil (mainly from coastal peat) will be generated from the lower layers. Such poor soil makes the farming and regeneration of vegetation difficult, resulting in abandonment of the land. Also, because water with extremely high acidity is discharged, water pollution

Table 6.1 Comparation of impact on the natural peatland/forest and the disturbed peatland of Mega Rice Project area

Natural peatland/forest	Disturbed peatland in mega rice project area
High biodiversity rain forest	Low biodiversity degraded landscape
Orangutan habitat	Orangutan killed or captured
Hydrology intact	Hydrology disrupted
Climate moderator	Climate extremes frequent
Chemical filter	Purification ability lost
Major carbon store	Major carbon losses
Fire resistant	Fire prone
Access difficult	Access facilitated
Good resources for local people	Only stealing trees
Sustainable	Unsustainable
Few illegal activities	Illegal activities promoted

From Rieley (1999)

is accelerated, causing damage to fisheries. Therefore, the development of peatlands cannot avoid being accompanied by problems in the lower soil layers, and it is necessary to deal with this issue with caution as long as we know of no effective measures to counteract it. The alternative is the creation of vast denuded land areas.

Thus, this tropical peat development project caused great damage to the environment and increased poverty of local people (Muhamad and Rieley 2002). Rieley (1999) compared key natural resource attributes of natural peat swamp forest and the area developed for the Mega Rice Project, which indicate great impact on ecology, environment, and economy (Table 6.1).

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Chapter 7
Sustainable Management Model for Peatland Ecosystems in the Riau, Sumatra

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Abstract The peat swamp forest of the Riau Biosphere Reserve has been degraded at an alarming rate. The development of large areas of peatland as timber estates and palm oil plantations has caused a serious threat to the remaining peat swamp forest ecosystems. Forest and land fires have occurred annually, especially in the dry season, and the remaining peat swamp forest is subject to illegal logging activities and natural disturbances. Villagers continuously convert the remaining natural peat swamp forest into jungle rubber gardens and oil palm plantations. Four objectives of the study: (1) to clarify the current condition and ecological characteristics of the remaining peat swamp forest ecosystems, (2) reestablishing typical canopy tree species and restoring degraded peat swamp forest and peatland areas, (3) to determine a mechanism or directions for the participation of the local population; and, (4) to discuss a model for the promotion of sustainable management of peat swamp forest ecosystems in the biosphere reserve. The improvement of management of remaining peat swamp forests and rehabilitation should consider the unique ecological characteristics particularly the dominant tree species, fast growing species as well as the peat characteristics. The remaining peat swamp forests should be kept in their natural conditions in order to provide continuous ecosystem services, given their unique biodiversity characteristics, protection could be enhanced by adding incentives to local communities including monetary incentives from biodiversity and climate change mitigation funds. The promotion of a sustainable management model should be the direction of actions to conserve the remaining natural forests, regenerate and restore the degraded peat swamp forests, and create economic incentives enabling sustainability for the local community.

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Keywords Biosphere reserve • Peat swamp forest • Rehabilitation • Sustainable management model

7.1 Introduction

The main area reported in this paper is located at the Giam Siak Kecil-Bukit Batu Biosphere Reserve of Riau Province in the coastal area of the east of Sumatra Island. Riau province covers an area of about 9 Mha. The Giam Siak Biosphere Reserve has a total area of 698,663 ha and is located between 0°44′–1°11′N and 0°11′–102°10′E in two districts (Bengkalis and Siak) and one city (Dumai), in Riau Province, Sumatra Island, Indonesia. Topographically, most of the terrain is at altitudes of 0–50 m a.s.l. Having the largest peatland area in Sumatra, Riau province plays a very significant role to the local environment as well as in the global environment.

Peatlands are huge deposits of organic carbon and the alteration of their natural condition has the potential to release the stored carbon at levels that may affect the global climate. Hooijer et al. (2006) estimated that between 1997 and 2006, regional peatland fires caused average annual CO_2 emissions of 1400 Mt (with 90 % of this originated in Indonesia, mostly from Riau in Sumatra). This is equivalent to almost 8 % of all global emissions from fossil fuel burning. A further 600 Mt year^{-1} is emitted by Indonesia due to the decomposition of drained peat. Following conversion to oil palm plantations, the water is typically drained to a depth of 1 m which causes subsidence of the peat of about 10 cm year^{-1} and emitting around 130–180 tons CO_2 year^{-1} ha^{-1} (Pearce 2007).

With a total area of 22.5 million ha, Indonesia has the largest peatland area in the tropical world (Page et al. 2010), and the Sumatra share is about 8.3 million ha or 30.7 %. Almost half (4.0 million) is located in Riau Province. By having the widest tropical peat-swamp forests in Sumatera, Riau certainly has an important role to promote sustainable management of peatland, especially for adaptation and mitigation of global warming impacts. Riau will have the position to determine of deciding to the fight for carbon emission reductions in Indonesia and also in the rest of the world. Unfortunately, most of the area of Riau has been deforested and converted to agro-silvocultural lands. The rest is left as shrublands and the drying peat is prone of fires. Currently, the only remaining tropical peat swamp forest is in the form of forest blocks with relatively pristine conditions. An area in this ecosystem whose status has been upgraded and has been designated as a Biosphere Reserve by UNESCO in 2009 is the Giam Siak Kecil – Bukit Batu (GSK – BB) in Riau Province (Gunawan et al. 2012). The main purpose of this designation is for conservation and sustainable development of the area. The landscape was divided into three zones: core, buffer, and transition. The core area is set aside for forest conservation, while the buffer and transition areas are allocated for economic activities. The Biosphere Reserve is unique because 75 % of its total area is covered by peatland. The poor management and land conversion, however, has resulted in a loss of almost 300,000 ha of natural peat swamp forest from 1998 to 2002. Moreover, forest fires occurred annually, especially in the dry season, and the remaining peat swamp forest was subject to illegal logging activities and natural disturbances. A significant part of the core and buffer areas have also been converted by the villagers into jungle rubber gardens and oil palm plantations (Gunawan et al. 2012).

Until the end of 1980s, the peatswamp forest ecosystem in the Giam Siak Kecil-Bukit Batu area supported the livelihood of local communities. The timber and various non-timber forest products provide subsistence for the local community. However, during the 1990s, dramatic changes took place in the area as forest concession-holding (HPH) companies conducted large-scale commercial logging operations. At the beginning of 2000s, even more dramatic change occurred, since much of the Productive Forest was converted to Industrial Forest Estates (HTI). These changes have limited access for local communities to forest products and forest land, the system inherited from generation to generation, to support their livelihood. Such deprivation induced local community involvement in illegal logging activities that spread throughout the area during 2002–2008. Such activities were stopped by force by the government. Unfortunately, little attention has been paid to provide non-destructive but income-generating activities to locals.

One of the serious problems in sustainably managing peat swamp forests is their current state of severe degradation. Compared to relatively good forest conditions, these degraded forests need innovative rehabilitation activities. In the Biosphere Reserve, land conversion and poor management have caused the loss of around 300,000 ha of natural peat swamp forest within the past 17 years (Jarvie et al. 2003). In addition to companies, local villagers also converted lands along the Bukit Batu river basin for rubber jungle gardens. The villagers used to plant jungle rubber as markers for their land but nowadays, younger villagers extend and convert more natural forest to establish wider areas of rubber jungle cultivation. As a result of these land conversions and loss of drainage, forest fires occur annually, especially during the dry season further worsening land degradation. Meanwhile, the remaining peat swamp forest in the core area of the Biosphere Reserve is subject to illegal logging activities. Local people used to gather timber and non timber forest products such as seeds of *Palaquium sumatranum* to produce oil for cooking, white latex from *Dyera lowii* and *Payena lerii*, and bark of *Alseodaphne cratoxylon* used as mosquito repellant. Other trees provide medicine and fruits. Nowadays, however, these forest products have gradually decreased with the deforestation and degradation of the natural peat swamp forests. Moreover, the Bukit Batu forest block was declared a conservation area in 1999 by the Central Government through the Forestry Department. This move demarcated conservation area boundaries separating areas claimed by villagers where there are jungle rubber gardens. An intensified conflict between the government and villagers has emerged and without appropriate forest conservation and management measures that address the livelihoods of the villagers, conservation will not succeed and forest degradation will continue.

This paper highlight the following: (1) to clarify the current condition and ecological characteristics of the remaining peat swamp forests ecosystem, (2) reestablishing typical canopy tree species and restoring degraded peat swamp forest and peatland areas, (3) to determine a mechanism or directions for local community participation; and, (4) to discuss a model for the promotion of sustainable management of peat swamp forest ecosystems in the biosphere reserve.

7.2 Characteristics of Mixed Peatland Forest (MPF) and Bintangur Forest (BF)

Table 7.1 details the Mixed Peatland Forest (MPF) and Bintangur Forest (BF), their distinct dominant species, floristic composition, diversity, and local environmental characteristics. These results listed here will have important implications for future

Table 7.1 Forest types and their local environmental characteristics

Sampling plot	Species	Local environmental characteristics	Forest type
Plot 1	*Diospyros hermaphroditica* *Calophyllum lowii* *Eugenia paludosa* *Shorea* spp. *Durio acutifolius*	Much water on the forest floor, 50–100 m from river, peat depth >6 m, *Pandanus* spp. Present	MPF
Plot 2	*Eugenia paludosa* *Shorea teysmanniana* *Diospyros hermaphroditica* *Calophyllum lowii* *Durio acutifolius*	100–150 m from the river, peat depth >6 m, dense *Pandanus* spp.	MPF
Plot 3	*Palaquium sumatranum* *Diospyros hermaphroditica* *Mezzetia parvifolia* *Shorea teysmanniana* *Mangifera longipetiolata*	Little or no surface water, relatively flat micro- topography, 50–100 m from the river, peat depth >6 m, asam paya (*Salacca conferta*) present	MPF
Plot 4	*Eugenia paludosa* *Madhuca motleyana* *Diospyros hermaphroditica* *Xylopia havilandii* *Palaquium sumatranum*	Ten years after selective logging, 150–1000 m from the river, peat depth >6.5 m. In the rainy season, water present 150 m from the river, asam paya (*Salacca conferta*) present	MPF
Plot 5	*Calophyllum lowii* *Shorea teysmanniana* *Eugenia paludosa* *Tetractomia tetrandum* *Mangifera longipetiolata*	Wind and indirect fire disturbance, surrounded by drainage canals and pulpwood plantation, approximately 23 km from the river, peat depth >10 m, *Calophyllum lowii* the dominant species	BF
Plot 6	*Calophyllum lowii* *Shorea teysmanniana* *Plantonela obovata* *Mangifera griffithii* *Eugenia paludosa*	Approximately 23 km from the river, wind and indirect fire disturbance, surrounded by drainage canals and pulpwood plantations, peat depth >10 m	BF

Table 7.2 Regeneration performance of the six main upper-story peat swamp forest trees

		Number of stems (DBH <10 cm)									
		Plot 4[a]			Plot 5[b]					Plot 6[c]	
		Sub-plot			Sub-plot					Sub-plot	
Species	Family	1	2	3	4	5	6	7	8	9	10
Calophyllum lowii	Clusiaceae	3	0	0	50	14	51	16	24	0	1
Shorea teysmanniana	Dipterocarpaceae	1	1	0	1	0	1	2	0	0	0
Palaquium sumatranum	Sapotaceae	0	54	24	0	0	0	0	0	0	2
Shorea uliginosa	Dipterocarpaceae	0	0	0	0	3	0	0	0	0	0
Tetramerista glabra	Theaceae	0	0	0	6	0	7	0	0	0	0
Gonystylus bancanus	Thymelaeaceae	0	1	5	0	0	6	0	0	0	0

[a]Logged-over forest
[b]Wind-disturbed forest
[c]Burnt forest

Table 7.3 Regeneration performance of the six main upper-story peat swamp forest trees after 1 year

		Number of stems (DBH <10 cm)									
		Plot 4[a]			Plot 5[b]					Plot 6[c]	
		]Sub-plot			Sub-plot					Sub-plot	
Species	Family	1	2	3	4	5	6	7	8	9	10
Calophyllum lowii	Clusiaceae	1	0	0	106	26	70	29	44	0	3
Shorea teysmanniana	Dipterocarpaceae	1	5	0	1	0	1	2	0	0	0
Palaquium sumatranum	Sapotaceae	0	44	19	0	0	0	0	0	0	2
Shorea uliginosa	Dipterocarpaceae	0	1	0	0	3	0	0	0	0	0
Tetramerista glabra	Theaceae	0	0	0	6	0	7	0	0	0	0
Gonystylus bancanus	Thymelaeaceae	0	2	5	0	0	6	0	0	0	0

[a]Logged-over forest
[b]Wind-disturbed forest
[c]Burnt forest

restoration and conservation efforts – on what species to plant and how to consider the natural succession. We used the Important Value (IV) index. The species with the highest IV index were considered to be the most "dominant" in a plot.

The regeneration performance of the six main upper-storey tree species was also examined. *Calophyllum lowii* has the best regeneration performance in the wind-disturbed forest plots, but the performance is poorer in the logged-over and burnt forest plots. It is not regenerated in sub-plots 2 and 3 in the logged-over forest or in sub-plot 9 of the burnt forest (in Table 7.2).

One year after the monitoring, the composition and regeneration performance had not changed significantly (Table 7.3). The number of stems of the *Calophyllum lowii* and *Palaquium sumatranum* had changed whereas both of these species differ in their regeneration performance. *Callophylum lowii* show increase number of stems. In the other hand *Palaquium sumatranum* decrease in regeneration performance that showed in lower of number of stems than in *Callophylum sumatranum*. Other typical canopy tree species show limited and even absence of regeneration in some of the sampling plots.

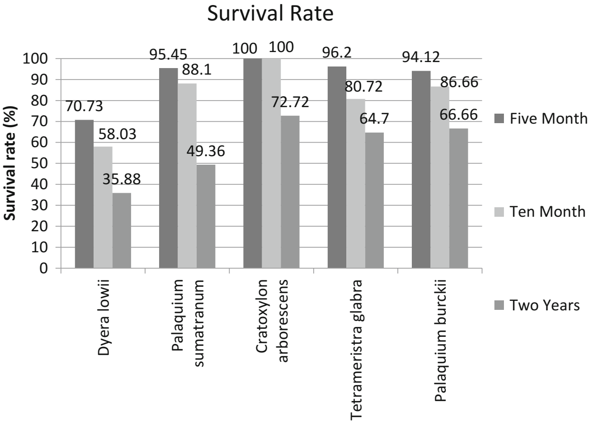

Fig. 7.1 Survival rates of seedling

For restoration experiments in logged over forests show in general, survival rates show a decreasing trend in all planted tree species. The survival rates of the seedlings after 5, 10 months, and 2 years of monitoring are presented in Fig. 7.1. The survival rate within 5 months ranges from 70.73 to 100 %, at 10 months after planted ranging from 58.03 to 100 %, and it drastically decreased 2 years after planting to a range of 35.88–66.66 %. The overall higher survival rate of tree species was *Cratoxylon arborescens*, *Palaquium burckii*, and *Tetramerista glabra* with ranges from 68.02 to 96.8 %. The lowest survival was for *Dyera lowii* with 35.88 %.

As shown in the results, the survival rate of peat swamp forest species during 5 and 10 months and 2 years of monitoring varies between species. Species with high survival rates (68.02–96.8 %) include *Cratoxylon arborescens*, *Palaquium burckii*, and *Tetramerista glabra* in both hill and normal planting methods using Gap experiment. A species with a low survival rate is *Dyera lowii*. Treatment to create more open gaps is important for improving survival and growth of this species.

7.3 Biomass, Carbon Content, and Carbon Sequestration in Mixed Peatland Forest

Biomass was estimated form allometric equation. The total aboveground biomass in each plot was also estimated using an allometric equation developed by Brown (1997). The Allometric equation was developed for tropical forests using data collected by several authors from different tropical countries and at different times. The allometric equation is:

$$Y = \exp(-2.134 + 2.53 * \ln(D)) \quad (7.1)$$

Where Y = total above-ground biomass in kg/tree; and D = diameter at breast height (DBH in cm). The above ground carbon storage was calculated by assuming that the carbon storage is 0.47 of the total above ground biomass (Brown and Lugo 1982; Brown et al. 1989; Houghton et al. 1997). For the quantification of carbon sequestration during a period of time, the most common method is based on the amount of carbon fixed in the biomass at a specific time, usually the end of a rotation period. This was referred to here as "carbon fixed" and it can be exemplified as the amount of carbon stored in planted trees at a certain time **t** after planting.

Total amounts of aboveground biomass and carbon accumulation were increasing during the 2 years of rehabilitation in logged over mixed peatland forest (Fig. 7.2). Biomass increased from 2.94 to 32.51 Kg ha^{-1}, and carbon storage increased from 1.55 to 16.28 kg C ha^{-1} in the experimental sites. Carbon sequestered by vegetation rehabilitation increased from 3.77 to 14.07 Kg C ha^{-1}.

Increases in biomass, carbon storage, and carbon sequestration in forested areas by natural regeneration processes in logged over mixed peatland forest are shown in Fig. 7.3. The forest recovery through natural processes contributed in sequestrating carbon of 0.71 Mg C ha^{-1} within 2 years of monitoring. There was an increase in biomass from 3.88 to 5.3 Mg ha^{-1} and carbon storage of 1.94–2.65 Mg ha^{-1}.

In this research, the effect of vegetation rehabilitation and natural regeneration processes on the total accumulation of carbon storage was counted. Our results

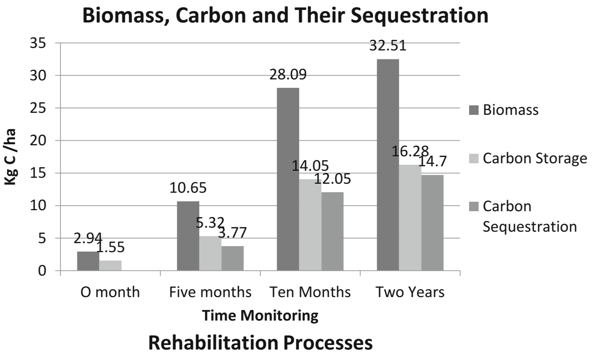

Fig. 7.2 Carbon sequestration in rehabilitation plots

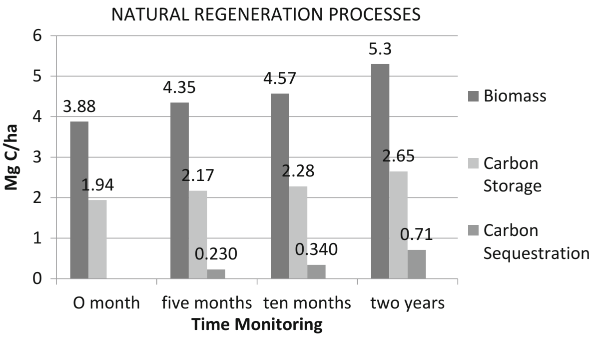

Fig. 7.3 Carbon sequestration in forest regeneration naturally

showed that the total amount of carbon sequestration was 0.72 C Mg ha^{-1} in both the experimental sites and forested areas which indicates that the combination of forest recovery by vegetation rehabilitation and natural regeneration processes have the potential to enhance carbon storage among the various forest rehabilitation efforts that may be contemplated.

Mixed Peat Swamp Forest and Bintangur Forest – and details their distinct dominant species, floristic composition, diversity, and local environment characteristics. These data could have important implications for future restoration, or conservation efforts – on what species to plant and how considering their natural succession. Generally, it is shown that the remaining natural peat swamp forests store huge above and below carbon volumes, even higher than in other peat swamp forests. The results highlight the uniqueness of the Biosphere Reserve and especially its importance in the worldwide efforts to reduce forest carbon emissions.

7.4 Sustainable Management Model of Peatland Ecosystem

We propose three ways to improve the current status: conservation and stopping further forest conversion, natural regeneration, and rehabilitation. The stopping of further forest conversion implies the need to designate boundaries and to enforce them. There is a conflict between the government and some villagers who wanted to utilize designated conservation areas. This conflict needs to be resolved through the preparation of a management plan that addresses both the integrity of the forest as well as the livelihoods of the villagers. Natural regeneration is an option for a faster recovery of forest vegetation after any disturbance. In the case of canopy species that could not be expected to undergo natural regeneration, some form of human-assisted regeneration is needed. Rehabilitation can target the areas that could undergo natural regeneration only with difficulty and would need human intervention such as planting.

We illustrate a logical framework for the activities conducted as well as the direction of actions to promote sustainable management of Giam Siak Kecil-Bukit Batu Biosphere Reserve (Fig. 7.4).

From the Fig. 7.4 the first level shows the different land cover types as well as their different levels of degradation without intervention, the natural forests could gradually convert into degraded or waste lands – as indicated by the dotted lines). As we have identified in each of the discussion sections above, these different land covers would need different management strategies. Ideally, the remaining natural forests should be conserved, the secondary forests allowed to regenerate and the degraded peat lands rehabilitated back into natural forests planted with endemic and economically valuable tree species, through agroforestry, or even as agriculture or plantation areas. Implementing these management strategies, however, is not easy. The strategies employed have to be based on paying attention to the reality that there are already villagers in the area who are dependent on the peat swamp forests for

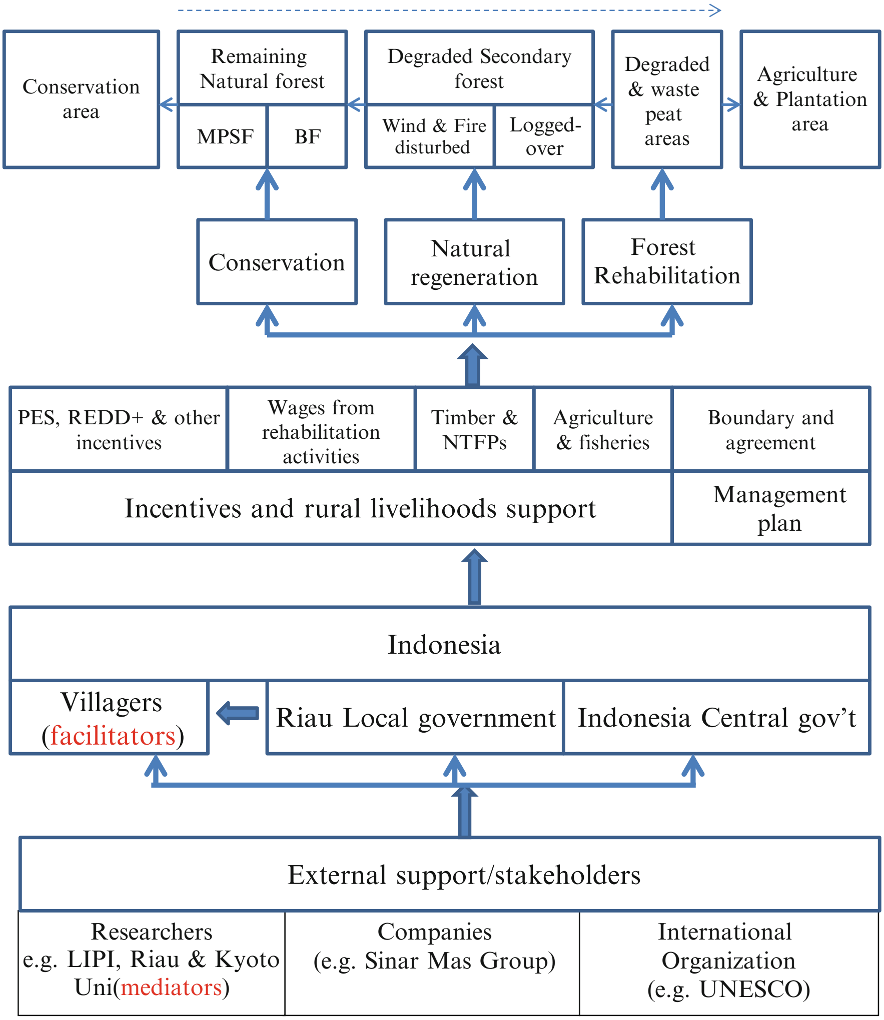

Fig. 7.4 A sustainable management model for the Biosphere Reserve

their livelihoods. Strategies, therefore, will need the participation of the villagers. In particular, an "interactive participation" by the local community is vital and here the villagers must have important roles in the decision-making and as well as they should be able to take a leading role in the activities. This will only be possible when strategies address not just the conservation or rehabilitation of the peat swamp forests but is especially addressing the needs of the livelihoods of the people living there.

We have made such consideration early in our rehabilitation activities with the planted tree species which have both economic value (i.e. timber and non-timber forest products) and ecosystem service value such as *Dyera lowii*, *Tetramerista glabra*, *Callophylum lowii*, *Palaquium sumatranum*, *Palaquium burckii*, *and Cratoxylon arborescens*. Placing stress on their potential to generate income from carbon storage and other ecosystem services, these trees can be cut and sold on the timber market, both on the international or the domestic market especially considering that there is a decreasing supply in timber given the increasing demand for building materials, furniture use or handicraft use because of strict controls on logging. Moreover, various non-timber forest products are provided by these different species such as the seeds of *Palaquium sumatranum* to produce oil for cooking, white latex from *Dyera lowii* and *Payena lerii*, and the bark of *Alseodaphne ceratoxylon* to be used as mosquito repellant.

It would be ideal if the above economically important but endemic tree species could be planted by the villagers themselves. However, the planting of these species is limited by the presence of other alternative tree crops such as rubber and oil palms. The wider planting of these species should then be supplemented by incentives in cash (i.e. wages paid for rehabilitation work) or in kind through the provision of other alternative livelihood strategies, or a combination of these. Financial incentives are especially important to induce people participation in rehabilitation efforts, in addition to the provision of information and technical assistance to communities about the species suitable for planting, their requirements in the restoration methods, and their market values.

As mentioned above, there is a current conflict between the villagers and the government since the declaration of the area into a conservation forests as access is now limited. A possible solution is the preparation of a development plan that is agreed upon by both villagers and local government wherein conservation, agroforest (rehabilitation with economic tree species and tree crops), and agricultural areas are designated. However, as was mentioned earlier, the villagers would also need to receive incentives not just from the rehabilitation but also from the forest conservation. There is also the possibility of some form of payment mechanism for the ecological services from peat swamp forests. These include funding mechanisms such as various Payments for Ecosystem Services (PES). In particular, we have discussed the possibility of tapping the newly proposed, although still being negotiated, the Reducing Emission from Forest Degradation and Deforestation (REDD+) mechanism.

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Part II
Peat Formation and It's Property

Mitsuru Osaki and Nobuyuki Tsuji

Chapter 8
Tropical Peat Formation

Masayuki Takada, Sawahiko Shimada, and Hidenori Takahashi

Abstract A summary of the peat formation process, and the classification and characterization of the peatlands in Southeast Asia, particularly those in Kalimantan in Indonesia was undertaken through a review of published studies. Based upon the location, mode of formation, and age of the peat deposits, ombrotrophic and eutrophic peatlands, or topogenous and ombrogenous peatlands are developed by the accumulation of plant debris in coastal and sub-coastal areas, inland areas and high altitude areas. In the areas along the coastline, the youngest peat formation started to occur between 3500 and 6000 years BP in response to the wet conditions generated by rising sea levels at the end of the last glacial period. In comparison, peat in inland peatland areas began to form much earlier, more than 20,000 years BP during the late Pleistocene era. Some tropical peatlands are likely to have been involved in the global carbon cycle before the initiation of boreal and temperate peatlands. One of the characteristics of the peatlands in Southeast Asia is the formation of a convex-shaped dome that formed beyond the extent of river floodwater and under rain-dependent conditions. This is known as ombrogenous peat.

Keywords Tropical peat • Peat formation • Classification • Dome-shaped peat

8.1 Introduction

According to Anderson (1964), Rieley and Page (2005), and Page et al. (2006), the first record of tropical peat in Southeast Asia was made by Tenison-Woods (1885) and was subsequently followed by Molengraaff (1900), Beccari (1904),

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and Potonie and Koorders (1909). Molengraaff (1900) was the first to explicitly report the existence of raised bogs in tropical south-east Asia (Dommain et al. 2010), and Potonie and Koorders (1909) drew attention to the deep peat of Sumatra (Anderson 1964). Subsequently fundamental studies of peats and peaty swamp forests in Kalimantan and Sumatra were undertaken by Polak (1933a, b, 1948) and Endert (1920). In these studies, Polak gave a detailed account of a raised peat bog and recognized two types of peats (ombrogenous and topogenous) and Endert described an oligotrophic forest in wet hollows between sandy terraces (Bruenig 1990). Moreover, Richards (1952) and van Steenis (1958) stated that topogenous peats extend over larger areas than do ombrogenous peats, but no comparative data are available (Anderson 1964). But it is generally said that most of the peatland is ombrogenous, and topogenous peat only exists in a narrow strip along the courses of major rivers in Southeast Asia.

Thereafter, many studies have been undertaken on the peat formation process and have classified and characterized the different peatlands. In this review, the research performed in these studies is summarized based on published papers and documents.

It is estimated that total peatland area in Southeast Asia is 24.7 million ha comprising 56 % of global total tropical peatland (Page et al. 2011). Indonesia, with 84 % of Southeast Asian peatland area, has the fourth-largest area of peatland in the world, after Canada, Russia, and the USA. Indonesia's peatlands cover 13 % of the country's total land area (Radjagukuk 1997; Page et al. 2011). Vast peat swamps cover 6.3 million ha of Indonesian Borneo (Kalimantan) (Soepraptohardjo and Driessen 1976). Survey results indicate that the peat soils of Indonesia have a thicknesses ranging from 0.4 to 20 m, and that approximately 50 % of these peatlands have a thickness of over 2 m (Radjagukuk 1997). Almost all of the Indonesian peats are ombrogenous, with topogenous peat occurring in only in a few isolated locations (Radjagukuk 1997).

8.2 Why Does Peat Occur in Tropical Areas?

Generally, lowland tropical areas are characterized by constantly high temperatures throughout the year (Anderson 1983). This promotes the activity of microorganisms. The formation of peat occurs because of two major constraints on microbial decomposition.

Firstly, water balance is critical for peatland maintenance and growth. In the humid tropics, precipitation exceeds evaporation and may frequently be more than 3000 mm per year, creating constantly wet conditions at the soil surface (Anderson 1983; Page et al. 2006). This water-saturated environment reduces and almost prevents organic decomposition as a result of oxygen deficiency, enabling peat to form and accumulate (Bruenig 1990; Radjagukuk 1997; Rieley et al. 1996a).

Secondly, chemical conditions can arise in the soil that are unfavourable and in some cases directly toxic to microorganisms, such as high levels of sulphur compounds in mangrove clay, free aluminum in upland clay, and high acidity and high levels of polyphenols and fulvo-acids in plant litter and humus (Bruenig 1990).

In addition to these factors, Radjagukuk (1997) described a combination of other conditions, including suitable topography, equatorial rainfall, and low silt content in rivers, which have resulted in the development of tropical peats in a restricted zone near the equator.

The accumulation of peat is a therefore a result of the higher rate of the addition of organic materials than the rate of decomposition. Most tropical peat is located at low altitudes where rain forest vegetation grows on a thick mass of organic matter that has accumulated over thousands of years, to form deposits that are up to 20 m thick (Anderson 1983; Radjagukuk 1997; Page et al. 2006).

8.3 The Formation Process

The formation process has been documented for coastal and sub-coastal plain areas and inland high altitude areas in many studies. Most of the extensive peatlands along the coastlines of Southeast Asia originated during the middle Holocene era (Page et al. 2004; Rieley et al. 2008). The accumulation of this peat commenced around 3500–6000 cal years BP (Anderson and Muller 1975; Staub and Esterle 1994; Page et al. 2004; Rieley et al. 2008). During the last glacial period, a large amount of water was fixed in glaciers and in thick polar ice caps. During post-glacial times, starting 10,000 years ago, this ice melted and caused the sea level to rise. In Indonesia, this initially rapid rise eventually almost stopped and in places, large coastal plains were formed, which consisted of fluvial and marine sediments (Subagjo and Driessen 1972; Wilford 1962). It has been shown from carbon-14 dating that the sea reached its present level some 5400 years ago (Anderson 1964).

The origin of peat, especially in the coastal and sub-coastal lowlands of Indonesia, is related not only to past and present climatic conditions, but also to fluctuations in sea level, coastal building, and uplift processes (Rieley et al. 1996a). Peat formation probably commenced in response to the wet conditions at the end of the last glacial period (Rieley et al. 1996a).

Subagjo and Driessen (1972) explained the origin of the peat formation processes as follows. The coastal plains are traversed by a number of rivers with low and generally heavily textured levees that rise slightly above the almost permanently waterlogged coastal plain. Under wet conditions, a dense vegetation of reeds and sedges developed in the natural depressions of the plain, and partly humidified mesotrophic or eutrophic topogenous peatlands were formed through the accumulation of plant debris. With the increasing thickness of peat, the inflow of comparatively mineral-rich river water became less frequent and the soil moisture regime became significantly drier with the peat growing above the groundwater level. The vegetation adapted to the changed conditions, resulting in a gradual expansion of marsh forest vegetation. With time, this forest became increasingly more extensive until it finally covered large areas of peat, which had, by this time, grown well above the original groundwater level. Despite the resulting relatively deep water table, a considerable amount of the organic debris generated from the forest did not decompose, as a permanently moist environment was maintained by the closed canopy of the forest.

Anderson (1983) described the environmental basis of peat formation in the coastal and sub-coastal areas of Indonesia as follows. Fine-textured weathered materials were transported from the mountain ranges in Sumatra and Borneo, and deposited on the coast, to form the margins of the Sunda Shelf. The vast alluvial deposits in the river valleys and deltas created conditions for the development of peat swamps.

Radjagukuk (1997) described ombrogenous peat formation in Indonesia as follows. The ombrogenous peat in the coastal areas of Indonesia started to form between 4000 and 5000 years BP, mainly from the accumulation of woody materials. Successive generations of forest survived merely through a nutrient-recycling mechanism and through the adaptation of the vegetation to gradually falling fertility levels. Initially, topogenous peat was formed owing to the anaerobic conditions maintained by the flooding of rivers. In the shallow depressions between the large rivers, the accumulation of peat continued, eventually forming dome-shaped ombrogenous bogs.

In the interior parts of Kalimantan peat started to form in the late Pleistocene era (40,000–23,000 ^{14}C years BP) much earlier than in today's coastal and riverine basin peatlands because sea level was about 5 m higher. There is also evidence of rapid peat accumulation in the early Holocene era (10,000–7000 ^{14}C years BP) from other peat deposits within Borneo (Rieley et al. 2008; Anshari et al. 2001, 2004; Page et al. 2004; Neuzil 1997; Sieffermann et al. 1988). Page et al. (2004) clarified that organic matter accumulation in an inland peatland in Kalimantan started around 26,000 cal years BP as the oldest record for lowland ombrotrophic peat formation in Southeast Asia. These inland peatlands would have been involved in the global carbon cycle long before the boreal and temperate peatlands, since the latter did not begin to accumulate until around 7000–8000 ^{14}C years BP (Maltby and Proctor 1996; Rieley et al. 2008). All types of peatland subsequently merged to form the vast peat-covered landscapes that extend over thousands of square kilometres in present day in Southeast Asia (Rieley et al. 1996a).

8.4 Classification

Anderson (1961) defined the two main types of peatland in Indonesia and Malaysia as fresh-water swamp and true peat swamp. The former is flooded regularly by river water in the wet season, forms topogenous peat with a muck soil, and has a pH generally higher than 4.0 and a loss on ignition below 75 %. The peat formed by the latter is ombrogenous, is not subject to river flooding, and has a pH less than 4.0, an ignition loss exceeding 75 % and a markedly convex surface (Anderson 1983).

In Indonesia, freshwater swamps receive an influx of nutrients via flooding. This sustains the forest biomass, in which there is only a shallow accumulation of organic material (<30 cm). The true peat swamps occupy the interior region away from the rivers, where the water and nutrient supply is derived only from aerosols, dust, and rain. In these locations, peat can accumulate to a considerable depth (Rieley et al. 1996a).

In addition, Andriesse (1974) subdivided the true peat swamps into valley peat swamps and basin peat swamps.

Bruenig (1990) recognized three types of peatlands: the two oligotrophic forested wetlands in the lowlands, described by Anderson (1983), and the montane zone. Oligotrophic forested wetlands occur in Borneo, Sumatra, and parts of New Guinea (Bruenig 1990).

Similarly, Rieley et al. (1992, 1996a, b) and Page et al. (1999, 2006) also recognized three types of lowland ombrogenous peatlands in Indonesia based upon their location, mode of formation, and the maximum age of the peat deposits. These are coastal peatlands; basin or valley peatlands; and high, interior, or watershed peatlands. Coastal peatlands occur along the maritime fringe and in deltaic areas, where they have developed from mangrove swamp, over marine sediments of clay and silt at, or only slightly above, sea level (1–2 m asl). Basin or valley peatlands occur in sub-coastal locations along river valleys at slightly higher altitudes than coastal peatlands (5–15 m asl). High, interior or watershed peatlands have only been described to occur in Central Kalimantan at low-altitude watershed locations (10–30 m asl) between major rivers extending up to 200 km, or more, inland from the coast (Page et al. 2006).

8.5 Properties

8.5.1 Convex-Shaped Dome

One of the characteristics of the peatlands in Southeast Asia is the formation of a convex-shaped dome. Polak (1933b) described the domed, biconvex shape and the ombrotrophic nature of lowland tropical peatlands. Anderson (1964) measured the topography of the dome and clarified the dome shape from a datum level and the depth of peat in Borneo (mainly Sarawak and Brunei). He observed that the structure of tropical peat swamps was similar to that of raised bogs in the temperate zone. Vast dome-shaped formations of oligotrophic (nutrient poor) peat have developed under rain-dependent conditions and are referred to as ombrogenous peat. They are located beyond the extent of river floods (Subagjo and Driessen 1972; Bruenig 1990).

The convex shape of the surface causes rapid radial drainage and prevents flooding (Neuzil and Supardi 1993). The steep marginal zone is not evident on the inland peat swamps of Central Kalimantan, where the gradients are much less (7.6 m in 5500 m, equivalent to 1 in 724) and the landscape appears to be virtually flat (Page

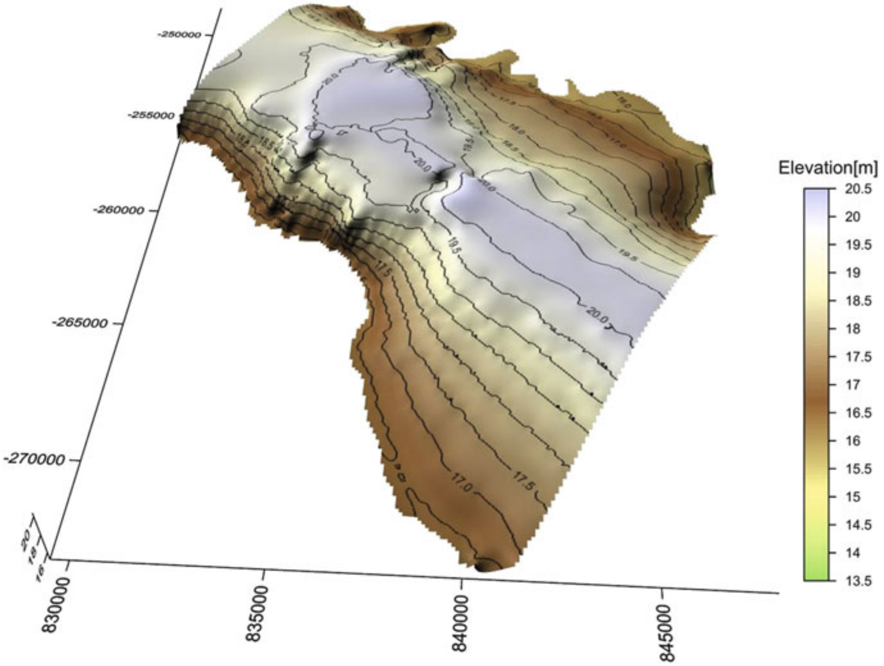

Fig. 8.1 Birds view of ground surface on the dome shape of peat, around the Kalampangan and Taruna Canals in Central Kalimantan, estimated by the elevation model produced from a topographical survey (Koizumi pers com)

et al. 2006). Dommain et al. (2010) revealed the hydrological properties of the dome and explained how water is retained in it. In intact tropical peat swamp domes, water is stored in depressions in the peat surface, between hummocks and buttress roots. This surface water store is analogous to the water stored in the loose upper layer of peat and vegetation in Sphagnum bogs (Dommain et al. 2010).

A digital elevation model of the dome shape in the Central Kalimantan peatlands produced from a topographical survey of the region around the Kalampangan and Taruna Canals, is shown in Fig. 8.1 (Koizumi pers com)[1].

Although it is within the same tropical zone, dome topography is not observed in the peatlands of Amazonia in South America, unlike Southeast Asia. Junk (1983) stated that the decomposition of organic material would be expected to proceed much more rapidly than the high production rate of aquatic and semi-aquatic macrophytes. Hueck (1966) referred to the importance of high temperature in decomposition in the region. Junk (1983) referred to the structures of the cell wall of aquatic and semi-aquatic macrophytes in relation to rapid decomposition. He explained that aquatic larvae occur in enormous numbers in areas with a white-water influence, but also colonize black- and clear-water areas in smaller numbers, and are very important for the decomposition processes in Amazonian waters.

The deposition of organic material and peat dome formation are inhibited to a large extent by the large annual water level fluctuations and the length of the associated dry phase, which accelerates decomposition. These factors were assumed to cause rapid decomposition that prevented the accumulation of peat under the high temperature of Amazonia (Junk 1983). In comparison with Amazonia, Southeast Asia relatively has less fluctuations of precipitation (Junk 1983; Bruenig 1990). However, it is estimated that dome development may be disturbed if the dry season is extended due to climate change.

8.5.2 Other Properties

In Southeast Asia, peatland vegetation was comprised mainly of trees rather than the mosses and dwarf shrubs known to be present in the raised bogs of the temperate zone (e.g. Molengraaff 1900).

The important characteristics of peatlands in Borneo are that they contain kerapah wetlands (a native name), which distinguishes them from the humid, deltaic peat-swamps and high-altitude peat soils, and from the dry Spodosols and related soils, which may accumulate fibrous peaty material on the surface and develop on non-calcareous substrates that are known as kerangas (Bruenig 1968, 1974, 1990). Kerapah is a type of heath forest (kerangas) that develops under waterlogged conditions on mineral soils and corresponds to Winkler's Heidewald (Bruenig 1990; Page et al. 2006). It is generally said that Kerapah forest is characteristic of the central peatland regions in Sarawak and Brunei but this has not been described for Kalimantan or Sumatra. Kerapah is not endemic in Borneo, and similar types of peatlands are distributed in the Malay Peninsula and on Hainan Island (Bruenig 1990).

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[1] This elevation model is based on static GPS survey point data and it was necessary to expand the data to the entire study area for modeling. The elevation data along the Kalampangan and Taruna Canals were interpolated using Airborne Laser Scanning data (provided by Kalteng Consultants, 2009), and the data for the remaining areas were estimated and extrapolated using SRTM (Shuttle Radar Topography Mission) data.

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Chapter 9
Tropical Peat and Peatland Definition in Indonesia

Mitsuru Osaki, Kazuyo Hirose, Hendrik Segah, and Farhan Helmy

Abstract Tropical peatland ecosystems consider as a key roles not only in the storage of carbon in forests and peat, but also in controlling water resources and in preserving bio-resources and biodiversity. This assessment on peatland definition is intended to adjust existing definition of peatland and further work to improve the existing peatland map that will help identify the gaps amongst various peatland definition. This chapter consists of part, which provides an overview of the importance of peatland both at global and national context, including variety of assessment of peatland contribution to GHG emission.

Based on available references, there are two broad peatland definitions: Authoritative and Scientific. In Indonesia, currently there are three Ministries operate under their own authoritative designations of peatland. The Ministry of Environment of Indonesia defines 'peat' as a plant residue formed naturally through long-term decomposition processes, accumulating in swamp areas or static reservoirs. The Ministry of Agriculture defines 'peat' as soil formed as a result of organic matter accumulation with a naturally occurring composition of greater than 65 % from the decaying vegetation growing on it, whose decomposition is slowed down by anaerobic and wet conditions. Meanwhile, the Ministry of Forestry defines 'peat' as organic matter residue accumulating over a long period of time.

Several scientific definitions have been introduced and acknowledged by scientific communities, including those developed. These definitions are based on field observations and analyses of peat soil properties. Key elements include physical

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peat properties, such as degree of decomposition (humification), bulk density, water content, porosity and others, and chemical properties, such as carbon content, ash content, pH, and C/N ratio.

Finally, Proposed Peatland Definition of Indonesia is described referencing POLICY MEMO: PEATLAND DEFINITION FROM UNCERTAINTY TO CERTAINTY (Agus Purnomo et al. 2012).

Keywords Carbon flux • IPCC guideline • MRV • National greenhouse gas inventories • 2013 Wetlands Supplement

9.1 Introduction

"*2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*: *Wetlands – Methodological Guidance on Lands with Wet and Drained Soils*, *and Constructed Wetlands for Wastewater Treatment* – (*Wetlands Supplement*)" provides new and supplementary guidance on estimating and reporting greenhouse gas emissions and removals from lands with organic soils and wet and drained mineral soils in Wetlands (Wetland 2013 Supplement 2013). The "*2013 Wetlands Supplement*" proposes to use – in addition to the dry mineral soils covered by the *2006 IPCC Guidelines* – a division into four soil subcategories; all with a coastal and inland subdivision where appropriate: (1) drained mineral soil, (2) wet mineral soil, (3) wet organic soil, and (4) drained organic soil. Therefore, peat in "*2013 Wetlands Supplement*" is categorized into (3) wet organic soil and (4) drained organic soil. However, in 2013 *Wetlands Supplement*, as the concept of 'wetland' is not defined precisely, other articulations of the concept of 'wetland' are possible, for example that used by the Ramsar Convention (2013).

An organic soil is a soil with a high concentration of organic matter. The "*2013 Wetlands Supplement*" follows the definition of organic soils in the *2006 IPCC Guidelines*. Organic soils are identified on the basis of criteria 1 and 2, or 1 and 3 listed below (FAO 1998): (1) Thickness of organic horizon greater than or equal to 10 cm. A horizon of less than 20 cm must have 12 % or more organic carbon when mixed to a depth of 20 cm, (2) Soils that are never saturated with water for more than a few days must contain more than 20 % organic carbon by weight (i.e., about 35 % organic matter), and (3) Soils are subject to water saturation episodes and has either: (a) At least 12 % organic carbon by weight (i.e., about 20 % organic matter) if the soil has no clay; or (b) At least 18 % organic carbon by weight (i.e., about 30 % organic matter) if the soil has 60 % or more clay; or (c) An intermediate proportional amount of organic carbon for intermediate amounts of clay. The *2006 IPCC Guidelines* largely follow the definition of Histosols by the Food and Agriculture Organization (FAO), but have omitted the thickness criterion from the FAO definition to allow for often historically determined, country-specific definitions of organic soils.

There are no IPCC definitions for peat and peatland. Definitions of peatland and peat soil differ between countries in relation to the thickness of the peat layer required to be determined as a peatland or a peat soil. In addition, the definition of peat varies among countries and disciplines, especially with respect to the minimum percentage of organic matter the material is required to contain (Joosten and Clarke 2002). In the *Wetlands Supplement* the concept of peatland is considered to be included in '(land with) organic soil'. Based on the definition by Ramsar Convention, peatland are ecosystems with a peat deposit that may currently support vegetation that is peat-forming, may not, or may lack vegetation entirely. Peat is dead and partially decomposed plant remains that have accumulated in situ under waterlogged conditions. It is understood in this guidance that the term "peatland" is inclusive of active peatland ("mire"). An active peatland ("mire") is a peatland on which peat is currently forming and accumulating. All active peatland ("mires") are peatland, but peatland that are no longer accumulating peat would not be considered as active peatland ("mires"). The presence of peat or vegetation capable of forming peat is the key characteristic of peatland.

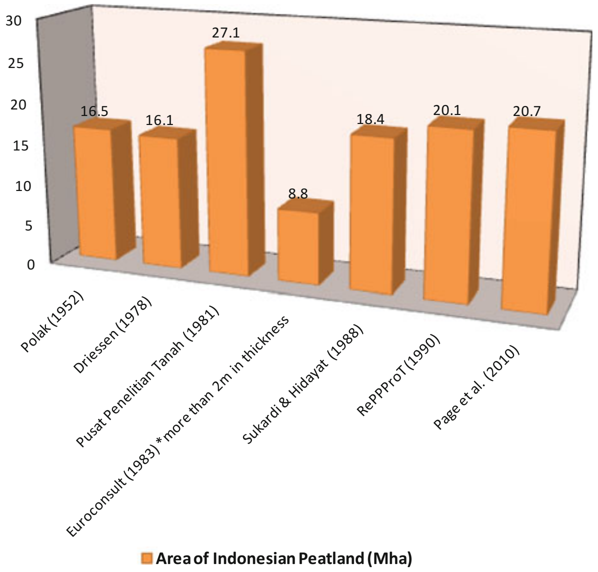
9.2 Peatland Definition in Indonesia

Indonesia has collected many data (such as land cover change, forest management, biomass above ground, biomass below ground, forest types, forest growth), but significant gaps exist to reach national monitoring system.

Difference of Peatland Area in Indonesia The data of peatland area in Indonesia is also available as presented in the Fig. 9.1. The differences of result and data uncertainties may stem from different assumption, methods, and technology used. The different organizations may use different methodologies and sources which contribute the different estimation, such as estimation of carbon emission.

Difference of GHG (Green House Gas) Assessment from Peatland While in the past emissions from deforestation and forest degradation have received the vast proportion of climate-focused attention, both domestically and internationally, carbon emission from Indonesian peat reserves is even more significant. Only very recently there been a broad recognition of the importance of peatland emissions, and while the science is still at a relatively early stage it has improved significantly in recent years. The importance of peat as a source of carbon emissions has gained greater acceptance globally. Figure 9.2 captures the difference between this DNPI (Dewan Nasional Perubahan Iklim, National Council on Climate Change) report (DNPI report 2010) and various estimates published by other government agencies, multilateral organizations, and non-governmental organizations. The differences may stems from the different data, methods, assumption as well as techniques used. Thus, peat and peatland definition is most essential issues for research and policy action.

Fig. 9.1 Various peatland areas have been reported in Indonesia



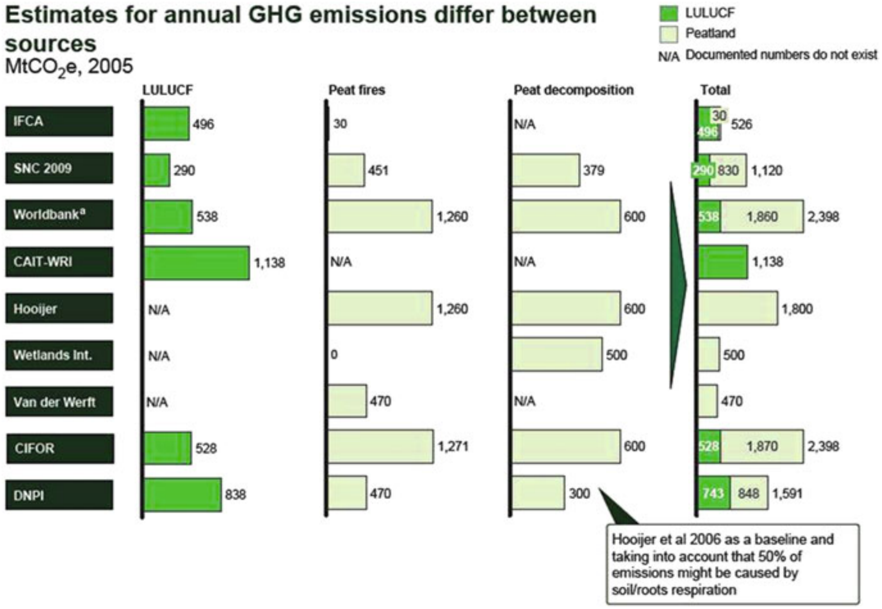


Fig. 9.2 Estimates for annual GHG emissions differ between sources (DNPI 2010)

Key Implications of Authoritative and Scientific Peatland Definitions in Indonesia Referencing POLICY MEMO: PEATLAND DEFINITION FROM UNCERTAINTY TO CERTAINTY (Agus Purnomo et al. 2012), there are two broad peatland definitions: Authoritative and Scientific. In Indonesia, currently there are three Ministries operate under their own authoritative designations of peatland. The Ministry of Environment of Indonesia defines 'peat' as a plant residue formed naturally through long-term decomposition processes, accumulating in swamp areas or static reservoirs. The Ministry of Agriculture defines 'peat' as soil formed as a result of organic matter accumulation with a naturally occurring composition of greater than 65 % from the decaying vegetation growing on it, whose decomposition is slowed down by anaerobic and wet conditions. Meanwhile, the Ministry of Forestry defines 'peat' as organic matter residue accumulating over a long period of time.

Several scientific definitions have been introduced and acknowledged by scientific communities, including those developed by Wüst et al. (2003), Moris (1989), Andrejko et al. (1983), Landva et al. (1983), Jarrett (1983), Mankinen and Gelfer (1982), Kearns et al. (1982), Kivinen and Heikurainen (1979), Davis (1946), and Arman (1923). These definitions are based on field observations and analyses of peat soil properties. Key elements include physical peat properties, such as degree of decomposition (humification), bulk density, water content, porosity and others, and chemical properties, such as carbon content, ash content, pH, and C/N ratio.

9.3 Current Definition and Classification of Tropical Peat

Most of schemes for common use for field and laboratory classification of peats were developed in boreal and humid temperate regions, and these schemes do not recognize the distinctive features and specific uses of tropical peats. Wüst et al. (2003) suggested that these schemes failed to fully characterize and classify the tropical organic deposits of Tasek Bera (Malaysia) peatland (which was chosen as an example of tropical peat deposit to evaluate different classification systems, which is ideal for testing the applicability of peat classification systems for lowland tropical peats), for the following reasons: (1) Temperate and boreal peats are often dominated by bryophytes/moss and shrubs; (2) Existing classification schemes for temperate and boreal peats are based on selected characteristics for specific uses in the fields of agriculture, engineering, energy, etc. rather than having a generic approach; and (3) Classifications of organic soil for agricultural purposes (e.g., CSSC 1987; Soil Survey Staff 1990; Paramananthan 1998) are based on a control section.

Peat is defined as having an ash content of 0–55 %, muck 55–65 %, organic-rich soil/sediment 65–80 % and mineral soil/sediment 80–100 %. And the peat class is subdivided into subclasses: (1) Very low ash (0–5 %); (2) Low ash (5–15 %); (3) Medium ash (15–25 %); (4) High ash (25–40 % 9; and (5) Very high ash (40–55 %). Wüst et al. (2003) analyzed carbon content and ash content of 137 samples from 20 cores of the Tasek Bera Basin, Malaysia. As shown in Fig. 9.3a, clear correlation was found and four classes can be distinguished: peat (ash = 0–55 %), muck (ash = 55–65 %), organic-rich soil or sediment (ash = 65–80 %) and mineral soil or sediment with organic matter (ash = 80–100 %). However, distinguishing between high-ash peat (i.e., muck) and organic-rich mud in the field is difficult because of the gradual transition between the two organic soils.

And also, the important aspects of peat texture (morphology of constituents and their arrangement) and laboratory ash content (residue after ignition) need modification to be valuable for classifying tropical peat deposits. Wüst et al. (2003) proposed three-group (fibric, hemic, sapric) field texture classification applicable to tropical organic deposits, which is based on classification by Esterle (1990), which was modified from the US Soil Taxonomy and developed for tropical low-ash, ombrotrophic peat deposits and soils (Fig. 9.3b). This field texture classification was made bases on: (1) Visual examination of the morphology of the peat constituents (texture); and (2) Estimates of fiber content and matrix.

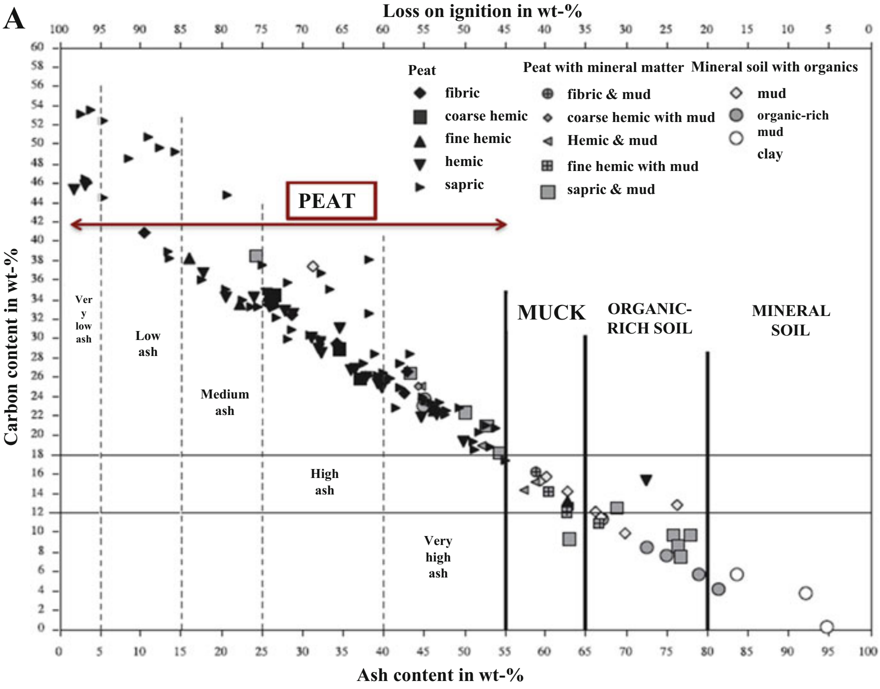


Fig. 9.3 Classification system of tropical peat (Wüst et al. 2003). (**a**) Classification by ash-carbon concentration relationship. (**b**) Various peat textures of the tropical lowland mire system of Tasek Bera (Malaysia) peatland. Sample material classified in the field according to the modified Esterle system (Esterle 1990). *A* Fibric (*left*) to fine hemic (*right*); ash contents 54 %. *B* Coarse hemic peat; ash contents between 25 and 28 %. *C* Hemic peat; ash contents 30 %. *D* Fine hemic peat; ash contents 34 %. *E* Sapric peat; ash contents between 19 and 21 %. *F* Basal section; (from *right* to *left*): typical progression from a kaolinitic clay with quarts grains (ash = 90–93 %); an organic-rich mud (ash = 70–74 %); to fine hemic; woody peat (ash = 50–55 %)

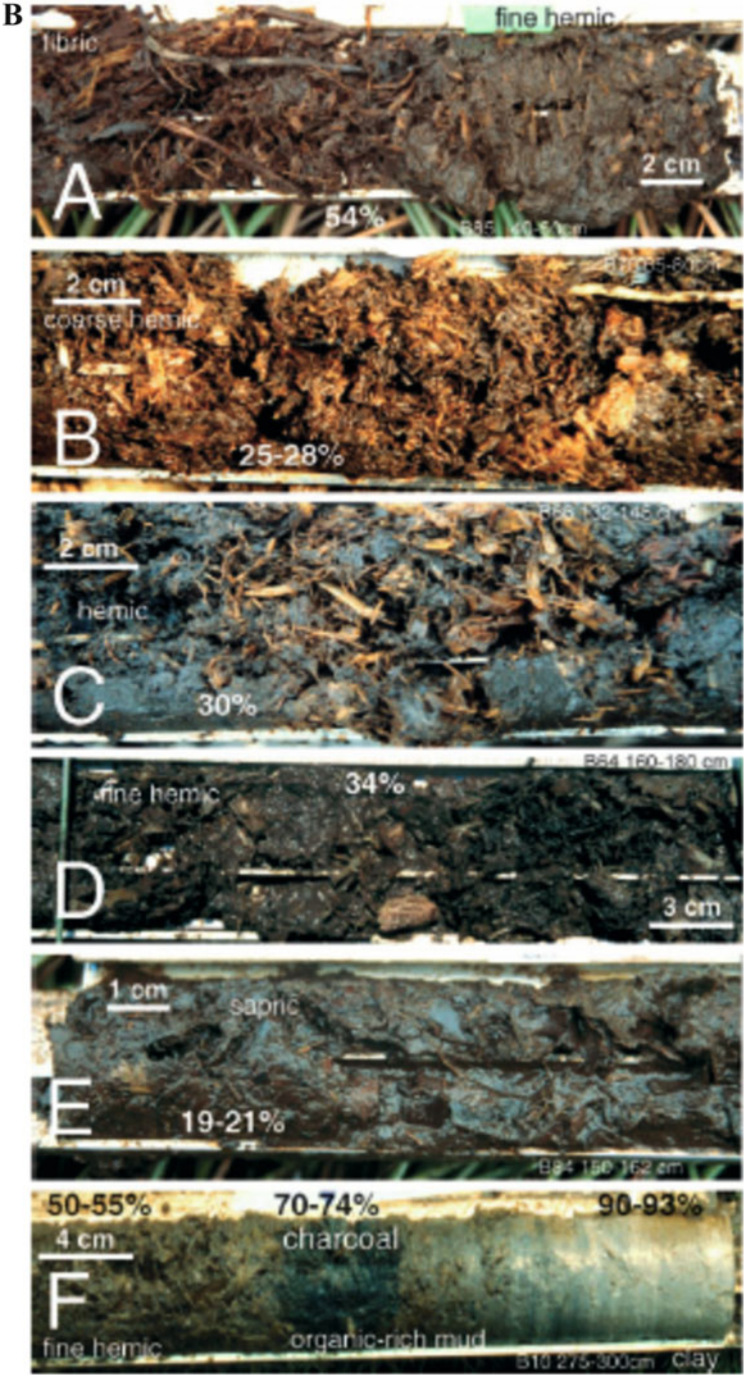


Fig. 9.3 (continued)

9.4 Water Factors to Define the Tropical Peatland

Peatland in "*2013 Wetlands Supplement to 2006 IPCC Guidelines*" is categorized into wet organic soil and drained organic soil, indicating that water statue is one of key elements to peat and peatland definition.

Tropical peat ecosystems are considered to play key roles not only in the storage of carbon in forests and peat, but also in controlling water resources and in preserving bio-resources and biodiversity. Once tropical peatland have been disturbed by deforestation/degradation and the digging of canals, the water table in the peat soil and the water content at the peat surface both decrease. Then, large amounts of the carbon contained in peat soil are lost through peat fires, respiration of the microbial fauna contained in peat, and the runoff of black carbon (Dissolved Organic Carbon, DOC) into rivers (Fig. 9.4). Also tree growth decreases and tree mortality increase by lowering water table, which cause seriously to degrade Forest (Unpublished data), and decrease biodiversity.

Because a strong relationship between deep peat fire and the water table has been confirmed that deep peat fires become more frequent and peat soil respiration increases (Takahashi et al. 2003; Hirano et al. 2007, 2009). The ratio (RE/GPP) of RE (Respiration in Ecosystem) to GPP (Gross Photosynthetic Product in Ecosystem) against groundwater level is plotted. One negative line ($r^2 = 0.38$) explains the relationship for both the un-drained peatland forest (UDF) and drained peatland forest (DF) sites. Another negative linear relationship ($r^2 = 0.69$) was found for the burnt peatland forest after drainage (BD) site. RE depends on GPP, because vegetation respiration consumes photosynthates. Thus, the ratio of vegetation respiration to GPP can be assumed to be almost constant. If so, variation in RE/GPP is mainly related to that of microbial respiration. Therefore, the negative linear relationships indicate that microbial respiration or peat decomposition was enhanced as groundwater level decreased.

Therefore, the following two methods were proposed for estimating and predicting carbon fluxes and balances; one is the direct measurement of carbon flux, and the other is simulating the carbon flux using either a water statue such as the

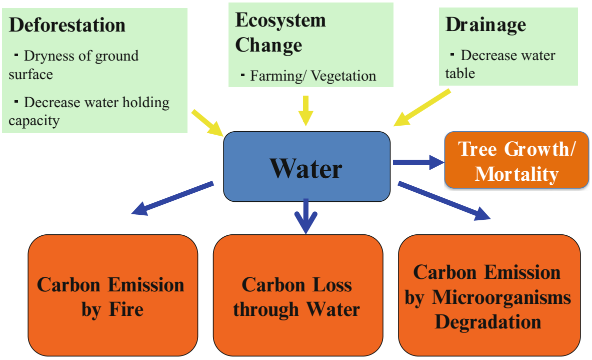


Fig. 9.4 Key element of water on carbon flux and loss from peatland

water table, the moisture content in peat soil, or evapotranspiration in peatland. In conclusion, the carbon and water model is essential to carry out the MRV (Measuring, Reporting, Verifying) system in tropical peat and forest.

Thus, carbon balance in the ecosystem is estimated as flux/loss of carbon, which is affected by the water level or content in peat soil. Water level has an effect on biodiversity through peat degradation, fire occurrence, and aquatic ecosystem changing. Carbon sensing network is a most important technique; however, as maintenance of the carbon sensing network is very costly, a more simplified model for carbon balance is required. From our long-term monitoring of carbon flux and the water table, it became clear that the water table is most important factor related to carbon loss by fire and respiration. Therefore, the Carbon-Water Model became the final Model for MRV and estimation on biodiversity.

9.5 Proposed Peatland Definition in Indonesia

Referencing POLICY MEMO: PEATLAND DEFINITION FROM UNCERTAINTY TO CERTAINTY (Agus Purnomo et al. 2012), particular attention needs to be paid to define ‘peatland’ for the purpose of estimating GHG emissions. The existing authoritative definitions may need to be further developed and integrated into one comprehensive definition to capture the notions of GHGs, such as carbon stocks and flows. Meanwhile, scientific definitions should also be developed or refined to reflect the characteristics of Indonesian peat as it is mostly very fibric and hemic with very high organic and carbon content, derived mostly from woody biomass. The prevailing scientific peat definition for boreal and temperate regions may not be suitable to fully capture the characteristics and classifications of tropical peat. For that reason, a clear and operable definition of ‘peat’ in Indonesia needs to be formulated in order to improve peat management across multiple ministries and agencies.

Having organized a series of technical meetings and consultations with eminent scientists, key stakeholders and government representatives from national and international organizations, the following has been recommended for defining peatland and proposed follow up activities:

- Key Elements to be considered for defining peatland: A comprehensive peatland definition has to cover the key elements of carbon content or mineral content and minimum depth.
- Recommended peatland definition: Peatland is an area with an accumulation of partly decomposed organic matter, with ash content equal to or less than 35 %, peat depth equal to or deeper than 50 cm, and organic carbon content (by weight) of at least 12 %.
- Peatland Delineation Methodology: Four categories for peatland delineation are recommended based on the following classification: (1) Peat depth, (2) Peat layer, (3) Hydrological area in peatland, and (4) Land-use in peatland. To formulate the

appropriate and precise methodology for peatland delineation for better peatland management in line with GHG emission reduction, other variables pertaining to peatland boundary and classification are also important to consider.

Acknowledgement Results shown in this paper were mainly obtained from SATREPS (Science and Technology Research Partnership for Sustainable Development) project entitled as "Wild fire and carbon management in peat-forest in Indonesia" founded by JST (Japan Science and Technology Agency) and JICA (Japan International Cooperation Agency).

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Part III
Ecosystem in Peatland

Takashi S. Kohyama and Joeni Setijo Rahajoe

Chapter 10
Forest Structure and Productivity of Tropical Heath and Peatland Forests

Kazuki Miyamoto, Takashi S. Kohyama, Joeni Setijo Rahajoe, Edi Mirmanto, and Herwint Simbolon

Abstract Allometric relationships between tree dimensions, aboveground forest structure and productivity were examined in tropical heath (kerangas) forest and peatland forest in Central Kalimantan, to determine the stand level properties of these forest types growing under stressful conditions, by comparing with those in mixed dipterocarp forests. In the peatland forest, tree density, trunk diameter-height relationships and aboveground biomass differed between sites, partly due to differences in disturbance history such as the intensity of selective logging in the past. The heath and peatland forests shared common characteristics such as high leaf mass per area and long leaf residence time at the stand level. Both forest types had high wood mass increment rates (maximum of 8.2 Mg ha^{-1} $year^{-1}$ in the heath forest and 10.9 Mg ha^{-1} $year^{-1}$ in the peatland forest), which fluctuated greatly during and after the severe 1997–1998 drought. The results here suggest that the heath and peatland forests maintain moderately high productivity under stressful conditions, probably owing to the adaptive leaf properties. The results also suggest that the aboveground forest structure of these forest types as well as peat deposit has the potential to play a significant role in the carbon balance in an area. To be able to properly conserve these forest ecosystems, more attention must be paid to elucidating the mechanisms maintaining primary productivity of heath and peatland forests.

Keywords Tropical heath forest • Kerangas • Peat swamp forest • Allometry • Biomass • Productivity

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10.1 Affinity of Forest Structure and Floristics of Heath and Peatland Forests

Tropical heath (kerangas) and peatland forests are unique and distinctive forest types in Borneo in terms of forest structure and floristics (Brünig 1974; MacKinnon et al. 1996). Both forest types are known as ecosystems with nutrient-poor and acidic (pH below 4) soils. Heath forest occurs on a white sandy substratum with shallow surface peat (less than 1 m thick), whereas peatland forest develops on periodically waterlogged areas with thick peat deposits, up to 20 m thick. The currently remaining areas in Kalimantan (Indonesian Borneo) are estimated as 24,750 km^2 heath and 34,510 km^2 peatland forests, which corresponds to around 11 % of total area of Kalimantan (MacKinnon et al. 1996). Central Kalimantan is a main distribution area of both forest types. Peatland forests are found mainly in southern coastal areas, whereas heath forests occur inland. At a smaller scale, similar distribution patterns (zonation) of the two forest types are also found around lakes and along rivers.

It is known that there are several common features in the forest structure and leaf morphology of heath and peatland forests (Whitmore 1975). Heath forest is known by trees of short stature, slender trunks, smooth canopy, and small and thick leaves (sclerophylls), and similar physiognomic features are also observed in peatland forest. Especially, the short-statured peatland forests at the center of peat dome show a similar forest structure to heath forests, probably reflecting low nutrient availability (Whitmore 1975; MacKinnon et al. 1996). The two forest types share a number of common species. Brünig (1974) demonstrated that in Sarawak and Brunei heath forests shared many species with both peatland and mixed dipterocarp forests but that the floristic affinity was closer to the peatland forests; the heath forests shared at least 146 species with the peatland forests (Brünig 1973).

The common structural and physiognomic features of heath and peatland forests could be associated with tree growth and forest productivity because these distinctive features are regarded as adaptations to stressful conditions such as low water and/or nutrient availability. In this respect, however, studies of forest productivity are still insufficient in both heath and peatland forests.

In the paper we demonstrate allometric relationships between tree dimensions, aboveground biomass, and primary productivity in heath and peatland forests in Central Kalimantan, by comparing with those in lowland mixed dipterocarp forests. Through these comparisons among forest types, we aim to provide details of stand-level properties of the heath and peatland forests growing under stressful conditions.

10.2 Study Sites

The study was undertaken at Lahei (1°55′S, 114°10′E; 20–30 m a.s.l.) and Setia Alam Jaya (hereafter Setia Alam; 2°18′S, 113°55′E; 10 m a.s.l.) in Central Kalimantan, Indonesia. Lahei is about 40 km northeast of Palangka Raya, the provincial capital of Central Kalimantan. This site is situated in the riparian vegetation along the Mangkutup river, a branch of the Kapuas river. Heath forest covers most of the area and peatland forest appears in patches along the river. During July 1997–January 1998, two 1-ha census plots (P1 and P4) were set in a heath forest and a 1-ha plot (P2) was in a peatland forest (Suzuki et al. 1998; Miyamoto et al. 2003; Nishimura et al. 2007).

Setia Alam is about 20 km southwest of Palangka Raya and located in the upper catchment of the Sebangau river. This area has a variety of peatland forests with respect to forest structure and species composition from the river edge to the inland (Page et al. 1999). Ten 0.25-ha (50 m × 50 m) plots (S1–S10), each located within 5.7 km from the river, were set in 1999. The forest type of these plots was classified as mixed swamp forest with 2.5–4.5 m thick peat (Page et al. 1999).

In Palangka Raya, annual mean temperature was 27 °C and annual precipitation was 3224 mm during 1993–1995 and 1999 (the data for 1996 was not available), but only 1912 and 2758 mm in 1997 and 1998 because of the drought associated with the El Niño–Southern Oscillation (ENSO) event. A similar pattern of rainfall influenced by the ENSO drought was recorded in Setia Alam (Takahashi et al. 2000). Although there was no meteorological data available for Lahei, it was assumed that the site also experienced a similar pattern of rainfall as Palangka Raya and Setia Alam during 1997–1998.

The dominant species at Lahei were *Cotylelobium lanceolatum*, *Calophyllum* spp., *Hopea griffithii*, *Palaquium leiocarpum*, *Shorea teysmanniana*, *Syzygium* spp. and *Tristaniopsis obovata* in the heath forest (Miyamoto et al. 2003), with *Buchanania sessifolia*, *Semecarpus* sp., *Shorea balangeran*, *Vatica oblongifolia Madhuca sericea* and *Tetractomia obovata* common in the peatland forest (Suzuki et al. 1998; Simbolon and Mirmanto 2000; Nishimura et al. 2007). At Setia Alam, *Hydnocarpus* sp., *Palaquium leiocarpum*, *Shorea guiso*, *Syzygium densinervium* and *Xanthophyllum palembanicum* dominated in the peatland forest (Simbolon and Mirmanto 2000).

Since Setia Alam is a logging concession area, the site has been subjected to selective logging, while Lahei had relatively undisturbed areas during the study period, although the road side areas were disturbed by slash and burn cultivation and selective logging. Unfortunately most of the study plots at Lahei were lost by 2003 mainly due to forest fires and land conversion.

10.3 Biomass and Productivity Estimates

Clear felling was carried out in a 10 m × 10 m subplot within P1 at Lahei in 1998 and in a 10 m × 10 m subplot within S1 in Setia Alam in 2002 to determine allometric relationships between tree dimensions. In P1, additional samplings were conducted for nine dominant species in the heath forest from 1998 to 2000 (Miyamoto et al. 2007). Tree height (H) and DBH (D) were measured for each sampled tree. The fresh mass of trunk (W_t), branch (W_b) and leaf (W_l) of the sample trees were separately weighed. For each part, subsamples were collected for estimation of the dry mass, and the subsamples were oven-dried at 70 °C for 1 week. The total leaf area (A_l) of the sample trees was calculated by multiplying the specific leaf area (SLA, leaf area per unit leaf mass) of leaf subsamples by total leaf dry mass. Detailed description for the biomass estimation was shown in Miyamoto et al. (2007).

Parameters of allometric relationships were estimated using linear regression equations on a double logarithmic scale. The reciprocal equation called expanded allometry (Ogawa 1969) was used for the D-H relationship.

Note that the results on the biomass estimation and productivity values of heath forest originate from the data of Miyamoto et al. (2007). However, estimated values shown here are slightly different with those of Miyamoto et al. (2007) because of different allometric equations. Miyamoto et al. (2007) used the allometric equations with D^2 as the independent variable to avoid an error caused by using D^2H as independent variable (because H was estimated from D). Here, results using D^2H are shown for comparison with previous literature in the same manner as the biomass estimation process. The allometric parameters used here are listed in Appendix (Tables 10.3 and 10.4).

10.4 Tree Size Distribution

The DBH size distribution of the heath forest stands at Lahei (P1 and P4) was characterized by the high tree density in the smallest size class (5–10 cm) which was more than 1000 trees ha^{-1} and accounted for around 65 % of the stand tree density (Fig. 10.1). The DBH size was up to 70 cm of the maximum and large trees ≥60 cm DBH were rare. The peatland forest at Lahei (P2) showed the DBH size distribution pattern intermediate between those of the heath forest at Lahei (P1 and P4) and that of the mixed dipterocarp forest at Serimbu in West Kalimantan (Fig. 10.1). The tree density in the smallest size class was lower than that of the heath forest and similar to that of the mixed dipterocarp forest. The maximum DBH size (100.2 cm) was larger than that of the heath forest plots, but it was still smaller than that of the mixed dipterocarp forest (158.6 cm).

In the peatland forest at Setia Alam, eight of the ten plots (S1–S8) showed a similar size structure as the high tree density in the smallest DBH size class and rarity of large trees ≥60 cm DBH (Fig. 10.2). The other two plots (S9 and S10) had lower tree densities in the smallest size class. The size structure of these ten plots at Setia Alam was different from the peatland forest (P2) at Lahei. This is probably due to the differences in species composition, especially lacking large-sized Anacardiaceae and Dipterocarpaceae trees, some of which were the object of selective logging in the past. This suggests that the degree of disturbance was more serious in the peatland forest at Setia Alam than at Lahei (Simbolon and Mirmanto 2000).

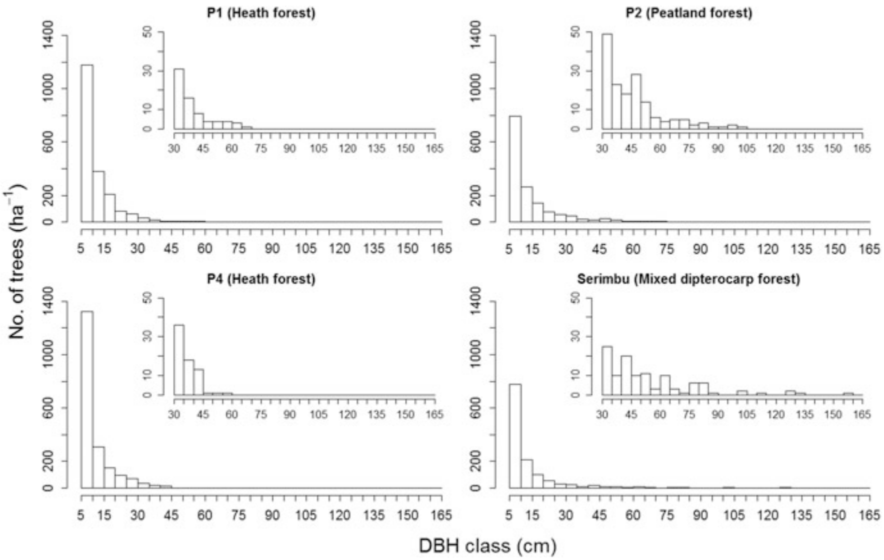

Fig. 10.1 Frequency distributions of diameter at breast height (DBH) for heath forest (P1 and P4) and peatland forest (P2) at Lahei in Central Kalimantan, and mixed dipterocarp forest at Serimbu in West Kalimantan (the same source as in Suzuki 1999; Kohyama et al. 2001, 2003). The *inset* shows the frequency distribution for the size class of DBH ≥ 30 cm

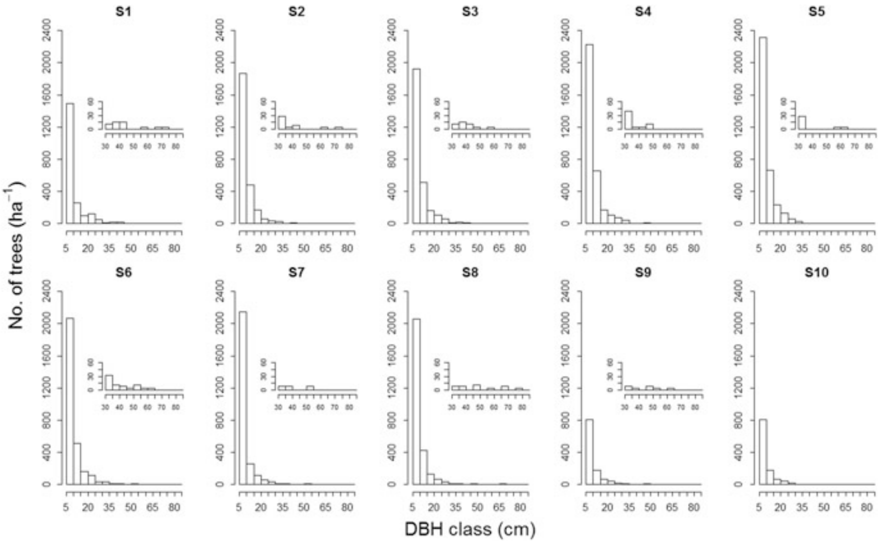

Fig. 10.2 Frequency distributions of diameter at breast height (DBH) for peatland forest (S1–S10) at Setia Alam in Central Kalimantan. The inset in S1–S9 shows the frequency distribution of trees with the size class of DBH ≥ 30 cm. No individuals with DBH ≥ 30 cm were observed in S10

10.5 Allometric Relationships

Stand-level allometric relationships of heath and peatland forests were compared with those of the mixed dipterocarp forest at Sebulu, East Kalimantan (source, Yamakura et al. 1986a). The allometric relationships are shown on a double logarithmic scale in Figs. 10.3, 10.4, 10.5, and 10.6.

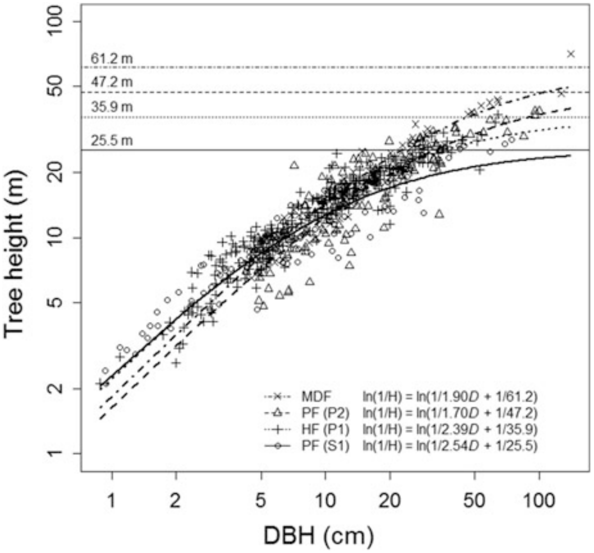

Fig. 10.3 The diameter at breast height (DBH or D)-tree height (H) allometric relationships for heath forest (HF, P1 and P4) and peatland forest (PF, P2 and S1) in Central Kalimantan with that of mixed dipterocarp forest (MDF) in East Kalimantan (source, Yamakura et al. 1986a). Allometric equations for each forest type are shown in the panel. Values with *horizontal lines* indicate the asymptotic tree height. The curves are statistically significantly different (F-test, $P < 0.0001$)

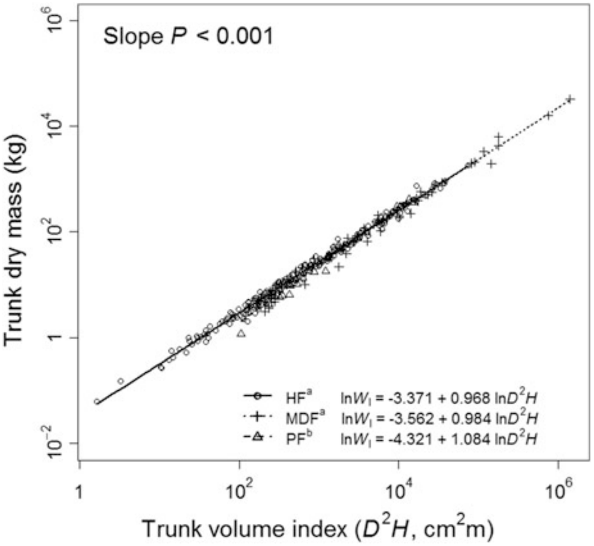

Fig. 10.4 The trunk volume index (D^2H)-leaf mass (W_l) relationships for heath forest (HF) and peatland forest (PF) with that of mixed dipterocarp forest (MDF). Significant level in the panel indicates an overall difference in regression slope or intercept among the three forest types (ANCOVA). Allometric equations for each forest type are shown in the panel. The same superscripts with forest type abbreviations indicate that there is no significant difference in slope or intercept between given two forest types ($P < 0.05$ with Bonferroni correction)

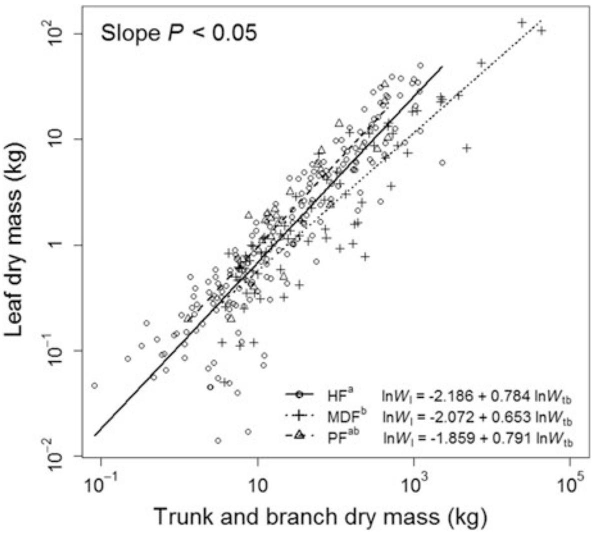

Fig. 10.5 The wood mass (trunk and branch mass, W_{tb})-leaf mass (W_l) relationships for three forest types. Allometric equations, forest type abbreviations, and superscripts are as in Fig. 10.4

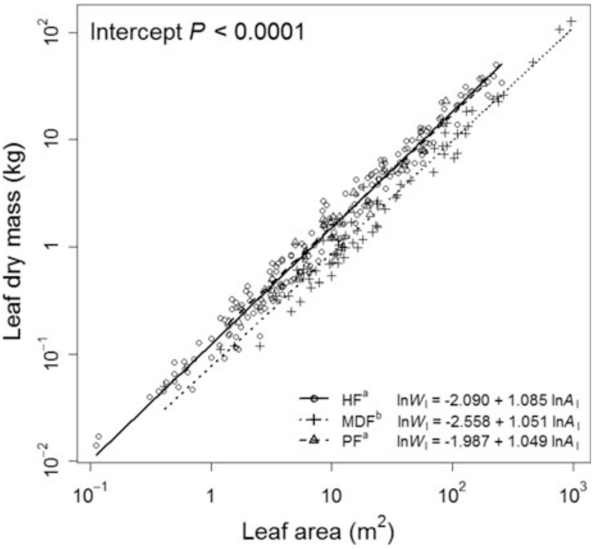

Fig. 10.6 The leaf area (A_l) -leaf mass (W_l) relationships for three forest types. Allometric equations, forest type abbreviations, and superscripts are as in Fig. 10.4

In the DBH-tree height relationship, the heath and peatland forests had lower asymptotic heights compared with the mixed dipterocarp forest (Fig. 10.3 and Appendix (Table 10.3)). Asymptotic tree heights of forests were lower at Setia Alam (S1) than at Lahei (P2), which was likely affected by the degree of logging disturbance and also by the distance from rivers (Page et al. 1999; Mirmanto et al. 2003). In case of relatively undisturbed peatland forests, located close to our plots at Setia Alam, the maximum tree height varied from 20 to 45 m with an extreme case of only 1.5 m at the interior stand (Page et al. 1999). Similarly in heath forest, the maximum tree size varies from tall forest with up to 110 cm in diameter and 40 m in height to short and scattered vegetation with less than 30 cm in diameter and 15 m in height (called padang, Brünig 1974; Whitmore 1975; MacKinnon et al. 1996). Our heath forest (P1 and P4) can be classified as tall heath forest.

In the trunk volume index (D^2H)-trunk mass (W_t) relationship, the three forest types showed similar patterns (Fig. 10.4). However, significant difference was found in regression slope between the peatland forest and other two forest types (Fig. 10.4). Also, the heath forest had slightly but significantly higher intercept than the mixed dipterocarp forest (ANCOVA, $p < 0.01$). These results imply that the heath forest trees could have relatively high wood density. The leaf mass (W_l)-wood mass (W_{tb}) relationship indicates that the heath and peatland forests allocate more to leaf mass relative to wood mass, especially at the large wood masses for the heath forest in comparison with the mixed dipterocarp forest (Fig. 10.5).

The most distinctive feature is recognized in the leaf area (A_l)-leaf mass (W_l) relationship (Fig. 10.6). This allometric relationship indicates that both heath and peatland forest leaves have greater leaf mass per unit leaf area (LMA) on an individual tree level, compared to the mixed dipterocarp forest leaves. This tendency was constant over the entire range of total leaf area. There was no significant difference in the leaf area-leaf mass allometric relationship between heath and peatland forests despite the different conditions of soil water availability. This result implies that the scleromorphic features of heath forests can not be simply attributed to water deficiency. Previous studies have suggested the scleromorphic features of leaves in heath and peatland forests are associated with water deficiency or periodic drought (e.g. Brünig 1974, cf. Moran et al. 2000), nutrient deficiency (e.g. Proctor et al. 1983b; Medina et al. 1990; Brady 1997; Coomes 1997; Dent et al. 2006), insect grazing (Janzen 1974), and more recently H-toxicity (Luizao et al. 2007; Vernimmen et al. 2013). Brady (1997) suggested that nutrient deficiency was likely to better explain the xeromorphic features of their peatland forest sites in Sumatra than water deficiency and insect grazing.

At the seedling stage, morphological differentiation is reportedly more apparent between heath and peatland forests. Nishimura and Suzuki (2001) demonstrated that the heath forest seedlings at Lahei have generally larger LMA leaves (smaller SLA leaves), and smaller crowns and total leaf areas at the same shoot mass than the adjacent peatland forest seedlings. They suggested that soil water availability is the most important factor for the differentiation of seedling morphology between the two forest types. The disagreement in the leaf area-leaf mass relationship of our data (Fig. 10.6) and Nishimura and Suzuki (2001) is probably due to the differences in accessibility to nutrients in the soil between seedlings and larger trees. It is likely that heath forest seedlings have more difficulty to access nutrients accumulating deep in the soil than large trees with well developed rooting systems (Riswan and Kartawinata 1991).

10.6 Aboveground Forest Structure

Table 10.1 shows details of the tree density, aboveground biomass, basal area (BA) and leaf area index (LAI) among the heath, peatland and mixed dipterocarp forests. In this table, application of the D^2H-base allometric equations (Appendix (Table 10.4)) would be more suitable for the aboveground biomass estimates than the D^2-base equations, because the DBH-tree height relationship was different among forest types and among stands within the same forest type (see also Sect. 10.3).

The heath and peatland forest stands generally had higher tree densities than the mixed dipterocarp forest with the exception of P2 at Lahei and two plots (S9 and S10) at Setia Alam. The aboveground biomass was similar in the heath forest at Lahei and the peatland forest at Setia Alam: 250.6 and 207.2 Mg ha^{-1} for P1 and P4 at Lahei and 189.2 Mg ha^{-1} at Setia Alam (an average of S1–S10 with a range of 57.6–264.8 Mg ha^{-1}). These values correspond to about one-half to one-third that in the mixed dipterocarp forests at Serimbu, West Kalimantan (Suzuki 1999; Kohyama et al. 2001, 2003), at Sebulu, East Kalimantan (Yamakura et al. 1986b), and at

Table 10.1 Tree density, above-ground biomass, basal area (BA), and leaf area index (LAI) for heath forest, peat swamp forest, and mixed dipterocarp forest (trees ≥5 cm DBH)

	Tree density (ha^{-1})	Trunk (Mg ha^{-1})	Branch (Mg ha^{-1})	Leaf (Mg ha^{-1})	Total (Mg ha^{-1})	BA (m^2 ha^{-1})	LAI (ha ha^{-1})
Peatland forest							
Lahei P2[a]	1,406	465.4	119.0	19.9	604.3	43.5	10.6
Setia Alam[b]	2,464	146.8	32.2	10.2	189.2	26.7	5.8
Heath forest							
Lahei P1[a]	1,838	186.3	54.9	9.3	250.6	27.2	5.3
Lahei P4[a]	1,942	154.4	44.6	8.2	207.2	26.6	4.7
Mixed dipterocarp forest							
Serimbu1[c]	1,249	495.7	138.6	5.7	640.0	42.3	5.5
Serimbu2[c]	1,333	519.4	144.5	6.3	670.1	44.4	6.1
Sebulu[d]	1,578	414.2	78.9	5.8	498.8	36.8	5.8
Pasoh[e]	–	341.8	76.9	7.7	426.4	–	6.8

[a] Data are averages from February 1998 to August 1999 for P1 and P2, and from February 1998 to November 1999 for P4

[b] Data are averages of the values in ten 50 m × 50 m plots (S1–S10) from 1999 to 2000

[c] Based on census data from two 1-ha plots at Serimbu, West Kalimantan (same data source as in Suzuki 1999; Kohyama et al. 2001, 2003), applying allometric equations from Yamakura et al. (1986a)

[d] Lowland mixed dipterocarp forest at Sebulu, East Kalimantan (trees ≥4.5 cm DBH, Yamakura et al. 1986b)

[e] Lowland mixed dipterocarp forest at Pasoh Forest Reserve, Peninsular Malaysia (trees ≥4.5 cm DBH, Kira 1978)

Pasoh, Peninsular Malaysia (Kira 1978). The aboveground biomass for P2 at Lahei (604.3 Mg ha^{-1}) was much higher than those in other plots of the heath and peatland forests. It was closer to the values in the above-mentioned mixed dipterocarp forests (426.4–670.1 Mg ha^{-1}). A comparison of BA also shows a similar pattern. In heath forest, the aboveground biomass estimated by previous studies ranged from 147.1 (Hozumi et al. 1969) to 470 Mg ha^{-1} (Proctor et al. 1983a). Brünig (1974) showed the range of basal area between 17.5 and 88.0 m^2 ha^{-1} (mean of 36.5 m^2 ha^{-1} with >2 cm DBH) for 57 heath forest stands in Sarawak and Brunei. The aboveground biomass and basal area of the two heath forest plots fall within the range of these studies. In the peatland forests of Sumatra, Brady (1997) showed 395–641 Mg ha^{-1} of total trunk mass (trees >5 cm DBH) with 3–6 m thick peat. The aboveground biomass was much higher at P2 than those at Setia Alam, but the value for P2 also falls within the range of previous data. Rather, the smaller aboveground biomass of the peatland forest at Setia Alam can be considered as a result of intensive logging activities in the past.

There is conspicuous variation in forest structure and species composition for heath and peatland forests (Whitmore 1975; MacKinnon et al. 1996; Page et al. 1999; Mirmanto et al. 2003). Peatland forest shows apparent changes in forest structure and species composition along the peat thickness or the distance from river (Brady 1997; Page et al. 1999; Mirmanto et al. 2003). It is likely that the changes are mainly determined by hydrological intactness and nutrient availability (e.g., Page et al. 1999). Although surface peat thickness is generally thin (less than 1 m) in heath forest, some tree species show different habitat preferences along the peat thickness (Miyamoto et al. 2003).

The heath and peatland forests had high total leaf masses relative to total wood mass compared to the mixed dipterocarp forest. Stand-level LMA (i.e. total leaf mass/LAI) of the heath forest (1.8 and 1.7 Mg ha^{-1} for P1 and P4) was similar to that of the peatland forest (1.9 for P2 and 1.8 Mg ha^{-1} for an average of S1−S10 at Setia Alam), whereas it was higher than that of the mixed dipterocarp forests (1.0–1.1 Mg ha^{-1} for Serimbu, Sebulu and Pasoh). These characteristics of the aboveground forest structure of the heath and peatland forests reflect the allometric relationships of each forest type (Figs. 10.5 and 10.6).

10.7 Productivity

Table 10.2 lists productivity data for heath and peatland forests with data for mixed dipterocarp forest. The productivity values of the Amazonian caatinga and the forest on the Oxisol hill in Venezuela (Jordan and Uhl 1978; Jordan 1989), both of which develop under stressful conditions with low water and/or nutrient availability, are also listed.

Table 10.2 Wood mass increment rates, fine litterfall rates, ANPP, and residence time of leaves among three forest types (trees ≥5 cm DBH)

Site[a]	Wood mass increment (Mg ha^{-1} $year^{-1}$)	Litter (Mg ha^{-1} $year^{-1}$)	ANPP (Mg ha^{-1} $year^{-1}$)	Leaf residence time (year)
Peatland forest				
Lahei P2 (drought)[a]	10.9	5.5[c]	16.4	6.5
Lahei P2 (postdrought)[a]	3.8	5.5[c]	9.3	6.4
Setia Alam	8.1[b]	–	–	–
Heath forest				
Lahei P1 (drought)[b]	0.4	–	–	–
Lahei P1 (postdrought)[b]	8.2	–	–	–
Lahei P4 (drought)[b]	3.9	5.8[c]	9.7	2.1
Lahei P4 (postdrought)[b]	7.2	5.3[c]	12.5	2.7
San Carlos, Oxisol[d]	4.9	5.9	10.8	1.7
San Carlos, Tall caatinga[d]	3.9	5.0	8.9	2.2
Mixed dipterocarp forest				
Serimbu1[e]	6.7[e]	–	–	–
Serimbu2[e]	5.9[e]	–	–	–
Pasoh[f]	5.2	10.8	16.0	1.1

[a] The drought period, February 1998 to August 1998; the postdrought period, August 1998 to August 1999 for P1 and P2, and August 1998 to November 1999 for P4

[b] Average of the values in ten 50 m × 50 m plots (S1–S10) from 1999 to 2000

[c] Adapted from Rahajoe and Kohyama (2003)

[d] Adapted from Jordan (1989)

[e] Based on census data from two 1-ha plots in 1992 and 1995; the same data source as in Suzuki (1999), Kohyama et al. (2001, 2003)

[f] Trees ≥4.5 cm DBH, adapted from Kira (1978)

Wood mass increment of the peatland forest at Setia Alam was similar to that of the heath forest during the postdrought period at Lahei and slightly higher than that of the Amazonian caatinga, the forest on the Oxisol hill, and the mixed dipterocarp forest (Table 10.2). The heath and peatland forests at Lahei were subjected to a severe drought associated with the El Niño Southern Oscillation (ENSO) event. During the drought period in 1997–1998, considerable reductions in the wood mass increment rates were observed for the heath forest at Lahei (0.4 and 3.9 Mg^{-1} ha^{-1} year; Table 10.2; see also Miyamoto et al. 2007). In the peatland forest at Lahei (P2) the wood mass increment rate decreased more during the postdrought period than during the drought period. Significantly higher tree mortality was observed in P2 during the postdrought period (8.4 % $year^{-1}$) compared with the drought period (6.0 % $year^{-1}$; Fisher's exact test, $p < 0.0001$). At the same sites at Lahei, Nishimura et al. (2007) observed higher tree mortality and lower DBH growth rates of peatland forest trees compared to heath forest trees. They suggested that the peatland forest apparently had poorer resilience to damage caused by drought. Overall, the heath and peatland forests seem to have potentially high wood mass increment rates, although they are susceptible to water stress by drought.

Only the litterfall rates for P2 and P4 at Lahei were available in our data, the further discussion is made by referencing previous data in the literature. The fine litterfall rate of the heath and peatland forests at Lahei was comparable to that of the Amazonian caatinga and the forest on the Oxisol hill, whereas it was approximately one-half that of the mixed dipterocarp forest at Pasoh (Table 10.2). Similar fine litterfall rates were reported at Sepilok, Sabah (5.6 Mg ha^{-1} year^{-1}, Dent et al. 2006) and in stunted and tall heath forests at Barito Ulu, Central Kalimantan (5.4 and 6.4 Mg ha^{-1} year^{-1}, Vernimmen et al. 2013). Other previous studies have reported higher fine litterfall rates: 9.2 Mg ha^{-1} year^{-1} in Sarawak (Proctor et al. 1983b) and 8.1 Mg ha^{-1} year^{-1} in Brunei (Moran et al. 2000). As with heath forest, data are limited for fine litterfall rate of peatland forest. In Sumatra, the fine litterfall rate in a peatland forest with a 4–5 m peat deposit was separately estimated at 9.4 Mg ha^{-1} year^{-1} for mound habitats and 7.0 Mg ha^{-1} year^{-1} for non-mound habitats (Shimamura and Momose 2005). Brady (1997) reported an increase in fine litterfall rates from 5.1 to 11.9 Mg ha^{-1} year^{-1} with decreasing peat deposit thickness (3–12 m) among different types of peatland forest (mixed, low pole, and tall pole forests). Overall, the fine litterfall rate is variable among sites either in heath or peatland forests. Such variation may be partly attributed to differences in tree size structure and species composition. Fine litterfall rates are also variable in mixed dipterocarp forest ranging from 5.3 (Kellman 1970 in Proctor 1984) to 11.1 Mg ha^{-1} year^{-1} (Burghouts et al. 1998).

Aboveground net primary production (ANPP, here defined as the sum of wood mass increment rate and fine litterfall rate) was estimated at 9.3 Mg ha^{-1} year^{-1} in P2 and 12.5 Mg ha^{-1} year^{-1} in P4 during the postdrought period (Table 10.2). These values are similar to that of the Amazonian caatinga and the forest on the Oxisol hill, while it was lower than that of the mixed dipterocarp forest at Pasoh, mainly reflecting low fine litterfall rate in the heath and peatland forests. However, P2 showed a higher ANPP (16.4 Mg ha^{-1} year^{-1}) during the drought period, which is comparable to that of the mixed dipterocarp forest. Taking the values of fine litterfall rate in the other heath forest sites into consideration (5.6–9.2 Mg ha^{-1} year^{-1}), the ANPP in P1 at Lahei during the postdrought period fall the range between 13.8 and 17.4 Mg ha^{-1} year^{-1}. Similarly, when the fine litterfall rates of the previous studies mentioned above (5.1–9.4 Mg ha^{-1} year^{-1}) are applied, the ANPP of the peatland forest at Setia Alam is estimated at 13.2–17.5 Mg ha^{-1} year^{-1}. These ANPP estimates imply that the heath and peatland forests are moderately productive despite being under stressful conditions.

Leaf residence time (estimated by dividing the leaf mass by the annual leaf litterfall mass) was longer in the peatland forest at Lahei (P2) than those of the heath forest plots (P1 and P4) at Lahei, the Amazonian caatinga and the forest on the Oxisol hill (Table 10.2). All of these four forest types had a longer leaf residence time than the mixed dipterocarp forest at Pasoh. This suggests that the leaves of the four forest types under stressful conditions are relatively long-lived. The long-lived, tough, and insect resistant leaves are probably advantageous under nutrient-poor and/or water-deficit conditions when the cost of leaf replacement is high (Janzen 1974; Chapin 1980; Jordan 1989; Reich et al. 1992; MacKinnon et al. 1996).

10.8 Prospects of Tropical Heath and Peatland Forest Studies

Our data showed that heath and peatland forests had several affinities in forest structure and primary productivity. Trees of the two forest types possessed common leaf properties such as high LMA and long-lived leaves, which are probably related to an efficient carbon assimilation to maintain forest productivity under stressful conditions. The comparison of wood mass increment rate implies that both forest types are moderately productive despite the low nutrient availability. This suggests that both forest types play a significant role in the carbon balance in the studied area. To verify these findings, further long-term studies are necessary taking into account spatial and temporal variations in the forest biomass and productivity of these forest types.

Heath and peatland forests are fragile ecosystems. The surface peat on the forest floor is quickly and irreversibly lost, once the vegetation cover is cleared (Whitmore 1975; MacKinnon et al. 1996). Peatland forest has received attention as both carbon sink and source because of its high amount of carbon accumulation by peat formation (e.g., Brady 1997; Page et al. 2002). Page et al. (2002) reported that in 1997 a considerable amount of carbon (0.81–2.57 Gt as a whole in Indonesia) was released to the atmosphere from burning peat and vegetation which is associated with the ENSO event. To be able to properly conserve these fragile forest ecosystems as well as for scientific interest, more attention must be paid to elucidating the mechanisms maintaining primary productivity of heath and peatland forests.

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Appendix

Table 10.3 Parameters of tree diameter (D)-height (H) relationship ($\ln[1/H] = \ln[1/AD + 1/H^*]$) of heath and peatland forests at Lahei and Setia Alam

Site	N	A	H^*	CF1[a]	CF2[b]
Lahei					
P1 (heath forest)[c]	306	2.39	35.9	1.01	1.01
P2 (peatland forest)	126	1.70	47.2	1.03	1.02
P4 (heath forest)	192	2.63	26.5	1.01	1.01
Setia Alam					
S1 (peatland forest)	119	2.55	25.5	1.02	1.02

[a] Correction factor based on Sprugel (1983)

[b] Correction factor based on Snowdon (1991)

[c] Parameters after Miyamoto et al. (2007)

Table 10.4 Allometric parameters for aboveground biomass estimation ($\ln y = a + b \ln x$) based on destructive sampling in a heath forest at Lahei (P1) and a peatland forest at Setia Alam (S1)

$x - y$	a	b	CF1[a]	CF2[b]
Lahei P1 (heath forest) $N = 184$[c]				
$D^2H - W_t$	−3.37	0.968	1.02	1.01
$D^2H - W_b$	−5.41	1.03	1.31	1.10
$D^2H - W_l$	−4.67	0.759	1.41	1.07
$D^2H - A_l$	−2.26	0.681	1.37	1.12
Setia Alam S1 (peatland forest) $N = 74$				
$D^2H - W_t$	−4.32	1.08	1.03	0.976
$D^2H - W_b$	−6.58	1.16	1.21	0.983
$D^2H - W_l$	−4.99	0.837	1.25	1.12
$D^2H - A_l$	−2.83	0.794	1.20	1.07

D^2H trunk volume index, W_t trunk dry mass, W_b branch dry mass, W_l leaf dry mass, A_l total leaf area

[a] Correction factor based on Sprugel (1983)

[b] Correction factor based on Snowdon (1991)

[c] $N = 183$ for the $D^2H - A_l$ relationship

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Chapter 11
Floristic Diversity in the Peatland Ecosystems of Central Kalimantan

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Abstract Tropical peatlands have accumulated huge amounts of carbon. However, the carbon pool is presently disturbed by land utilization practices, and consequently it is becoming vulnerable to the effects of the changes. Tropical peatlands present a threat if they switch from being carbon sinks to carbon sources for the atmosphere. In the present state they provide a number of ecosystem services, such as biodiversity, habitat maintenance, water cycling, and commodities for exploitation. Tree diversity in the peatland forests of various study sites in Central Kalimantan are described here. In the Sebangau, Bawan, and Hampangen villages, the trees species were only 42.5 % of the total number of tree species found in the peatland forest. The estimates of above-ground biomass was about 331 t ha^{-1}, and the litterfall around 6.5–9.1 t ha^{-1} $year^{-1}$. The litterfall varied among locations, different in the degraded and intact peatland forests, and the nitrogen and carbon input of litterfall in these peatland forest types were 39.1 and 2,724 kg ha^{-1} $year^{-1}$, respectively.

Keywords Above ground biomass • Central Kalimantan • Litterfall • Peatland forest

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11.1 Introduction

About 83 % of the South East Asian tropical peat lands are found in Indonesia (wetland http://www.wetlands.org/TabId=2739&AlbumID=11455-88). Indonesia has the largest area of peatland forests in the tropics, covering an estimated 20.7 Mha (range 16–27 Mha) (Radjaguguk 1992; Rieley et al. 1996) and distributed mainly across Sumatra (4.7–9.7 Mha), Kalimantan (3.1–6.3 Mha), and Papua (8.9 Mha) (Silvius 1989; Rieley et al. 1996). Peatland forests occur in waterlogged soils, which prevent dead leaves and wood from full decomposition, and which over time creates thick layers of acidic peat. The water of peatland forests is dark brown due to the large amounts of tannins that leach from the fallen leaves. Peat is mainly fibrous with low ash and mineral contents, and nutrient content commonly decreases from top to base of the acidic peat and the pH is below 4.0 (Haraguchi et al. 2000). Peatland forests are a unique and important wetland ecosystem, but they are also fragile and sensitive to large changes when developed.

About 258,650 higher plants have been recorded worldwide, and an estimated 13–15 % of these are found in Indonesia (35,000–40,000 species). At least 5,575 higher plant species have been found in Kalimantan, including 71 lichens, 376 mosses, 235 fungi, and other families (Anonim 2011). In Borneo there are around 927 species of flowering plants and ferns, while in Peninsular Malesia there are 260 (http://en.wikipedia.org/wiki/Borneo_peat_swamp_forests). In Sebangau (Central Kalimantan), 808 plants species were reported by the WWF (personal communication, 2006). Sebangau peatland forests are mainly composed of Dipterocarpaceae, Clusiaceae, Myrtaceae, and Sapotaceae (Mirmanto 2010).

Peatland forests in Borneo have been studied for the tree species found there, DOC (Dissolved Organic Carbon), biomass, and carbon content (Saribi and Riswan 1997; Page et al. 1999; Siregar and Sambas 2000; Nishimura et al. 2007; Miyamoto et al. 2007; Ludang and Jaya 2007; Rahajoe 2003). However, the biodiversity of the peatland forests needs to be explored due to the fast rate of degradation.

Forest fires is one factor in forest degradation in Kalimantan. At the end of the extremely dry season in 1997 (caused by an ENSO event), the historically largest fires broke out in almost all forest types in Kalimantan and Sumatra Islands. Forest fires have a very large impact on tropical forest ecosystems and biodiversity (Barber and Schweithelm 2000). The estimated extent of fires during 1997–1998 in Kalimantan were 75,000 ha of peatland forest, 2,375,000 ha of lowland forest, 2,829,000 ha of agricultural land, 116,000 ha of timber plantations, 55,000 ha of estate crops, and 375,000 ha of dry scrub, and grasslands for a total of 6,500,000 ha (Bappenas 1999). Frequent forest fires occurred during the past 10 years, and repeated cycles of burning have transformed forests completely into grass or scrubland. In a study of the effect of forest fires on biodiversity, about 90 % of 240 trees died in a 1.6-ha permanent plot (Whitmore 1984).

Land-use changes may be among the most important factors which significantly affect ecosystem processes and services, since land use change potentially alters, either positively or negatively, the available net primary production area. However, monitoring and projecting the impacts of such land-use changes are difficult because of the large volume of data and the interpretation required as well as the lack of information about the contribution of alternative landscapes to these effects. It has been predicted that in the future, land use change is likely to occur predominantly in the tropics, associated with decreases in net primary productivity and increases in surface temperatures (DeFries and Bounoua 2004). In addition, land-use changes are mainly driven by agricultural expansion and deforestation (DeFries et al. 1999).

Kalimantan is the biggest island in Indonesia, and peatland forests mainly occur in Central Kalimantan. Palangkaraya is the capital of Central Kalimantan province, covering 153,800 km^2, with more then 80 % of the area covered with dense jungle, while swamps, rivers, and lakes take up approximately 2 % and agricultural land about 3 % of the area (http://www.borneotourgigant.com/Central_Kalimantan_Introduction.html).

Two habitat types found in Central Kalimantan are heath forests and peat-swamp forests, and these each cover over 10 % of the lowlands of Kalimantan. Heath forests develop on white sandy soils and are called “Kerangas”, very similar to forests growing on white sand in Neotropical areas (areas south of the equator). Because of low water retention, sandy soils periodically cause severe desiccation of heath forests where the saplings have deep root systems enabling them to endure the dry season however. Peat-swamp forests develop over waterlogged low areas along rivers, where the high water table in the rainy season prevents dead trees from decomposition. In high latitude regions, peat is mainly composed of undecomposed herbaceous plants, and develop due to high water contents and low temperatures.

Almost four-fifths of Central Kalimantan is made up of tropical forests, producing valuable commodities such as rattan, resin, and wood of many kinds. Palangkaraya is located on the upstream regions of the Kahayan River, and covers an area of about 2,400 km^2. Plantations cover 3,139,000 ha growing palm-oil, rubber, rattan, coffee, cocoa, and coconuts. Food crops cover an area of 5,980,750 ha of paddy, cassava, pineapples, corn, bananas, rambutan, and cempedak (a locally growing fruit tree). The annual mean temperature varies between 26.8 and 28.1 °C. The lowest annual rainfall was recorded in 1996, 2001, and 2004, while the highest annual temperature was recorded in 1998, a year after the biggest forest fires ever broke out in Central Kalimantan.

11.2 Tree Species in the Peatland Forests of Central Kalimantan

The natural vegetation of an area is dictated by a combination of several factors: topography, altitude, geology, soils, climate, and water supply. Kalimantan lies on the equator in a region experiencing high temperatures throughout the year and is within the wettest parts of Indonesia. These conditions and its geological history have resulted in high species diversity. Kalimantan supports of the largest areas of tropical rainforests in Southeast Asia, providing the most species-rich habitat of this region. Long monitoring and field surveys of tree diversity in peatland forests have mainly focused on Central Kalimantan.

A total of 927 species of flowering plants and ferns have been recorded in the peatland forests (Yule 2010). A decade of research in the peatland forest, recorded 103, 73, and 187 species in the Bawan, Hampangen, and Sebangau Villages, respectively (Rahajoe 2003; Anonim 2010). Tree species numbers were lower than the number of species that were recorded in the Sebangau peatland. The total of plant species that were recorded in Sebangau, Bawan, and Hampangen were about 426 (Annex 1). This number is only 42.5 % of the total number of plant species in the peatland forests of Kalimantan. The data from our study site reported 61 species found in the heath forests of Lahei Village, and 22 species in the heath and peatland forests.

Locations were selected for monitoring the biodiversity, biomass estimates, and carbon stock and these included the Sebangau, Bawan, Hampangen, Lahei, and Klampangan peatland forests. The forest that was monitored was described as comprising intact and degraded peatland forests, based on the tree species dominance and from the history of the location based the information of the villagers in surrounding areas.

The density of trees with GBH (Girth at Breast Height) $\geq$15 cm were between 1,475 and 3,809 ha^{-1}, the basal area ranging from 25.1 to 45.5 m^2 ha^{-1}, and the number of tree species 69–134 in the Peatland forests (Suzuki et al. 1998; Simbolon and Mirmanto 2000; Miyamoto et al. 2007; Mirmanto 2010) and our study site in Central Kalimantan (Table 11.1). The species dominance varied among the locations and were *Combretocarpus rotundatus* and *Cratoxylum glaucum* in the peatland forests after forest fires or in degraded peatland forests such as in the Klampangan and Hampangen villages, while in the intact peatland forests the dominant species were *Palaquium leiocarpum* and *Vatica oblongifolia* in the Sebangau and Lahei Villages, respectively. Suzuki et al. (1998) and Nishimura and Suzuki (2001), reported that the forest community (for trees $\geq$15 cm trunk girth) consisted of 69 species and was dominated by *Vatica oblongivolia* Hook f. ssp. *oblongifolia* Ashton, *Buchanania sessilifolia* Blume, and *Gluta rugulosa* Ding Hou in the Lahei peatland forest. This peatland forest consisted of some large trees where trunk diameters reached 100.2 cm with the tallest trees 30 m high. The density of trees with GBH $\geq$15 cm in the forest community was 1,475 ha^{-1}, and the basal area was 45.5 m^2 ha^{-1}.

The Klampangan peatland forest was dominated by: *Combretocarpus rotundatus, Palaquium cochlorifolium, Cratoxylum glaucum*, *Callophyllum canum,* and *Ctenolophon parvifolius* and this forest was degraded due to establishment of a man made canal and wildfires in 1997 and 2002 (Table 11.1). After the forest fires of 2002, the dominant species were: *C. rotundatus, C. arborescens, Palaquium gutta, Shorea teysmaniana* and *Syzygium ochneocarpum*. Of 1,158 individuals; 1,102 individuals had grown after the wildfires, while the remaining 56 individuals were pre-fire trees that had survived the wildfires of December 1997, they mostly belong to: *C. canum, C. rotundatus, Dyera lowii, and P. gutta* (Simbolon 2004). In September 2002, wildfires burnt all trees for the second time, only two individuals,

Table 11.1 Data of field studies in the peatland and heath forests of Central Kalimantan

Locations	GBH ≥15 cm ($ha^{-1)}$	Basal area (m^2 ha^{-1})	Number of species	Dominant species
Heath forest[d]	1982	27.6	122	1. *Calophyllum pulcherrimum* 2. *Tristaniopsis obovata* 3. *Palaquium leiocarpum*
Heath forest (Bawan Village)[d]	2207	30.32	49	1. *Calophyllum elegans* Ridley 2. *Hopea ferruginea* Parijs 3. *Ternstroemia aneura* Miq.
Peatland forest (Lahei)[a]	1475	45.5	69	1. *Vatica oblongifolia* ssp. *oblongifolia* 2. *Buchanania sessilifolia* 3. *Gluta rugulosa*
Peatland forest (Klampangan)[b]	3014	33.2	88	1. *Combretocarpus rotundatus* 2. *Calophyllum canum* 3. *Cratoxylum glaucum*
Peatland forest Sebangau[c]	2689	31.5	103	1. *Palaquium leiocarpum* 2. *Combretocarpus rotundatus* 3. *Eugenia catnaneum*
Peatland forest (Hampangen)[d]	3809	25.1	134	1. *Cratoxylum glaucum* Korth 2. *Garcinia rigida* Miq. 3. *Nephelium ramboutan-ake* Leenh

Note: [a]Suzuki (1998); [b]Simbolon (2004); [c]Mirmanto (2010). [d]field study (unpublished data) in note

Table 11.2 Tree inventories (GBH ≥15 cm) in the sampling of peat and heath forests, Central Kalimantan, Indonesia

Variable	Hampangen (peat forest)	Bawan (heath forest)
Species richness	14.9	40.1
Diversity indices		
(a) Shannon-Wiener (H)	1.4	1.6
(b) Simpson (D)	16.4	16.5
(c) Evenness (E)	0.8	0.7
Stem density	3,809 tree ha^{-1}	2,207 tree ha^{-1}
Stand basal area	25.18 m^2 ha^{-1}	30.32 m^2 ha^{-1}

both *D. Lowii,* were still standing and producing new leaves in August 2004, and both these individuals had also survived the first wildfires. In August 2004 or about 2 years after the second round of wildfires the floor of the peatland after the second year of wildfires was covered by 12 species of herbs and seedlings, which were mainly the ferns *Stenochlaena palustris* (Burm.f.) Bedd. and *Blechnum indicum*. Species richness and diversity indices of peat forest in Hampangen and heath forest in Bawan area was found in Table 11.2.

In Hampangen, the altitude is 50 m above sea level (asl) in the secondary peatland forest. Forest fires have burned through this forest, and the area will be developed into an oil palm plantation. The rate of plant population growth and species composition establishment is rapid in the early phase of a succession, and then decline. The rate of plant population growth and change in species composition in the next stage are affected by environmental factors and are not suitable to support the survival of certain species in the regeneration (Marsono and Sastrosumarto 1981 in Irwanto 2006).

11.2.1 Species Composition

The waterlogged condition, the high level of acidity and organic materials, the low input of nutrients, and the lack of soil or firm ground in peatland forests have resulted in different forest structures. In one of our permanent plots in Bawan village, the trees were dominated by 53 pioneer species, with small diameters and high tree density per hectare. The sampling plot was dominated by species of *Cratoxylum glaucum* and *Garcinia rigida*. Both species had higher relative densities (RD) than other species (>10) and *C. glaucum* is often found to be dominant in the peat of burned forests. Other species are also widely encountered including *Syzygium garcinifolium*, *S. moultonii*, and *Nephelium ramboutan-ake*, as shown in the Table 11.3.

The high density also directly affects the high basal area of a species, to result in high relative coverage (RC). The Importance value (IV) of both types showed that all three variables, basal area, presence in a subplot, and density were high for both dominant species. This also indicates that those species are able to compete well in utilizing water resources, nutrients, and growing space. A dominant species is a species that can utilize the environmental factors more efficiently than other species in the same place (Smith 1977), giving it higher productivity (Odum 1971). Some species typical of peatland forests was found in the sampling plot, *Palaquium rostratum*, *P. ridleyii*, *P. leiocarpum*, *Tetramerista glabra*, *Camnosperma auriculatum,* and *Dyera costulata*.

In Bawan village, there are around 135 species with trees generally shorter and smaller than those of lowland mixed dipterocarp forests, and the characteristics of the type of forest detailed by Whitmore (1984) and Kartawinata (1980). This forest also had a low, uniform and single layer canopy formed by the crowns of large saplings and thin stems Although only a low number of individual trees was observed, the basal area and species composition in the area was slightly larger than in peat areas (Table 11.4), indicating that some trees had large gbh values (girth at breast height), >110 cm, these included *Dipterocarpus borneensis*, *Shorea teysmaniana*, *S. rugosa*, *S. brunnescens,* and *Hopea ferruginea*. The in heath forests the genera of *Shorea*, *Hopea,* and *Tristaniopsis* were also found (Whitmore 1984).

Table 11.3 List of the 30 most common species in the tree inventories (GBH ≥15 cm) in the sampling plot of peat forest in Hampangen, Central Kalimantan, Indonesia

No	Species name	RC	RF	RD	IV
1	*Cratoxylum glaucum* Korth	18.4	6.2	14.3	38.9
2	*Garcinia rigida* Miq.	15.1	6.6	11.2	33.0
3	*Nephelium ramboutan-ake* Leenh.	5.0	5.5	5.9	16.3
4	*Syzygium garcinifolium* (King.) Merr. & Perry	3.6	5.6	6.9	16.1
5	*Horsfieldia crassifolia* (HK.f.etsh) Warb.	4.9	5.7	5.1	15.8
6	*Lhitocarpus leptogyne* (Korth.) Hatusima	4.9	5.1	5.3	15.4
7	*Palaqium rostratum* Burck.	6.8	3.3	4.9	15.0
8	*Syzygium moultonii* Merr.n.sp	3.2	5.3	6.1	14.5
9	*Combretocarpus rotundatus* (Miq) Danser	6.4	2.6	3.1	12.1
10	*Shorea teysmaniana* Dyer.	3.5	3.5	3.1	10.0
11	*Acronychia porteri* Hook.f.	2.1	4.0	3.9	10.0
12	*Tetramerista glabra* Miq.	3.4	3.4	2.2	8.9
13	*Palaquium ridleyii* K.& G.	2.6	3.5	2.8	8.9
14	*Tristaniopsis merguensis* (Griff.) P G.Willson	1.6	2.9	3.1	7.5
15	*Bouea oppositifolia* (Roxb.) Meisn	1.9	2.9	2.6	7.4
16	*Syzygium creaghii* (Ridl.) Merr & Perry	1.1	2.9	2.3	6.3
17	*Xylopia fusca* Maing.	1.5	2.4	1.4	5.3
18	*Camnosperma auriculatum* (Bl) Hook.f.	1.6	1.9	1.4	5.0
19	*Palaquium leiocarpum* Boerl.	1.7	1.9	1.2	4.8
20	*Syzygium valdevenosa* Duhie	1.4	2.2	1.1	4.7
21	*Ilex* cf *hypoglauca* (Mig.) Loes.	0.9	2.0	1.7	4.7
22	*Calophyllum canuum*	0.9	1.9	1.3	4.1
23	*Garcinia* sp.	0.5	2.2	1.1	3.8
24	*Disepalum coronatum* Beccarii	1.1	1.8	0.9	3.7
25	*Sterculia coccinea* Jack.	0.5	1.9	1.0	3.3
26	*Dalbergia ferruginea*	1.1	1.3	0.7	3.1
27	*Neonauclea calycina* (Korth) Merr.	0.3	1.3	0.7	2.3
28	*Diospyros polyalthoides* Korth.ex Hieron	0.3	1.2	0.6	2.1
29	*Tristaniopsis whitiana* (Griff.) P G.Willson	0.3	1.2	0.6	2.1
30	*Dyera costulata* Hook.f	0.6	0.9	0.5	2.0

Note: RC, RF, RD, and IV are respectively, relative coverage, relative frequency, relative density, and importance value

The sampling plot was dominated by the species *Calophyllum elegans* followed by *H. ferruginea*, *Ternstroemia aneura,* and *Calophyllum calcicola*. The dominant tree species had high IV, larger than 15, indicating that those species are crucial in an ecosystem (Heriyanto 2004).

The basic study of ecosystem services and the biodiversity survey recorded that 12 species of timbers and 14 medicinal plants were commonly used by the local inhabitants before 1960s in the Bawan Village. The survey among Bawan villagers

Table 11.4 List of the 30 most common species in tree inventories (GBH ≥15 cm) in the sampling plot of a heath forest in Bawan, Central Kalimantan, Indonesia

No	Species name	RC	RF	RD	IV
1	*Calophyllum elegans* Ridley	9.6	7.1	18.5	35.2
2	*Hopea ferruginea* Parijs	6.1	5.7	9.5	21.3
3	*Ternstroemia aneura* Miq.	5.2	5.5	6.9	17.6
4	*Calophyllum calcicola* P.F. Stevens	7.3	3.1	5.8	16.2
5	*Shorea rugosa* Heim.	8.9	3.6	2.6	15.0
6	*Baccaurea javanica* (BL) Muell Arg.	2.2	5.3	3.9	11.5
7	*Mangifera swintonioides* Kosterm.	2.9	3.5	3.5	9.9
8	*Neoscortechinia kingii* (Hook.f.) Pax.	3.9	3.1	2.6	9.6
9	*Dipterocarpus elongatus* Korth.	6.3	1.7	1.1	9.0
10	*Tristaniopsis obovata* (Benn.)	3.4	2.1	1.9	7.4
11	*Shorea brunnescens* Ashton.	5.1	1.3	0.9	7.3
12	*Stemonurus secundiflorus* Bl.	2.3	2.5	2.4	7.2
13	*Kayea borneensis* P.F. Stevens	3.2	1.8	1.6	6.7
14	*Gluta wallichii* (Hook. f) Ding Hou.	2.5	2.3	1.5	6.4
15	*Shorea* cf. *faquetiana* Heim.	2.7	1.5	1.5	5.7
16	*Syzygium ochneocarpa* Merr.	0.7	2.4	2.4	5.6
17	*Shorea atrinervosa* Sym.	1.0	1.9	2.2	5.1
18	*Ilex cymosa* Bl.	1.1	1.8	1.7	4.6
19	*Garcinia nitida* Pierre	0.9	2.0	1.6	4.5
20	*Parastemon urophyllus* A. DC.	1.2	1.6	1.6	4.4
21	*Lithocarpus dasystachyus* Miq.) Rehd.	1.0	1.8	1.2	4.1
22	*Syzygium cerinum* (M.R.Hend.)	0.4	1.8	1.5	3.7
23	*Croton oblongus* Burm.f.	1.1	1.3	1.0	3.5
24	*Diospyros curaniopsis* Bakh.	0.4	1.8	1.4	3.5
25	*Elaeocarpus petiolosus*	1.5	0.9	0.7	3.1
26	*Plectronia glabra* Kurz.	0.3	1.4	0.9	2.6
27	*Ilex macrophylla* wall. Ex hook. f.	0.7	1.1	0.8	2.6
28	*Calophyllum venulosum* Zoll.	0.3	1.1	0.9	2.3
29	*Syzygium* sp.	0.8	0.8	0.6	2.2
30	*Santiria laevigata* Bl.	0.4	1.0	0.8	2.2

Note: RC, RF, RD and IV are respectively, relative coverage, relative frequency, relative density, and importance value

showed that since 2006 only six kinds of timber trees and four medicinal plants were commonly found in the forest. The population of major timber species Benuas and Meranti of the *Shorea* timber group) declined after the 1960s. This tendency was also found for medicinal plants.

11.3 Nutrients in the Peatland Forest

Ecosystem services are the conditions and processes through which natural ecosystems and the species sustain and assist in human life. They represent the multiple benefits human beings can obtain, either directly or indirectly, from the available ecosystem functions (Daily 1997). Many of these are very crucial to human survival (food and fiber, watershed protection, climate modulation, nutrient cycling, and habitats for plants and animals). Economic evaluations of ecosystem services are becoming increasingly important to understand the multiple benefits provided by ecosystems (Guo et al. 2001).

Nutrient cycling in forests involves a complex set of direct and indirect feedback mechanisms between soil and vegetation. Tropical forest ecosystems are characterized by high primary production and rapid decomposition rates of organic matter (Jordan 1985). The nutrient input and output of the ecosystem of the peatland discussed here are shown in Table 11.5, with a total biomass of about 351.9 t ha^{-1} from the accumulation of the aboveground biomass, litterfall, and the litter on the forest floor. This value is higher than in the heath forest.

The literfall in the tropical forest varied among the ecosystems. The litterfall ranges from 3.1 to 15.3 t ha^{-1} $year^{-1}$ (Vitousek 1984). The litterfall in temperate forest is 3.1–3.8 t ha^{-1} $year^{-1}$ (Vogt et al. 1986). In Borneo it was reported to range from 5.7 to 12.0 t ha^{-1} $year^{-1}$ and the lowest litterfall was reported for heath forests (Moran et al. 2000). While in the degraded and intact peatland forests in Lahei and Klampangan Villages, the litterfall were recorded as around 6.5 and 9.1 t ha^{-1} $year^{-1}$ respectively (Rahajoe 2003). This was reflected by the high contribution of the leaf litter of the dominant species, such as *Combretocarpus rotundatus* and *Cratoxylum glaucum*, their leaves were accumulated during the rainy season.

Litter biomass on the forest floor was high in peatland forests, here the higher canopy mass of peatland forests resulted in a greater accumulation of litter on the forest floor, due to the low rate of decomposition in peatland forests (Table 11.5). This suggests that the nutrient cycling is slower in peatland forests.

Table 11.5 Biomass inputs and outputs in heath and peatland forests

Components	Heath forest	Peatland forest
Biomass (t ha^{-1})	232[b]	336[b]
Canopy leaf mass (t ha^{-1})	5.9[a]	12.0[a]
Annual litterfall (t ha^{-1} $year^{-1}$)	6.2[a]	9.1[a]
Annual leaf litterfall (t ha^{-1} $year^{-1}$)	3.4[a]	5.9[a]
Litter in the forest floor (t ha^{-1})	7.5[a]	6.8[a]
Leaf turnover rate ($year^{-1}$)	0.5[a]	0.8[a]
Total biomass	245.7[a]	351.9[a]

Note: [a] Rahajoe (2003)

[b] Based on allometric equation for both forest types (Biomass = x $Diameter^y$; x and y represented as constant values)

Table 11.6 Estimated nitrogen and carbon supply from leaf litterfall (mean ± SE; n = 4)

	Heath forest		Peat forest[a]	
	N	C	N	C
Components	($kg\ ha^{-1}\ year^{-1}$)		($kg\ ha^{-1}\ year^{-1}$)	
Leaves >1 cm	20.6 ± 1.9	1537.0 ± 60.2	20.1 ± 0.9	1164.0 ± 41.8
Leaves <1 cm	0.8 ± 0.1	59.2 ± 6.5	0.4 ± 0.001	23.6 ± 3.0
Stem <2 cm	10.1 ± 2.4	853.2 ± 176.1	11.2 ± 1.5	788.4 ± 152.7
Reproductive parts	2.4 ± 0.7	128.1 ± 29.8	3.7 ± 0.6	139.2 ± 32.3
Others	3.4 ± 0.8	146.4 ± 23.7	2.8 ± 0.5	111.2 ± 25.9
Total	37.4 ± 5.2	2,724 ± 268	39.1 ± 1.3	2,227 ± 123

[a] The estimation of N and C in peatland forest based on the 10-month data excluding rainy season. Rahajoe (2003)

The decomposition and nutrient cycling occur rapidly in some tropical rain forests, but as the present study shows there are slow cycling environments in particular forest types. This is both due to the high concentration of lignin in the leaf litter of the dominant species and water logging of the humus layer as well as to the low amount of standing biomass of heath and peatland forests (Rahajoe 2003).

The total nitrogen supply from leaf litterfall was higher in peatland forests than in heath forests (39.1 ± 1.3 and 37.4 ± 5.2 kg ha^{-1} $year^{-1}$ respectively) (Table 11.6). while the opposite was the case for carbon ($P < 0.01$) (2,227 ± 123 and 2,724 ± 268 kg ha^{-1} $year^{-1}$ respectively). The nitrogen content of fallen litter was higher in peatland forests than in heath forests. The idea that heath forests are N-limited compared to peatland forests is consistent with the findings in other tropical forest types on white sand substrates (Cuevas and Medina 1986). The high level of nitrogen supply in peatland forests was due to the high rate of leaf litterfall, and also due to a high nitrogen concentration in the peatland forests (0.8–1.2 %). Although the nitrogen supply was high in peatland forests. the slow decomposition rate was a cause of the slow turnover of the nutrients. Therefore, even though a peatland forest is known as an ecosystem, this nutrient component (N) is not available for plant uptake. The carbon supply in forests was higher than in peatland forests, even though the litterfall was higher in the peatland forests, which is possibly because the carbon concentration of all litter components was higher in the heath forests than in the peatland forests (Rahajoe 2003). In the heath forest, the combination of low litter production and high decomposition may lead to a high rate of nutrient cycling.

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Annex 1

Plant species in the peatland forests in various locations in Central Kalimantan

No	Species	Family	Heath forest	Peatland forest Bawan village	Peatland Hampangen	Peatland Sebangau[a, b]	Peatland Tuanan[b]
1	*Acronychia pedunculata* (L.) Miq.	Rutaceae					✓
2	*Acronychia porteri* Hook.f.	Rutaceae			✓		
3	*Adenanthera malayana* Kosterm.	Fabaceae					✓
4	*Adenanthera pavonina* L.	Fabaceae				✓	
5	*Agathis borneensis* Warb.	Araucariaceae			✓		
6	*Aglaia rubiginosa* (Hiern) Pannell	Meliaceae				✓	
7	*Aglaia silvestris* (M.Roem) Merr.	Meliaceae		✓			
8	*Aglaonema nitidum* (Jack) Kunth.	Araceae				✓	
9	*Alseodaphne coriacea* Kosterm.	Lauraceae				✓	✓
10	*Alseodaphne glomerata*	Lauraceae				✓	
11	*Alseodaphne* sp.2	Lauraceae					✓
12	*Alyxia reinwardtii* Blume	Apocynaceae				✓	
13	*Antidesma coriaceum* Tul.	Euphorbiaceae	✓			✓	
14	*Antidesma montanum* Blume	Euphorbiaceae				✓	
15	*Appendicula* sp.4	Orchidaceae				✓	
16	*Archidendron borneense* (Benth.) I.C.Nielsen	Fabaceae			✓	✓	
17	*Archidendron* sp.	Fabaceae					
18	***Ardisia oxyphylla* Wall. ex A.DC.**	Myrsinaceae	✓				
19	***Ardisia sanguinolenta* Blume**	Myrsinaceae	✓				
20	*Aromadendron nutans* Dandy	Magnoliaceae	✓			✓	
21	***Austrobuxus nitidus* Miq.**	Euphorbiaceae	✓				

(continued)

(continued)

No	Species	Family	Heath forest	Peatland forest Bawan village	Peatland Hampangen	Peatland Sebangau$^{a, b}$	Peatland Tuanan^{b}
22	*Baccaurea bracteata* Müll.Arg.	Euphorbiaceae		✓		✓	✓
23	*Baccaurea javanica* (Blume) Müll.Arg.	Euphorbiaceae	✓	✓			
24	*Baccaurea stipulata* J.J.Sm.	Euphorbiaceae				✓	
25	***Baccaurea sumatrana* (Miq.) Müll.Arg.**	Euphorbiaceae	✓				
26	*Blechnum indicum* Burm f.	Blechnaceae				✓	
27	*Blumedendron tokbrai* (Blume) Kurz	Euphorbiaceae		✓		✓	
28	*Blumeodendron elateriospermum* J.J.Sm.	Euphorbiaceae				✓	
29	*Bouea macrophylla* Griff.	Anacardiaceae				✓	
30	*Bouea oppositifolia* (Roxb.) Adelb.	Anacardiaceae			✓		
31	*Buchanania* sp.	Anacardiaceae					✓
32	*Calophyllum elegans*	Clusiaceae	✓				
33	*Calophyllum longiforum*	Clusiaceae	✓				
34	*Calophyllum biflorum* M.R.Hend. & Wyatt-Sm.	Clusiaceae				✓	
35	*Calophyllum calcicola* P.F. Stevens	Clusiaceae	✓	✓			
36	*Calophyllum canum* Hk.f.	Clusiaceae		✓	✓	✓	
37	*Calophyllum confertum* P.F. Stevens	Clusiaceae	✓				
38	*Calophyllum elegans* Ridl.	Clusiaceae		✓			
39	*Calophyllum fragrans* Ridl.	Cluciaceae				✓	
40	***Calophyllum gracilipes* Merr.**	Clusiaceae	✓				
41	*Calophyllum hosei* Ridl.	Clusiaceae				✓	
42	*Calophyllum inophyllum* L.	Clusiaceae				✓	
43	***Calophyllum lanigerum* Miq.**	Clusiaceae	✓				
44	*Calophyllum lowii* Hook.F	Clusiaceae		✓			
45	*Calophyllum nodusum*	Clusiaceae					✓
46	***Calophyllum pseudomolle* P.F. Stevens**	Clusiaceae	✓				

47	*Calophyllum sclerophyllum* Vesque	Clusiaceae				✓	
48	*Calophyllum soualattri* Burm.f.	Clusiaceae		✓			
49	*Calophyllum* sp.	Clusiaceae				✓	
50	*Calophyllum teysmannii* Miq.	Clusiaceae				✓	
51	*Calophyllum venulosum* Zoll.	Clusiaceae		✓			
52	*Camnosperma auriculatum* (Bl) Hook.f.	Anacardiaceae			✓	✓	
53	*Campnosperma coriaceum* (Jack) Hallier f.	Anacardiaceae				✓	✓
54	*Campnosperma squamatum* Ridl.	Anacardiaceae				✓	
55	***Canarium caudatum* King**	Burseraceae	✓				
56	*Canarium* sp.1	Burseraceae				✓	
57	*Canthium confertum* Korth.	Rubiaceae				✓	
58	*Canthium didymum* C.F.Gaertn.	Rubiaceae				✓	
59	***Carallia brachiata* (Lour.) Merr.**	Rhizophoraceae	✓				
60	***Carallia calophylloidea* Ding Hou**	Rhizophoraceae	✓				
61	*Carallia* sp.1	Rhizophoraceae					✓
62	*Castanopsis foxworthyi* Schottky	Fagaceae				✓	✓
63	***Castanopsis tungurrut* (Blume) A.DC.**	Fagaceae	✓				
64	*Cephalomappa* sp. 1	Euphorbiaceae				✓	
65	cf. *Anisoptera* sp. 1	Dipterocarpaceae				✓	
66	cf. *Cubilia cubili*	Sapindaceae				✓	
67	cf. *Rapanea borneensis*	Primulaceae				✓	
68	***Chaetocarpus castanocarpus* (Roxb.) Thwaites**	Euphorbiaceae	✓				
69	*Cinnamomum iners* Reinw. ex Blume	Lauraceae		✓			
70	***Cinnamomum javanicum* Blume**	Lauraceae	✓				
71	***Cleistanthus brideliifolius* C.B.Rob.**	Euphorbiaceae	✓				
72	*Combretocarpus rotundatus* (Miq.) Danser	Rhizophoraceae		✓	✓	✓	
73	*Combretum tetralophum* C.B.Clarke	Combretaceae				✓	

(continued)

(continued)

No	Species	Family	Heath forest	Peatland forest Bawan village	Peatland Hampangen	Peatland Sebangau[a, b]	Peatland Tuanan[b]
74	*Connarus cf. semidecandrus* Jack.	Connaraceae				√	
75	*Cotylelobium burckii* (Heim) Heim	Dipterocarpaceae	√				
76	*Cotylelobium lanceolatum* Craib	Dipterocarpaceae		√		√	
77	*Cotylelobium melanoxylon* (Hook.f.) Pierre	Dipterocarpaceae				√	√
78	*Cratoxylon arborescens*	Hypericaceae				√	
79	*Cratoxylum glaucum* Korth.	Hyperiaceae	√	√	√	√	
80	*Croton oblongus* Burm.f.	Euphorbiaceae	√	√			
81	*Cryptoaria* sp.1	Lauraceae					√
82	*Cryptocarya mentek* Blume ex Nees	Lauraceae			√		
83	*Ctenolophon parvifolius* Oliv.	Linaceae		√		√	
84	*Cyathocalyx biovulatus* Boerl.	Annonaceae		√			
85	*Cyperus sp.*	Ciperaceae				√	
86	*Dactylocladus stenostachys* Oliv.	Melastomataceae		√		√	
87	*Dalbergia ferruginea* Roxb.	Fabaceae			√		
88	***Daphniphyllum laurinum* (Benth.) Baill.**	Daphniphyllaceae	√				
89	*Davallia solida* Ogata	Davalliaceae				√	
90	*Dendrophthoe pentandra* (L.) Miq.	Loranthaceae				√	
91	*Derris heptaphylla* (L.) Merr.	Leguminosae				√	
92	*Dialium indum* L.	Fabaceae					√
93	*Dialium patens* Baker	Fabaceae	√	√			
94	*Dialium platysepalum* Baker	Fabaceae		√			
95	*Dicranopteris linearis* (Burm. f.) Underw.	Gleicheniaceae				√	
96	*Diospyros bantamensis* Koord. & Valeton ex Bakh	Ebenaceae		√		√	√
97	*Diospyros* cf. *Evena*	Ebenaceae				√	

98	***Diospyros* cf. *hermaphroditica* (Zoll.) Bakh.**	Ebenaceae	✓				
99	*Diospyros confertiflora* (Hiern) Bakh.	Ebenaceae				✓	
100	*Diospyros curraniopsis* Bakh.	Ebenaceae		✓			
101	***Diospyros curranii* Merr.**	Ebenaceae	✓				
102	*Diospyros dajakensis* Bakh.	Ebenaceae				✓	
103	*Diospyros foxworthyi* Bakh.	Ebenaceae				✓	
104	*Diospyros hermaphroditica* (Zoll.) Bakh. ex Steenis	Ebenaceae	✓			✓	
105	*Diospyros maingayi* (Hiern) Bakh.	Ebenaceae				✓	
106	***Diospyros oblonga* Wall. ex G.Don**	Ebenaceae	✓				
107	*Diospyros pendula* Hasselt ex Hassk.	Ebenaceae			✓	✓	
108	*Diospyros polyalthioides* Hiern	Ebenaceae			✓		
109	*Diospyros pseudomalabarica* Bakh.	Ebenaceae				✓	
110	*Diospyros siamang* Bakh.	Ebenaceae				✓	✓
111	*Diospyros* spp. (exc. *bantamensis*/*pseudo-malabarica* and *siamang*)	Ebenaceae					✓
112	*Diospyros toposioides* King & Gamble	Ebenaceae		✓			
113	*Dipterocarpus acutangulus* Vesque	Dipterocarpaceae		✓			
114	*Dipterocarpus borneensis* Slooten	Dipterocarpaceae		✓			
115	*Dipterocarpus elongatus* Korth.	Dipterocarpaceae	✓	✓			
116	*Dipterocarpus fagineus* Vesque	Dipterocarpaceae					✓
117	*Disepalum coronatum* Becc.	Annonaceae			✓		
118	*Drynaria sparsisora* (Desv.) T. Moore	Polypodiaceae				✓	
119	*Dryobalanops lanceolata* Burck	Dipterocarpaceae				✓	
120	*Dyera costulata* (Miq.) Hook.f.	Apocynaceae		✓	✓	✓	
121	*Dyera lowii* Hook.f.	Apocynaceae				✓	✓
122	*Dyera polyphylla* (Miq.) Steenis	Apocynaceae				✓	

(continued)

(continued)

No	Species	Family	Heath forest	Peatland forest Bawan village	Peatland Hampangen	Peatland Sebangau[a, b]	Peatland Tuanan[b]
123	***Elaeocarpus petiolosus* F.Muell.**	Elaeocarpaceae	√				
124	*Elaeocarpus acmocarpus* Stapf ex Weibel	Elaeocarpaceae			√		
125	*Elaeocarpus* cf. *griffithii*	Elaeocarpaceae				√	
126	*Elaeocarpus floribundus* Blume	Elaeocarpaceae				√	
127	*Elaeocarpus griffithii* (Wight) A.Gray	Elaeocarpaceae	√		√		
128	*Elaeocarpus marginatus* Stapf ex Weibel	Elaeocarpaceae				√	
129	*Elaeocarpus mastersii* King	Elaeocarpaceae				√	√
130	*Elaeocarpus ovalifolius* Wall. ex Müll.Berol.	Elaeocarpaceae				√	
131	*Elaeocarpus petiolatus* (Jacq.) Wall.	Elaeocarpaceae	√	√			
132	*Elaeocarpus* sp.	Elaeocarpaceae				√	
133	*Elatostema* sp.	Urticaceae				√	
134	***Elongatus* sp.**	Dipterocarpaceae	√				
135	*Embelia* sp.	Primulaceae				√	
136	*Endiandra rubescens* (Blume) Miq.	Lauraceae			√		
137	*Engelhardia serrata* BL	Juglandaceae		√			
138	*Eugenia castaneum*	Myrtaceae				√	
139	*Eugenia cerina* M.R.Hend.	Myrtaceae		√			
140	*Eugenia* cf. *spicata*	Myrtaceae				√	
141	*Eugenia densinervia Merr.*	Myrtaceae				√	
142	*Euthemis leucocarpa* Jack	Ochnaceae				√	
143	*Fagraea auriculata* Jack	Gentianaceae				√	
144	*Fagraea ceilanica* Thunb.	Gentianaceae				√	
145	*Fagraea racemosa* Jack	Gentianaceae				√	
146	*Fibraurea chloroleuca* Miers	Menispermaceae				√	
147	*Ficus consociata* Blume	Moraceae				√	

148	*Ficus deltoidea* Jack	Moraceae			✓	✓	
149	*Ficus* sp.1	Moraceae				✓	
150	*Ficus* sp.2	Moraceae				✓	
151	*Ficus sumatrana* Miq.	Moraceae				✓	
152	*Ficus xylophylla* (Miq.) Wall. ex Miq.	Moraceae				✓	
153	*Freycinetia angustifolia* Blume	Pandanaceae				✓	
154	*Gaertnera vaginans* (DC.) Merr.	Rubiaceae				✓	
155	*Garcinia bancana* Miq.	Clusiaceae	✓	✓		✓	
156	***Garcinia candiculata* Ridl.**	Clusiaceae	✓				
157	*Garcinia* cf. *parvifolia*	Clusiaceae					✓
158	***Garcinia* cf. *vidua* Ridley**	Clusiaceae	✓				
159	*Garcinia forbesii* King	Clusiaceae			✓		
160	*Garcinia havilandii* Stapf	Clusiaceae		✓			
161	***Garcinia merguensis* Wight**	Clusiaceae	✓				
162	*Garcinia nitida* Pierre	Clusiaceae		✓			
163	*Garcinia rigida* Miq.	Clusiaceae		✓	✓		
164	***Garcinia rostrata* Hassk. ex Hook.f.**	Clusiaceae	✓				
165	*Garcinia* sp.	Clusiaceae			✓		
166	*Garcinia* spp. (exc. cf. *parvifolia*. SA sp. 1 and TU sp.1)	Clusiaceae				✓✓	✓
167	*Garcinia vidua* Ridl.	Clusiaceae		✓			
168	*Gardenia leiocarpum*	Clusiaceae					✓
169	*Gardenia pterocalyx* Valeton	Rubiaceae				✓	
170	*Gardenia tubifera* Wall. ex Roxb.	Rubiaceae				✓	
171	*Glochidion rubrum* Blume	Phyllanthaceae				✓	
172	***Gluta aptera* (King) Ding Hou**	Anacardiaceae	✓				
173	***Gluta renghas* L.**	Anacardiaceae	✓				
174	*Gluta sabahana* Ding Hou	Anacardiacea			✓		

(continued)

(continued)

No	Species	Family	Heath forest	Peatland forest Bawan village	Peatland Hampangen	Peatland Sebangau[a, b]	Peatland Tuanan[b]
175	*Gluta wallichii* (Hook.f.) Ding Hou	Anacardiaceae		✓			
176	*Gnetum neglectum* Blume	Gnetaceae				✓	
177	*Gonystylus bancanus* (Miq.) Kurz	Thymelaeacea				✓	
178	*Guioa diplopetala* (Hassk.) Radlk.	Sapindaceae			✓		
179	*Gymnacranthera contracta* Warb.	Myristicaceae				✓	
180	*Gymnacranthera eugeniifolia* (A.DC.) J.Sinclair	Myristicaceae				✓	
181	*Gymnacranthera farquhariana* (Hook.f. & Thomson) Warb.	Myristicaceae					✓
182	***Gymnacranthera forbesii* (King) Warb.**	Myristicaceae	✓				
183	*Gymnostoma sumatranum* (Jungh. ex de Vriese) L.A.S.Johnson	Casuarinaceae				✓	
184	*Gynotroches* sp.1	Rhizophoraceae				✓	
185	*Hopea beccariana* Burck	Dipterocarpaceae		✓			
186	***Hopea* cf. *cernua* T. et B**	Dipterocarpaceae	✓				
187	*Hopea ferruginea* Parijs	Dipterocarpaceae	✓	✓			
188	***Horsfieldia brachiata* (King) Warb.**	Myristicaceae	✓				
189	*Horsfieldia crassifolia* (Hook.f. & Thomson) Warb.	Myristicaceae		✓	✓	✓	✓
190	*Horsfieldia glabra* (Reinw. ex Blume) Warb.	Myrysticaceae		✓			
191	***Horsfieldia irya* (Gaertn.) Warb.**	Myristicaceae	✓				
192	*Horsfieldia polyspherula* (Hook.f. ex King) J.Sinclair	Myristicaceae		✓			
193	*Ilex* cf. *hypoglauca* (Mig.) Loes.	Aquifoliaceae			✓		
194	***Ilex* cf. *macrophylla* Wall. ex hook. f.**	Aquifoliacea	✓				

195	*Ilex cymosa* Blume	Aquifoliaceae	√	√			
196	*Ilex hypoglauca* Loes.	Aquifoliaceae				√	
197	*Ilex macrophylla* wall. Ex hook. f.	Aquifoliaceae		√			
198	*Ilex pleiobrachiata* Loes.	Aquifoliaceae			√		
199	***Ilex wallichii* Hook. f.**	Aquifoliacea	√	√		√	
200	*Isonandra lanceolata* Wight	Sapotaceae				√	
201	*Isonandra* sp.1	Sapotaceae				√	
202	*Ixora havilandii* Ridl.	Rubiaceae				√	
203	*Kayea borneensis* P.F.Stevens	Calophyllaceae		√			
204	***Knema cf. latericia* Elmer**	Myristicaceae	√				
205	*Knema cinerea* Warb.	Myristicaceae				√	
206	*Knema intermedia* Warb.	Myristicaceae				√	
207	*Knema latericia* Elmer	Myristicaceae				√	
208	*Knema laurina* Warb.	Myrysticaceae		√			
209	*Kokoona ovatolanceolata* Ridl.	Calastraceae			√		
210	*Koompassia malaccensis* Benth.	Leguminosae				√	√
211	*Labisia acuta* Ridl.	Primulaceae				√	
212	*Labisia pumila* (Blume) Mez.	Primulaceae				√	
213	*Lepironia articulata* (Retz.) Domin	Cyperaceae				√	
214	*Lithocarpus leptogyne* (Korth.) Soepadmo	Fagaceae			√		
215	*Licania splendens* (Korth.) Prance	Chrysobalanaceae				√	√
216	*Lithocarpus rassa* (Miq.) Rehder	Fagaceae		√			
217	*Lithocarpus bancanus* (Scheff.) Rehder	Fagaceae				√	
218	***Lithocarpus* cf. *gracilis* (Korth) Soepadmo**	Fagaceae	√				
219	*Lithocarpus conocarpus* (Oudem.) Rehder	Fagaceae		√			
220	*Lithocarpus dasystachyus* (Miq.) Rehder	Fagaceae	√	√			
221	*Lithocarpus elegans* (Blume) Hatus. ex Soepadmo	Fagaceae				√	

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No	Species	Family	Heath forest	Peatland forest Bawan village	Peatland Hampangen	Peatland Sebangau[a, b]	Peatland Tuanan[b]
222	***Lithocarpus korthalsii* (Endl.) Soepadmo**	Fagaceae	✓				
223	*Lithocarpus leptogyne* (Korth.) Soepadmo	Fagaceae		✓			
224	*Lithocarpus* spp.	Fagaceae				✓	✓
225	*Litsea angulata* Blume	Lauraceae			✓		
226	*Litsea* cf. *elliptica*	Lauraceae				✓	
227	*Litsea* cf. *resinosa*	Lauraceae				✓	
228	*Litsea* cf. *rufo-fusca*	Lauraceae				✓	
229	*Litsea elliptica* Blume	Lauraceae		✓			
230	*Litsea fufo-fusca*	Lauraceae				✓	
231	*Litsea gracilipes* Hemsl.	Lauraceae				✓	
232	*Litsea* spp.	Lauraceae				✓	✓
233	*Lophopetalum javanum* Turcz.	Celasteraceae				✓	
234	*Lophopetalum* sp.1	Celesteraceae				✓	
235	*Lucinaea bilitonensis* Valleton	Rubiaceae				✓	
236	*Lycopodiella cernua* (L.) Pic. Serm.	Lycopodiaceae				✓	
237	*Macaranga caladifolia* Becc.	Clusiaceae				✓	
238	***Macaranga peltata* (Roxb.) Müll.Arg.**	Clusiaceae	✓				
239	*Macrosolen retusus* Blume	Loranthaceae				✓	
240	*Madhuca korthalsii* (Pierre ex Burck) H.J.Lam	Sapotaceae		✓			
241	*Madhuca motleyana* (de Vriese) J.F.Macbr.	Sapotaceae				✓	✓
242	*Magnolia bintuluensis* (A.Agostini) Noot.	Magnoliaceae				✓	
243	*Magnolia* sp.	Magnoliaceae					✓
244	*Mangifera swintonioides* Kosterm.	Anacardiaceae		✓			
245	*Medinilla crassifolia* Blume.	Melastomataceae				✓	

246	*Melastoma malabathricum* L.	Melastomataceae				✓	
247	***Memecylon edule* Roxb.**	Melastomataceae	✓				
248	*Memecylon* sp.1	Melastomataceae				✓	
249	*Mesua* sp.1	Clusiaceae				✓	
250	*Mezzettia leptopoda* (Hook. f. & Thomson) Oliv.	Annonaceae				✓	✓
251	*Mezzettia umbellata* Becc.	Annonaceae				✓	
252	*Mezzettia parviflora* Becc.	Annonaceae		✓		✓	
253	*Microcos* sp.	Tiliaceae					✓
254	*Mussaendopsis beccariana* Baill.	Rubiaceae					✓
255	*Myristica lowiana* King	Myristicaceae				✓	
256	***Myristica maxima* Warb.**	Myristicaceae	✓				
257	*Neonauclea calycina* (Bartl. ex DC.) Merr.	Rubiaceae			✓		
258	*Neoscortechinia kingii* (Hook.f.) Pax & K.Hoffm.	Euphorbiaceae	✓	✓	✓		✓
259	*Neoscortechinia philippinensis* (Merr.) Welzen	Euphorbiaceae				✓	
260	*Nepenthes mirabilis* (Lour.) Druce	Sapindaceae				✓	
261	*Nepenthes ampullaria* Jack	Sapindaceae				✓	
262	*Nepenthes gracilis* Korth.	Sapindaceae				✓	
263	*Nephelium lappaceum* L.	Sapindaceae				✓	
264	*Nephelium mangayi* Hiern	Sapindaceae	✓	✓			
265	*Nephelium ramboutan-ake* (Labill.) Leenh.	Sapindaceae			✓		
266	*Nephelium lappaceum* L.	Sapindaceae				✓	
267	*Nephelium mangayi* Hiern	Sapindaceae				✓	
268	*Nephellium* sp.1	Sapindaceae				✓	
269	*Nepenthes rafflesiana* Jack	Sapindaceae				✓	
270	*Nephrolepis hirsutula* (G. Forst.) C. Presl	Davalliaceae				✓	

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No	Species	Family	Heath forest	Peatland forest Bawan village	Peatland Hampangen	Peatland Sebangau$^{a, b}$	Peatland Tuanan^{b}
271	*Notaphoebe* sp.1	Lauraceae				✓	
272	*Notaphoebe umbeliflora*	Lauraceae					✓
273	*Pachycentria constricta* Blume	Melastomataceae				✓	
274	*Afzelia rhomboidea* (Blanco) S.Vidal	Fabaceae		✓			
275	***Palaquium gutta* (Hook.) Burck**	Sapotaceae	✓				
276	*Palaquium leiocarpum* Boerl.	Sapotaceae		✓			
277	*Palaquium ridleyi* King & Gamble	Sapotaceae		✓			
278	*Palaquium rostratum* (Miq.) Burck	Sapotaceae		✓	✓		
279	*Palaquium calophyllum* (Teijsm. & Binn.) Pierre ex Burck	Sapotaceae		✓			
280	*Palaquium cochleariifolium* P.Royen	Sapotaceae				✓	✓
281	***Palaquium dasyphyllum* Pierre ex Dubard**	Sapotaceae	✓				
282	*Palaquium leiocarpum* Boerl.	Sapotaceae		✓	✓	✓	✓
283	*Palaquium pseudorostratum* H.J.Lam	Sapotaceae				✓	✓
284	*Palaquium ridleyii*/cf. *xanthochymum*	Sapotaceae				✓	
285	*Palaquium ridleyi* King & Gamble	Sapotaceae					
286	*Palaquium rostratum* (Miq.) Burck	Sapotaceae			✓		
287	*Palaquium sumatranum* Burck	Sapotaceae		✓			
288	*Pandanus* sp.	Pandanaceae				✓	
289	*Parartocarpus venenosa* Becc.	Moraceae				✓	✓
290	*Parastemon urophyllus* (Wall. ex A.DC.) A.DC.	Chrysobalanaceae		✓			
291	***Payena* cf. *khoonmengiana* J.T.Pereira**	Sapotaceae	✓				
292	*Payena leerii* (Teijsm. & Binn.) Kurz	Sapotaceae				✓	✓
293	*Phoebe* cf. *grandis* (Nees) Merr.	Lauraceae				✓	

294	*Pimelodendron griffithianum* (Müll.Arg.) Benth. ex Hook.f.	Euphorbiaceae				√	
295	*Piper* sp.	Piperaceae				√	
296	*Pittosporum* sp.1	Pittosporaceae				√	
297	*Platea excelsa* Blume	Icacinaceae				√	
298	*Platea* sp.	Icacinaceae					√
299	*Platea* sp.1	Icacinaceae				√	
300	*Canthium glabrum* Blume	Rubiaceae	√	√			
301	*Ploiarium alternifolium* (Vahl) Melch.	Theaceae			√	√	√
302	***Podocarpus neriifolius* D.Don**	Podocarpaceae	√				
303	*Poikilospermum suaveolens* (Blume) Merr.	Urticaceae				√	
304	*Polyalthia glauca* (Hassk.) Boerl.	Annonaceae				√	
305	***Polyalthia glauca* (Hassk.) Boerl.**	Annonaccea	√				
306	*Polyalthia hypoleuca* Hook.f. & Thomson	Annonaceae				√	√
307	*Polyalthia sumatrana* (Miq.) Kurz	Annonaceae				√	
308	*Pometia pinnata* J.R. Forst. & G. Forst.	Sapindaceae					√
309	*Pouteria* cf. *malaccensis* (C.B.Clarke) Baehni	Sapotaceae					√
310	***Prunus grisea* Kalkman**	Rosaceae	√				
311	*Psychotria* sp.	Rubiaceae				√	
312	*Psychotria viridiflora* Reinw. ex Blume	Rubiaceae				√	
313	*Pteridium aquilinum* (L.) Kuhn	Dennstaedtiaceae				√	
314	*Pteris* sp.	Pteridaceae				√	
315	*Vitis cissoides* (Blume) Backer	Vitaceae				√	
316	*Pternandra* cf. *coerulescens/galeata*	Melastomataceae				√	
317	*Pternandra echinata* Wall.	Melastomataceae		√			
318	*Pternandra reticulata* (Cogn) Ohwi	Melastomataceae		√			
319	*Pyrostria* sp.	Rubiaceae				√	

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No	Species	Family	Heath forest	Peatland forest Bawan village	Peatland Hampangen	Peatland Sebangau[a, b]	Peatland Tuanan[b]
320	*Quassia borneensis* Noot.	Simaroubaceae				√	
321	***Rapanea borneensis*** **(Scheff.) Mez**	Myrsinaceae	√				
322	*Rhodamnia cinerea* Jack	Myrtaceae					√
323	*Rhodomyrtus tomentosa* (Aiton) Hassk.	Myrtaceae				√	
324	*Rothmannia grandis*	Rubiaceae				√	
325	*Sagaraea lanceolata* Miq.	Annonaccea	√		√		
326	*Sandoricum beccarianum* Baill.	Meliaceae				√	√
327	*Sandoricum borneense* Miq.	Meliaceae			√		
328	*Sandoricum emarginatum* Hiern	Meliaceae				√	
329	*Santiria apiculata* A.W.Benn.	Burseraceae	√				
330	*Santiria griffithii* Engl.	Burseraceae		√		√	
331	*Santiria laevigata* Blume	Burseraceae	√	√			
332	*Santiria rubiginosa* Blume	Burseraceae		√			
333	*Santiria* spp.	Burseraceae				√	√
334	*Sarcotheca* spp.	Oxalidaceae					√
335	*Shorea atrinervosa* Symington	Dipterocarpaceae		√			
336	*Shorea balangeran* Burck	Dipterocarpaceae				√	
337	*Shorea bracteolata* Dyer	Dipterocarpaceae	√			√	
338	*Shorea brunnescens* P.S.Ashton	Dipterocarpaceae	√	√			
339	*Shorea* cf. *bracteolata* Dyer	Dipterocarpaceae		√			
340	*Shorea* cf. *faguetiana* F.Heim	Dipterocarpaceae		√			
341	***Shorea*** **cf.** ***gibbosa*** **Brandis**	Dipterocarpaceae	√				
342	***Shorea*** **cf.** ***scaberrima*** **Burck**	Dipterocarpaceae	√				
343	*Shorea crassa* P.S.Ashton	Dipterocarpaceae				√	
344	*Shorea guiso* Blume	Dipterocarpaceae				√	

345	*Shorea leprosula* Miq.	Dipterocarpaceae		✓			
346	***Shorea materialis* Ridl.**	Dipterocarpaceae	✓				
347	*Shorea parvifolia* Dyer	Dipterocarpaceae					✓
348	*Shorea parvistipulata* F.Heim.	Dipterocarpaceae					✓
349	***Shorea retusa* Meijer**	Dipterocarpaceae	✓				
350	*Shorea rugosa* F.Heim	Dipterocarpaceae	✓	✓			
351	*Shorea* sp.	Dipterocarpaceae	✓				
352	*Shorea teysmanniana* Dyer ex Brandis	Dipterocarpaceae	✓	✓	✓	✓	
353	*Shorea uliginosa* Foxw.	Dipterocarpaceae				✓	
354	*Sindora leiocarpa* de Wit	Fabaceae	✓	✓			
355	*Sloetia elongata* Koord.	Moraceae			✓		
356	*Stemonurus scorpioides* Becc.	Icacinaceae		✓	✓	✓	
357	*Stemonurus secundiflorus* Blume	Icacinaceae	✓	✓	✓	✓	
358	*Stemonurus umbellatus* Becc.	Icacinaceae			✓		
359	*Stenochlaena palustris* (Burm. f.) Bedd.	Blechnaceae				✓	
360	*Sterculia bicolor* Mast.	Sterculiaceae				✓	
361	*Sterculia coccinea* Roxb.	Sterculiaceae			✓		
362	*Sterculia rhoidifolia* Stapf ex Ridl.	Sterculiaceae				✓	
363	Sterculia sp.	Sterculiaceae				✓	✓
364	*Swintonia glauca* Engl.	Anacardiaceae		✓			
365	*Syzygium caudatilimbum* (Merr.) Merr. & L.M.Perry	Myrtaceae		✓			
366	*Syzygium oligomyrum* Diels	Myrtaceae		✓			
367	***Syzygium bankense* (Hassk.) Merr. & L.M.Perry**	Myrtaceae	✓				
368	***Syzygium borneense* (Miq.) Miq.**	Myrtaceae	✓				
369	*Syzygium myrtifolium* Walp.	Myrtaceae				✓	

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No	Species	Family	Heath forest	Peatland forest Bawan village	Peatland Hampangen	Peatland Sebangau[a, b]	Peatland Tuanan[b]
370	*Syzygium castaneum* (Merr.) Merr. & L.M.Perry	Myrtaceae		√			
371	*Syzygium caudatilimbum* (Merr.) Merr. & L.M.Perry	Myrtaceae		√			
372	*Syzygium incarnatum* (Elmer) Merr. & L.M.Perry	Myrtaceae	√	√			
373	***Syzygium chloranthum* (Duthie) Merr. & L.M.Perry**	Myrtaceae	√				
374	*Syzygium claviflorum* (Roxb.) Wall. ex A.M.Cowan & Cowan	Myrtaceae				√	
375	*Syzygium creaghii* (Ridl.) Merr. & L.M.Perry	Myrtaceae			√		
376	*Syzygium densinervium* (Merr.) Merr.	Myrtaceae	√			√	
377	***Syzygium ecostulatum* (Elmer) Merr.**	Myrtaceae	√				
378	*Syzygium garciniifolium* (King) Merr. & L.M.Perry	Myrtaceae	√		√	√	
379	*Syzygium glanduligerum* (Ridl.) Merr. & L.M.Perry	Myrtaceae	√				
380	*Syzygium havilandii* (Merr.) Merr. & L.M.Perry	Myrtaceae				√	√
381	*Syzygium inophyllum* DC.	Myrtaceae				√	
382	*Syzygium laxiflorum* (Blume) DC.	Myrtaceae		√			
383	***Syzygium lineatum* (DC.) Merr. & L.M.Perry**	Myrtaceae	√				
384	***Syzygium macromyrtus* (Koord. & Valeton) Merr. & L.M.Perry**	Myrtaceae	√				
385	*Syzygium moultonii* (Merr.) Merr. & L.M.Perry	Myrtaceae		√	√		

386	*Syzygium muelleri* (Miq.) Miq	Myrtaceae		✓			
387	*Syzygium oligomyrum* Diels	Myrtaceae		✓			
388	*Syzygium remotifolium* (Ridl.) Merr. & L.M.Perry	Myrtaceae				✓	
389	*Syzygium* sp.	Myrtaceae	✓	✓			
390	*Syzygium* sp.1	Myrtaceae		✓			
391	*Syzygium* cf. *spicata*	Myrtaceae				✓	✓
392	***Syzygium tawahense* (Korth.) Merr. & L.M.Perry**	Myrtaceae	✓				
393	*Syzygium valdevenosum* (Duthie) Merr. & L.M.Perry	Myrtaceae		✓	✓	✓	
394	***Syzygium zeylanicum* (L.) DC**	Myrtaceae	✓				
395	*Tarenna fragrans* (Blume) Koord. & Valeton	Rubiacea				✓	
396	*Tarenna* sp.	Rubiacea				✓	
397	*Ternstroemia aneura* Miq	Theaceae	✓	✓			
398	*Ternstroemia hosei* Ridl	Theaceae				✓	
399	*Ternstroemia magnifica* Stapf ex Ridl	Theaceae				✓	
400	*Tetractomia tetrandra* (Roxb.) Merr	Rubiaceae		✓		✓	
401	*Tetramerista glabra* Miq	Tetrameristaceae			✓	✓	
402	*Thrixspermum* sp.	Sebangau				✓	
403	*Timonius flavescens* (Jacq.) Baker	Rubiaceae			✓	✓	
404	***Trigonopleura malayana* Hook.f.**	Euphorbiaceae	✓				
405	***Tristaniopsis merguensis* subsp. *Merguensis***	Myrtaceae	✓				
406	*Tristaniopsis merguensis* (Griff.) Peter G.Wilson & J.T.Waterh.	Myrtaceae		✓	✓		
407	*Tristaniopsis obovata* (Benn.) Peter G.Wilson & J.T.Waterh	Myrtaceae		✓		✓	

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No	Species	Family	Heath forest	Peatland forest Bawan village	Peatland Hampangen	Peatland Sebangau[a, b]	Peatland Tuanan[b]
408	Tristaniopsis spp.	Myrtaceae				✓	✓
409	*Tristaniopsis whiteana* (Griff.) Peter G.Wilson & J.T.Waterh	Myrtaceae		✓	✓	✓	
410	*Uncaria gambir* (Hunter) Roxb.	Rubiaceae				✓	
411	*Urceola brachysepala* Hook.f.	Apocynaceae				✓	
412	*Vatica mangachapoi* Blanco	Dipterocarpaceae				✓	
413	***Vatica umbonata* Burck**	Dipterocarpaceae	✓				
414	*Xanthophyllum ellipticum* Korth. ex Miq.	Polygalaceae		✓		✓	
415	*Xanthophyllum eurhynchum* Miq.	Polygalaceae				✓	
416	*Xanthophyllum palembanicum* Miq.	Polygalaceae				✓	
417	*Xanthophyllum amoenum* Chodat	Polygalaceae				✓	
418	*Xanthophyllum ellipticum* Korth. ex Miq.	Polygalaceae		✓			
419	*Xerospermum laevigatum/noronhianum*	Sapindaceae				✓	✓
420	***Xerospermum noronhianum* Blume**	Sapindaceae	✓				
421	*Xylopia* cf. *malayana* Hook.f. & Thomson	Annonaceae				✓	
422	*Xylopia coriifolia* Ridl.	Annonaceae				✓	
423	*Xylopia elliptica* Maingay ex Hook.f.	Annonaceae				✓	
424	*Xylopia fusca* Maingay ex Hook.f. & Thomson	Annonaceae		✓	✓	✓	✓
425	*Xylopia malayana* Hook.f. & Thomson	Annonaceae		✓			
426	*Xylopia* spp. (exc. fusca)	Annonaceae					✓

[a] Mirmanto (2010), [b] Anonim (2010) and Duma (2007)

Bold indicates species found only in the heath forest in Lahei Village

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Chapter 12
Peat-Fire Impact on Forest Structure in Peatland of Central Kalimantan

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Abstract Tropical peatland forests are unique ecosystems, because of their extreme acidic, anaerobic and nutrient poor conditions. They support diverse forms of flora, fauna and microbes with many endemic and endangered species. In Central Kalimantan, peat fire has been a serious problem since the last decade. Peat fire is a major cause of peatland degradation that leads to loss of biodiversity and carbon stocks. In this study, we evaluated the impact of fire disturbance to forest structure and reforestation from the comparison among peatland forests with different disturbance severity. Results from current research revealed that (1) un-burnt forest

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maintained higher tree species diversity, larger basal area and trunk volume index than burnt forests, (2) once-burnt forest showed potential capacity of high recovery, (3) the forest affected fire showed significant floristic and structural changes and difficulty of recover.

Keywords Disturbed forest • Human disturbance • Peat swamp forest • Reforestation • Rehabilitation • Slash-and-burn farming

12.1 Introduction

Tropical peatland forests are unique ecosystems, because of their extreme acidic, anaerobic and nutrient poor conditions. They support diverse forms of flora, fauna and microbes with many endemic and endangered species. However, almost all regional peatlands are threatened and destroyed by logging, drainage, agricultural development (plantation of oil palm and rubber, and farmland for rice, coconut and pineapple), fire or other human activities. In Sumatra and Kalimantan, peat fire has been a serious problem since the last decade. Peat fire is a major cause of peatland degradation that leads to loss of biodiversity and carbon stocks. Analysis using Satellite Pour I'Observation de la Terre (SPOT) image clarified that less than 4 % of the peatland areas remain covered by intact peatland forests, while 37 % are covered by peatland forests with varying degrees of degradation, and over 20 % is considered to be unmanaged degraded landscape, occupied by ferns, shrubs and secondary forests in Sumatra and Kalimantan (Miettinen and Liew 2010). Langner and Siegert (2009) defined that about 21 % of the land surface (16.2 Mha) has been affected by fire at least once and 6 % of it suffered fire disturbance more than one time in Borneo over a 10-year span from 1997 to 2006. The fire dominantly localized on the Indonesian side and carbon rich peatland forest ecosystems were most severely affected. Page et al. (2002) estimated that under the 1997 El Nino event, 32 % (0.79 Mha) had burnt in the 2.5 Mha study area in Central Kalimantan and of which 91.5 % (0.73 Mha) was peatlands. According to their estimation, 0.19–0.23 Gt of carbon was released into the atmosphere through peat combustion and 0.05 Gt of carbon was released from burning of the overlying vegetation. When peat is ignited, fire will develop underground slowly and may spread vertically and horizontally dominated by a smoldering process. Finally, peat fire will destroy an ecosystem completely and change the environment drastically. Because, peatland forests are sustained in the sensitive balance among a deep water table, canopy cover and leaf litter inputs (Yule 2010), forest recovery would be difficult after a fire. In other words, it may be said that this type of landscape is highly susceptible to further degradation and slow to regenerate into forests (Page et al. 2009). In this study, we evaluated the impact of fire disturbance to forests.

We studied (1) how tree species composition, biomass (carbon stocks) and forest structure will be changed after peat fire, (2) how forests will recover after peat fire, (3) is the level different according to peat fire severity ? We compared tree species composition, forest structure and reforestation according to disturbance severity by peat fire.

12.2 Study Sites

The study was carried out in the Hampangen Educational Forest (HEF) of the University of Palangka Raya, Kabupaten Kasongan, Central Kalimantan, Indonesia. HEF is located at 1°53′S, 113 °28′ E, at 42 m above sea level. The entire area of 5,000 ha HEF is covered by about 4–6 m shallow peat soil. Palangka Raya, the provincial capital of Central Kalimantan, is located about *ca*. 70 km south-southeast of the study site. An average annual precipitation was *ca*. 2,800 mm (1993–1997) at Palangka Raya, with monthly averages ranging from 80 mm in August to 370 mm in January. The dry season occurs from July to October, when mean monthly rainfall is <130 mm. In the rainy season, some parts of HEF will be flooded by a long spell of rain. The topography of the study site was generally flat. However, the elevation increases gently from roadside to inside forest. Then, groundwater and flooding level is higher near the road. On the other hand, in the dry season, some parts of HEF will suffer severe damage by human-induced-peat fire. Consequently, a mixed distribution of un-burnt and burnt forests is created in the HEF.

12.3 Research Methods

Three 0.2 ha (20 × 100 m) transect plots (P1, P2 and P3) were established in the peatland forest in December 2010. To identify the impact of peat fire to tree species composition, forest structure and recovery, the plots were set up according to disturbance severity by peat fire. P1, P2 and P3 were located in un-burnt forest, burnt forest in 1997, and burnt forest in 1997 and 2009, respectively (Fig. 12.1). All trees with GBH (girth at breast height) more than 15 cm within the plots were identified and their species were recorded. Tree height (H) was also measured for all trees. For trees measured in the plots, herbarium specimens were collected, treated with alcohol, and then sent to Research Center for Biology, Indonesian Institute of Sciences (RCB-LIPI) in Cibinong for further identification. Based on GBH, DBH (diameter at breast height) and tree basal area were calculated. Shannon's diversity (H') and evenness as the equitability index of Pielou (J') were calculated to obtain the overall vegetation characteristics (Zar 1999). To estimate dry mass of the trunk, trunk volume index (D^2H; cm^2 m 0.2 ha^{-1}) was calculated. To compare DBH and tree height among plots, GLM (Generalized liner model) was used with Gamma distribution.

To evaluate the dissimilarity of species composition among the three sites, the Bray-Curtis dissimilarity index was calculated based on the density of species in each plot. Bray-curtis dissimilarity index (BC_{jk}) is defined as follows:

$$BC_{jk} = \frac{\sum_{i=1}^{n} \left|X_{ij} - X_{ik}\right|}{\sum_{i=1}^{n} \left(X_{ij} + X_{ik}\right)} \tag{12.1}$$

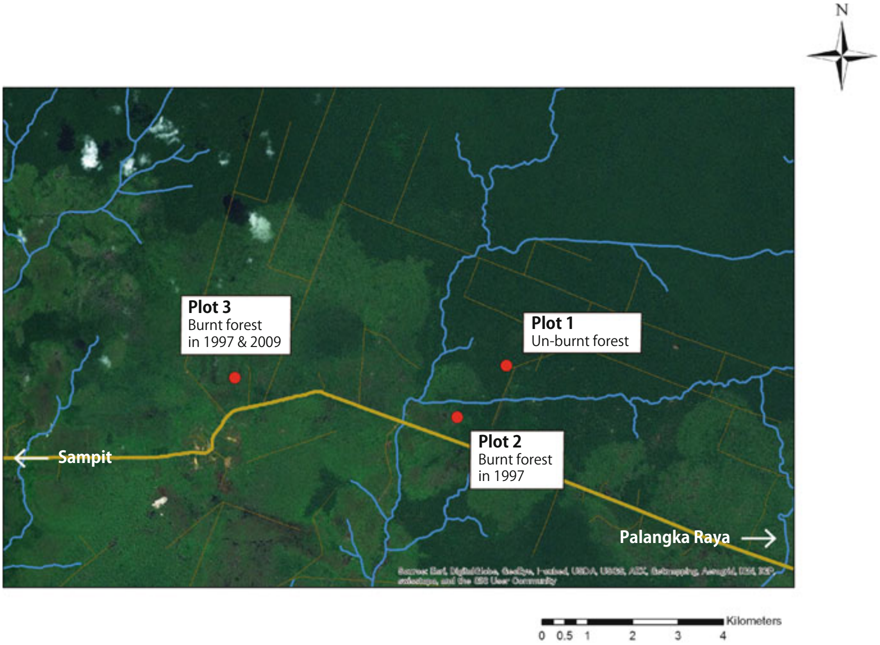

Fig. 12.1 Map of study sites

where species composition of community j is $(X_{ij},\ \ldots\ X_{nj})$ and species composition of community k is $(X_{ik},\ \ldots\ X_{nk})$.

Allometric relationships between DBH and H were regressed by the following equation:

$$\mathrm{Log}\,(\mathrm{H}) = a + b\mathrm{Log}\,(\mathrm{DBH})\,, \tag{12.2}$$

where a and b are the regression parameters. Analysis of covariance (ANCOVA) with Bonferroni correction was used for comparison of regression coefficients for linier allometric relationships.

All statistical analyses were performed using R 2.15.3, package “vegan” version 2.0-8 and “labdsv” version 1.5-0.

12.4 Species Composition

Our results showed that forest structure among the three plots was different in consequence of peat fire as indicated by distinctive characteristics. We found 47 species (29 families) in P2 and the species number was close to 61 species (31 families) in P1 (Table 12.1), although, there were only 5 species (5 families) in P3.

Table 12.1 Tree density, number of species, basal area, median DBH and tree height, Shannon's diversity (H'), the equitability index of Pielou (J') and trunk volume index of 0.2 ha transect plots in three un-burnt and burnt forests

Plot	Tree density (0.2 ha^{-1})	Number of species (families) (0.2 ha^{-1})	Basal area (m^2 0.2 ha^{-1})	Median DBH (cm)	Median tree height (m)	H'	J'	Trunk volume index (cm^2 m 0.2 ha^{-1})
P1	465	61 (31)	5.71	8.02^a	12.1^a	3.55	0.86	185.3
P2	742	47 (29)	3.75	6.69^b	10.4^b	3.16	0.82	57.3
P3	364	5 (5)	3.69	9.74^a	10.3^b	0.50	0.31	52.3

The difference of median DBH and height were analyzed using Generalized liner model (GLM)
The same superscripts (a, b) indicate that there is no significant difference between plots ($P < 0.05$)

The largest value of tree density was 742 0.2 ha^{-1} in P2, which was followed by 465 0.2 ha^{-1} in P1 and 364 0.2 ha^{-1} in P3. Basal area displayed different tendencies. P1 had the largest basal area (5.71 m^2 0.2 ha^{-1}) among the three plots. The values of P2 and P3 were 3.75 m^2 0.2 ha^{-1} and 3.69 m^2 0.2 ha^{-1}, respectively. Basal area of P1 was very similar with that of Setia Alam than Lahei (Miyamoto et al. 2016, this book). Miyamoto et al. (2016) suggested that the lower basal area in Setia Alam was probably due to the difference in species composition, especially due to the lack of large-sized Anacardiaceae and Dipterocarpaceae trees. The species might have been cut down by selective logging in the past. So, Hampangen have also been disturbed to the same extent as in Setia Alam (Simbolon and Mirmanto 2000). P1 is located about 2 km inside of the forest from the road. Although we could not determine the fire history in this study, the position and current forest structure of P1 might illustrate that there were no forest fires. The median DBH and tree height were 8.02 cm and 12.1 m in P1, 6.69 cm and 10.4 m in P2, and 9.74 cm and 10.3 m in P3. Trunk volume index (cm^2 m 0.2 ha^{-1}) of P1 (185.3) was about three times larger than those of P2 (57.3) and P3 (52.3), respectively. The lowest H' was obtained from plot P3 (0.50), which was burnt in 1997 and 2009. Contrary to our expectations, P1 and P2 showed similar H' values (3.55 and 3.16). J' was 0.86, 0.82 and 0.31 in P1, P2 and P3, respectively. The values indicated a lower species diversity and higher evenness in P3. Figure 12.2 indicated the tendency clearly. The slopes of P1 and P2 were steep only for the first few species abundance rankings, and the lines curved in a moderate hollow shape to around 50–60 species rankings. This meant that P1 and P2 included many rare species. However, the curve of P3 was very steep and the hyperbolic line was formed with just a few common species.

When we compared species composition, the similarity between P1 and P2 was clear. The value of the Bray-Curtis dissimilarity index between P1–P2 was 0.64, P1–P3 was 0.99, and P2–P3 was 0.83, respectively (Table 12.2). The difference between species composition of P3 with the other two sites was larger than that of P1 with P2. In P1, the dominant species were *Palaquium leiocarpus* Boerl. and *Stemonurus umbellatus* Becc. Whereas P2 and P3 dominated by *Combretocarpus rotundatus* (Miq.) Danser and *Cratoxylum glaucum* Korth. In P3, almost all individuals were *C.*

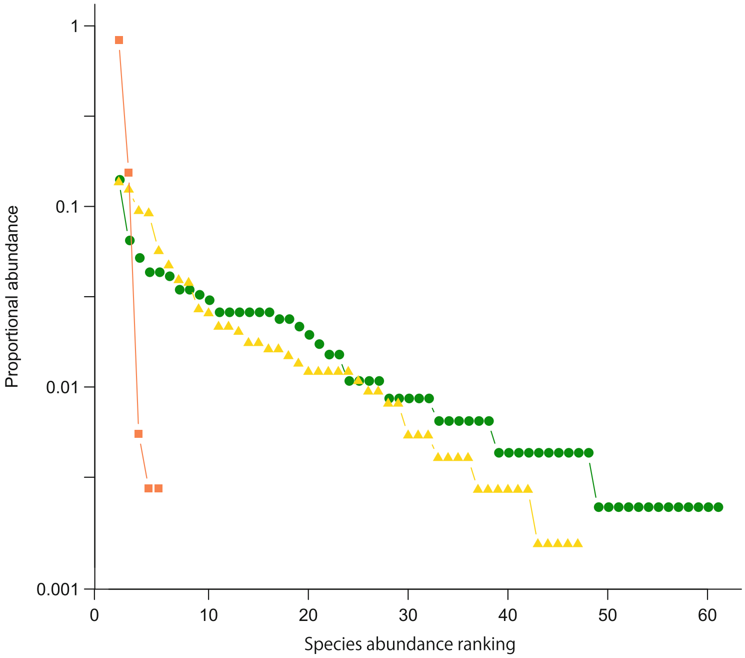

Fig. 12.2 The proportional abundance of the tree species according to fire severity level are ranked from commonest to rerest in the three plots. *Green circle*, P1 (un-burnt forest); *yellow triangle*, P2 (burnt forest in 1997); *orange square*, P3 (burnt forest in 1997 and 2009)

Table 12.2 The unsimilarity of species composition among three transect plots. The Bray-Curtis dissimilarity index was used

	P1	P2	P3
P1	–	0.64	0.99
P2	–	–	0.83

rotundatus. Generally, *C. rotundatus* and *C. glaucum* were found in an after-burnt site which was well-lighted and opened. *C. rotundatus* survives peat fire and sprouts new stem easily. This species makes huge amount of seeds and spreads them to the burnt area. We can found almost pure forest of *C. rotundatus* after heavily burnt site. However, the percentage of the species decreases according to succession. *C. rotundatus* seems to be an light-demanding species. The fact that dominant species in P2 was *C. rotundatus* showed that the forest had not yet mature. The proportion of species that was found only in P1 was 23/61 species (37.7 %), although it was 9/47 species (19.1 %) in P2. The value was highest in P3 and only 3/5 species was selected (60.0 %). *C. rotundatus* and *C. glaucum* were found in all three sites. However, only the percentage of *C. rotundatus* increased with the disturbed level by fire (P1 < P2 < P3). This species was one of the dominant species at suffered site in Kalampangan, Central Kalimantan (Simbolon 2004).

It is well known that forest fires are also huge issue in Amazon region. Change of forest structure and species composition after repeated fires have been detailed in various studies in Brazil (Balch et al. 2013; Hoscilo et al. 2013; Massad et al. 2013; Xaud et al. 2013). Xaud et al. (2013) revealed that the forests affected by one low-intensity fire showed only slight evidence of alteration in comparison with forests that have not burnt, although the forests affected by repeated or one high-intensity fire showed to have undergone significant floristic and structural changes. A similar trend was found in the Southern Amazon (Massad et al. 2013). Forest fires reduced the number and diversity of regenerating stems, and then community composition changed substantially after repeated fires. They found that species common in the Cerrado (tropical savanna in Brazil) became more abundant in the sites after forest fire. In the repeated or intensely burnt forest experimentally, sprouts increased and dominant species were replaced by 11 new species that often presented along fragmented forest edges (Balch et al. 2013). In the peatland, Hoscilo et al. (2013) identified the long-lasting effect of repeated fires on vegetation recovery.

Repeated fires drastically reduced not only species diversity and biomass, but also ecosystem carbon (42 %) and nitrogen (21 %) stocks along the forest-grassland gradient (Cheng et al. 2013). The reduction was caused by the disappearance of living tree biomass, and followed by the loss of soil carbon and nitrogen. In the grassland, 84 % of forest-derived carbon was lost, whereas the gain of grass-derived carbon only compensated for 18 % of the loss (Cheng et al. 2013). Moore et al. (2013) clarified that the total fluvial organic carbon flux from disturbed peatland forest was about 50 % larger than that from intact peatland forest. The leaching of dissolved organic carbon from intact peatland forest originated mainly from recent primary production (plant growth). However, dissolved organic carbon from disturbed peatland forest consisted mostly of much older carbon from deep within the peat column. The living tree biomass had decreased to one-third of un-burnt forest (P1) in two burnt forests (P2 and P3) in the current research (Table 12.1). Although, we did not identify carbon loss from peat soil, carbon loss from dead trees should be large in burnt forests.

12.5 Frequency Distributions of Tree Diameter Size and Allometric Relationships

Frequency distributions of tree diameter size indicated unimodal distributions in all three sites (Fig. 12.3). The figure also showed that the number of trees of P2 was larger than those of P1 and P3 in smaller size classes. The DBH distribution of P2 demonstrated a high frequency of small trees (3≤ DBH <10 cm), especially for the class 5–10 cm (>70 trees). It implied that many small trees had been recruiting in P2. Meanwhile, many trees had reached DBH >25 cm in P1 (maximum DBH = 46.9 cm). P2 and P3 presented a clear pattern of absence of larger DBH trees. There were no or only a few individuals more than 20 cm of DBH in P2

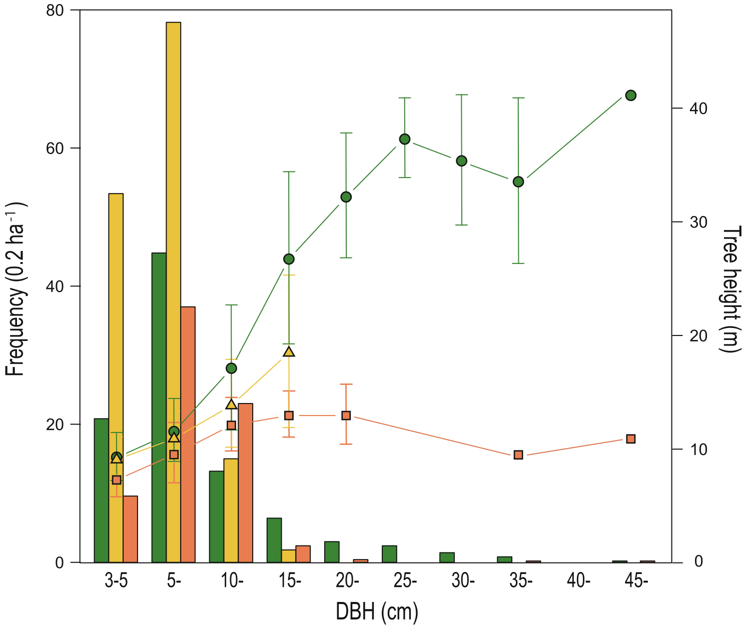

Fig. 12.3 The DBH distributions and mean tree heights with standard deviations at different level of disturbance by peat fire: *Green circle*, P1; *yellow triangle*, P2; *orange square*, P3

or P3, although P1 had many larger trees. It means that the larger trees had burnt down in previous fire in P2 (in 1997) and P3 (in 1997 or 2009). In other words, almost all trees in P2 and P3 had regenerated in the last decade. On the other hand, when P2 and P3 were compared, we found that individuals only in smaller size classes are reduced in P3, and the number of individuals in larger classes was similar between the two sites. The results indicated that the fire in 2009 was less severe than that of 1997. The different strength of effects on forest species construction due to frequency and severity of fires were also found in ombrophylous and semi-deciduous seasonal forests in Brazil's Roraima State (Xaud et al. 2013). Forests affected by one low-intensity fire showed slight evidence of alteration in comparison with those forests not having experienced fire. On the other hand, in extremely degraded forest plots, the heavily disturbed forests lost their primary-forest characteristics, showing significant floristic and structural changes and a similarity to areas of young secondary succession. However, even if the forests suffered by high intensity or repeated fire, the basal area and number of species were much higher in Brazilian forests than peatland forests in Indonesia. Although our research data are very limited, the results clarified that the vulnerability of forest ecosystems and difficulty of recover in peatland forests disturbed by repeated fires.

The mean tree heights in each DBH size class were different between the three sites. Figure 12.3 showed that P1 had taller tree heights than other plots for some

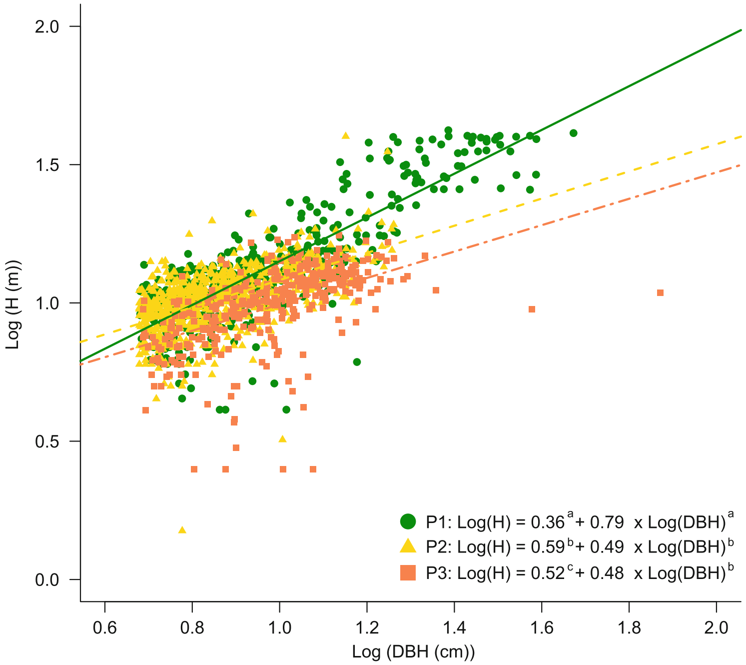

Fig. 12.4 Comparison of the allometric relationships between trunk diameter (DBH) and tree height (H), Log (H) $= a + b$ Log(DBH) in un-burnt and burnt forests. *Green circle* and *solid line*, P1; *yellow triangle* and *broken line*, P2; *orange square* and *dashed-dotted line*, P3. The regression lines of un-burnt (P1) and burnt (P2 and P3) forests are significantly different. The differences of allometric equations for each plot were analyzed using analysis of covariance (ANCOVA). The same superscripts in the equations indicate that there is no significant difference in slope or intercept between plots ($P < 0.05$ with Bonferroni correction)

DBH classes. Especially, in P2 and P3, there were fewer trees in larger DBH classes and the median tree height of all trees in their plots was 10.4 and 10.3 m, respectively (Table 12.1). On the other hand, the median tree height was 12.1 m in P1. The allometric relationships between DBH and H also demonstrated the difference among the three sites (Fig. 12.4). The slope of P1 was steeper than that of P2 and P3. Although, there was no significant difference between slope of P2 and P3, intercept was higher in P2 than that of in P3. It means that trees in P1 have taller heights and more slender trunks than trees in P2 and P3 in the same DBH. The taller trees in P2 and P3 were *C. Rotundatus*. On the other hand, they were the species in different families (Sapotaceae, Myrtaceae etc.) in P1. Then, the difference of species composition was the factor which they showed the different allometry among three plots. These characteristics in the forest structure caused the lower trunk volume index in disturbed forests (P2 and P3) as displayed in Table 12.1.

12.6 Various Successional Recoveries After Fire

The impact of forest fires on the tree diversity or ecological functions of mixed dipterocarp forests have been studied elsewhere (Kartawinata et al. 1981; Whitmore 1984; Riswan et al. 1984; Riswan and Yusuf 1986; Simbolon et al. 2002; Slik 2004; Slik and van Balen 2006; Balch et al. 2013; Hoscilo et al. 2013; Massad et al. 2013; Xaud et al. 2013). We can also find some previous researches on the effects of fire on tropical peatland forests, but their systems were poorly understood. Simbolon (2004) studied a peatland forest of 4.5 years-after wildfire in Central Kalimantan. From the effects of fire disturbance, the site had changed from forest to open land. However, after several years, it recovered to a forest that contains 1,158 trees of 103 species ha^{-1} (Fishers'$\alpha = 27.3$) over a total basal area of 7.49 m^2 ha^{-1}. The dominant species were *C. rotundatus*, *Cratoxylum arborescens*, *Palaquium gutta*, *Shorea teysmaniana* and *Syzygium ochneocarpum*. The number of individuals and total basal area were much lower than those in the drained natural peatland forest, but the species number was higher in the recovered forest. He also pointed out that the natural recovery of peat land after a second fire was supposed to be slower than after the first fire. It is said that the recovery of biomass after a fire was much slower than in tropical dry-land rainforests (Uhl 1987; Brown and Lugo 1990; Aide et al. 1995; Pinard et al. 2000; Ohtsuka 2001; Kauffman et al. 2003). When the forest recovery in peatlands (Simbolon 2004 and this study) are compared with that of Amazon (Xaud et al. 2013), it is very clear that the forests can keep potential ability for recovery after one low-intensity fire. However, the heavily or repeated fire decreased the ability. It is same with our results. Ohtsuka (2001) and Mirmanto (2011) suggested that the biomass recovery after fire was almost 1/10 of that after large-scale shifting cultivation near Kota Kinabalu in Sabah (Ohtsuka 2001) and in Central Kalimantan (Mirmanto 2011). Simbolon (2004) demonstrated that within 8 months after the second fire, the disturbed site was still an open peatland and became covered only 15.3 % by mostly pioneers of the herb fern species. Then, seedlings of shrubs and small trees were rarely found within 2 years after the second fires. Peatland forests that suffered one or low-intensity fire soon changed into a community dominated by secondary pioneer tree species of peatland forests. However, after second or high-intensity fire, the site changed to open land dominated by pioneer herb fern species; *Neprolepis* sp, *Nephrolepis falcata*, *Stenochlaena palustris* and *Blechnum orientale* (Simbolon 2004; Mirmanto 2011). This early site will change slowly into a community of pioneer secondary tree species in typical peatland forests that are mainly dominated by *C. arborescens*. This species grows from seeds carried from surrounding area and sprouted from laid stems. The dominant species in two-type burnt forests were the same (P2 and P3) and they were very different from un-burnt forest (P1) in this research (Tables 12.2 and 12.3). *C. rotundatus* and *C. glaucum* are the specific species that dominate after-burnt forest. After peat fire, these two species survive or sprout from the base of burnt stems. Moreover, *C. rotundatus* can produce flowers and fruits throughout the year. The seeds have wings and can float on water. In the rainy season, the seeds are carried

Table 12.3 Species composition of three transect plots (P1, P2 and P3), showing number of stems ≥15 cm GBH

Family	Species	Plot		
		P1	P2	P3
Anacardiaceae	*Campnosperma auriculatum* (Blume) Hook.f	12	13	–
–	*Gluta sabahana* Ding Hou	2	–	–
–	*Bouea oppositifolia* (Roxb.) Adelb	1	35	–
Annonaceae	*Disepalum coronatum* Becc	15	11	–
–	*Sageraea lanceolata* Miq.	2	–	–
–	*Xylopia fusca* Maingay ex Hook.f. & Thomson	12	4	–
Apocynaceae	*Alstonia angustifolia* Wall. ex A.DC	2	4	–
–	*Dyera costulata* (Miq.) Hook.f	3	2	–
Aquifoliaceae	*Ilex pleiobrachiata* Loes	4	–	–
–	*Ilex* cf. *hypoglauca* Loes	–	2	–
Araucariaceae	*Agathis borneensis* Warb	4	–	–
Burseraceae	*Santiria laevigata* Blume	5	2	–
Celastraceae	*Kokoona lanceolata* Ridl	2	1	–
Clusiaceae	*Calophyllum canum* Hook.f. ex T.Anderson	4	–	–
–	*Calophyllum lanigerum* Miq	3	–	–
–	*Garcinia bancana* Miq	1	9	–
–	*Garcinia forbesii* King	1	–	–
–	*Garcinia rigida* Miq	2	4	–
–	*Garcinia vidua* Ridl	2	–	–
Crypteroniaceae	*Dactylocladus stenostachys* Oliv	1	9	–
Dipterocarpaceae	*Dipterocarpus acutangulus* Vesque	7	–	–
–	*Shorea acuminata* Dyer	12	9	–
Ebenaceae	*Diospyros bantamensis* Koord. & Valeton ex Bakh	4	3	–
–	*Diospyros pendula* Hasselt ex Hassk	1	1	–
–	*Diospyros polyalthioides* Hiern	3	3	–
Elaeocarpaceae	*Elaeocarpus acmocarpus* Stapf ex Weibel	1	19	–
–	*Elaeocarpus griffithii* (Wight) A.Gray	20	7	–
Euphorbiaceae	*Baccaurea javanica* (Blume) Müll.Arg	1	8	–
–	*Neoscortechinia kingii* (Hook.f.) Pax & K.Hoffm	12	–	–
Fabaceae	*Adenanthera pavonina* L	1	–	–
–	*Archidendron borneense* (Benth.) I.C.Nielsen	–	3	–
–	*Dalbergia* cf. *ferruginea* Roxb	1	1	–
Fagaceae	*Lithocarpus leptogyne* (Korth.) Soepadmo	8	16	–
Hyperiaceae	*Cratoxylum glaucum* Korth	9	101	56
Icacinaceae	*Stemonurus scorpioides* Becc	–	10	–
–	*Stemonurus umbellatus* Becc	30	–	–
Lauraceae	*Cinnamomum iners* Reinw. ex Blume	1	–	–
–	*Cryptocarya mentek* Blume ex Nees	10	29	1
–	*Endiandra rubescens* (Blume) Miq	2	–	–
–	*Litsea angulata* Blume	–	2	–

(continued)

Table 12.3 (continued)

Family	Species	Plot		
		P1	P2	P3
Magnoliaceae	*Aromadendron nutans* Dandy	–	2	–
Meliaceae	*Aglaia silvestris* (M.Roem.) Merr	5	–	–
–	*Sandoricum borneense* Miq	14	9	–
Moraceae	*Sloetia elongata* Koord	–	3	–
–	*Ficus deltoidea* Jack	–	–	2
Myristicaceae	*Horsfieldia crassifolia* (Hook.f. & Thomson) Warb	16	68	–
–	*Horsfieldia glabra* (Reinw. ex Blume) Warb	1	–	–
Myrtaceae	*Syzygium castaneum* (Merr.) Merr. & L.M.Perry	11	6	–
–	*Syzygium creaghii* (Ridl.) Merr. & L.M.Perry	16	16	–
–	*Syzygium garcinifolium* (King.)Merr.&Perry	3	28	–
–	*Syzygium moultonii* (Merr.) Merr. & L.M.Perry	11	70	–
–	*Syzygium ochneocarpum* (Merr.) Merr. & L.M.Perry	2	12	–
–	*Syzygium valdevenosum* (Duthie) Merr. & L.M.Perry	4	13	–
–	*Tristaniopsis merguensis* (Griff.) Peter G.Wilson & J.T.Waterh	–	1	–
–	*Tristaniopsis whiteana* (Griff.) Peter G.Wilson & J.T.Waterh	3	2	–
Polygalaceae	*Xanthophyllum ellipticum* Korth. ex Miq	1	–	–
Rhizophoraceae	*Combretocarpus rotundatus* (Miq.) Danser	5	92	304
Rubiaceae	*Neonauclea calycina* (Bartl. ex DC.) Merr	3	1	–
–	*Gardenia tubifera* Wall. ex Roxb	1	–	–
–	*Plectronia glabra* (Blume) Benth. & Hook.f. ex Kurz	2	–	–
–	*Timonius flavescens* (Jacq.) Baker	7	–	–
Rutaceae	*Acronychia pedunculata* (L.) Miq	12	20	–
Sapindaceae	*Guioa diplopetala* (Hassk.) Radlk	12	7	–
–	*Nephelium ramboutan-ake* (Labill.) Leenh	24	12	–
Sapotaceae	*Palaquium leiocarpum* Boerl	65	9	–
–	*Palaquium ridleyi* King & Gamble	19	–	–
–	*Palaquium rostratum* (Miq.) Burck	20	15	–
Sterculiaceae	*Sterculia* cf. *coccinea* Jack	2	6	–
Theaceae	*Ploiarium alternifolium* (Vahl) Melch	–	–	1
–	*Tetramerista glabra* Miq	5	42	–
Number of species	–	61	47	5

everywhere in the flooded forest floor. As a result, the burnt forest will change into a pure forest of *C. rotundatus*. However, the species cannot survive under the dark closed canopy, because they are a light-demanding species. So this species will decrease gradually along succession process.

After peat fire, soil nutrient levels also became lower as compared to those of intact peatland forest (Mirmanto 2011). Repeated fires not only suppress forest regeneration, but also further combust top layers of peat, lowering the surface level. In the worst case, they change these areas to seasonal lakes of over one meter deep (Wösten et al. 2006).

Miettinen et al. (2012) researched peatland degradation and conversion processes using 50 high-resolution satellite images in Sumatra. They found that fires were not practically existent in nearly pristine peatland forests, but were highly concentrated in heavily degraded forest areas leading to either an extremely degraded landscape or conversion to agriculture. Langner and Siegert (2009) also demonstrated that the trends of fire occurrence were clearly affected by land cover types in Borneo. They clarified that the degraded lands and peatland forests showed higher fire occurrence than other land cover types (Dipterocarp, Mangrove and mountain forests). In Central Kalimantan, peat fire tends to occur near the roadside or in place where new road has been established for human activities such as logging, hunting or navigating the plantation. Especially, multiple fires that have spread due to slash-and-burn farming occur often there. The unmanaged degraded peatland areas are increasing drastically in Central Kalimantan (Langner and Siegert 2009; Page et al. 2009). In addition, establishment of channels changes the height of water table. This type of landscape is highly susceptible to further degradation and is very difficult to regenerate into forest (Page et al. 2009). A lowering of the groundwater level leads to an increase in oxidation and subsidence of peat. Moreover, peat fire also increases because of the drying land. Therefore, the groundwater level is the main control on carbon dioxide emissions from peatlands. Jaenicke et al. (2010) presented a method for rewetting of peatlands by dam constructions. They suggested establishing dams that prevent the draining of peat water and depleting carbon nutrients. However, to construct dams to the channel systems are not easy point. The most important thing is to get local government and people’s permissions.

12.7 For Recovery of Peatland Forests

The results from current research revealed that only the forest that burnt in 1997 (once-burnt forest) showed potential capacity of high recovery. In this forest, tree density was the highest among the three forests where the disturbance severity was different (Table 12.1). The number of species and H' in P2 was sufficiently higher or similar level with those of un-burnt forest (P1). The comparison of DBH distributions indicated that many small individuals were included in the once-burnt forest, although the other forests did not show such a tendency (Fig. 12.3). Because it seems that the small individuals in the once-burnt forest were recruited after peat fire in 1997, the high recruit rate would contribute to forest recovery there. However, in terms of carbon storage, the once-burnt forest is estimated to be only one third of the un-burnt forest (Table 12.1).

In terms of stand-level allometry for multiple species, marked differences among un-burnt and burnt forests were observed in the DBH-H relationship (Fig. 12.4). The DBH-H relationship indicated that trees in burnt forests had shorter stature compared to those in the un-burnt forest. In other words, trees in un-burnt forest are taller heights and more slender trunks than the others. Then, it is indicated that after-burnt forests have a different forest structure with un-burnt forest. From the difference of dominant species composition and allometry regressions between DBH and H, we concluded that after-burnt forests have a similar forest structure. They are very different from un-burnt forest and require a long time to recover.

It is indicated that the tallest forest (canopy up to 45 m) developed on the thickest and oldest peat in a forest in Central Kalimantan, and the low pole forest (up to 20 m) and mixed swamp forest (upper canopy 35 m) developed on the thinner and younger peat (Page et al. 1999). Simbolon and Mirmanto (2000) compared the dominant species in peatland forests among the three sites in Central Kalimantan and determined that their species compositions were very different. They suggested that the differences in the dominant tree species among sites might be related to the degree of forest disturbance, intensity of logging, peat depth and other edaphic factors. Variation in the species composition and forest structure of peatland forests are related with hydrology, nutrient status and thickness of peat (Anderson 1963; Whitmore 1984; Page et al. 1999). Gunawan et al. (2008) indicated that tree regeneration is controlled by the degree of disturbance severity, peat depth, seed availability, predation of seeds and seedlings, and also competition with other plant species. If there are no mother trees and suitable water table, the forest cannot regenerate for a long time. In current study, we revealed that if burnt forest could avoid peat fire damage for only 10 years, they could reforestate at a reasonable level in our sites. However, more detailed study about the relationships between forest recovery, and fire severity and environmental factors is important. Meanwhile, to clarify the parameters of forest succession is also needed for understanding of forest recovery system in degraded peatlands.

To prevent forest degradation, we need to prevent forests from suffering serious damages due to peat fire by keeping our forests natural without logging, or deforestation.

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Chapter 13
A Comparative Zoogeographic View on the Animal Biodiversity of Indonesia and Japan

Hitoshi Suzuki and Anang Setiawan Achmadi

Abstract The Indonesian Archipelago harbors unique fauna with a high level of species diversity and endemism. In this report, we provide basic information on the spatial and temporal aspects of the animal ecosystem in the Indonesian Islands. We discuss four zoogeographic topics, including (1) lineage dispersal events from the continents to the Islands, (2) speciation processes in the insular area, (3) accelerated phenotypic evolution and (4) human impact on commensal animals compared to previous cases in the Japanese Archipelago, in which the same eustatic geological events and global climatic changes have occurred.

Keywords Biogeography • Indonesia • Japan • Molecular phylogeny • Mammals • Evolution

13.1 Introduction

The Indonesian Islands are situated on the southeastern side of the Eurasian continent and harbor ecosystems with high species diversity and endemism, consisting of two biodiversity hotspots—namely, "Sundaland" (western Indonesia and Malay Peninsula) and "Wallacea" (eastern Indonesia, Papua New Guinea, and Melanesia), representing important biological areas, together with the nearby regions of "Philippines" and "Indo-Burma" (Myers et al. 2000; Mittermeier et al. 2004). The two hotspots Sundaland and Wallacea include around 3,000 vertebrate species, accounting for 10 % of the world's species (half of which are endemic) (Sodhi et al. 2004). Notably, the proportion of endemic bird species in the Philippines may be

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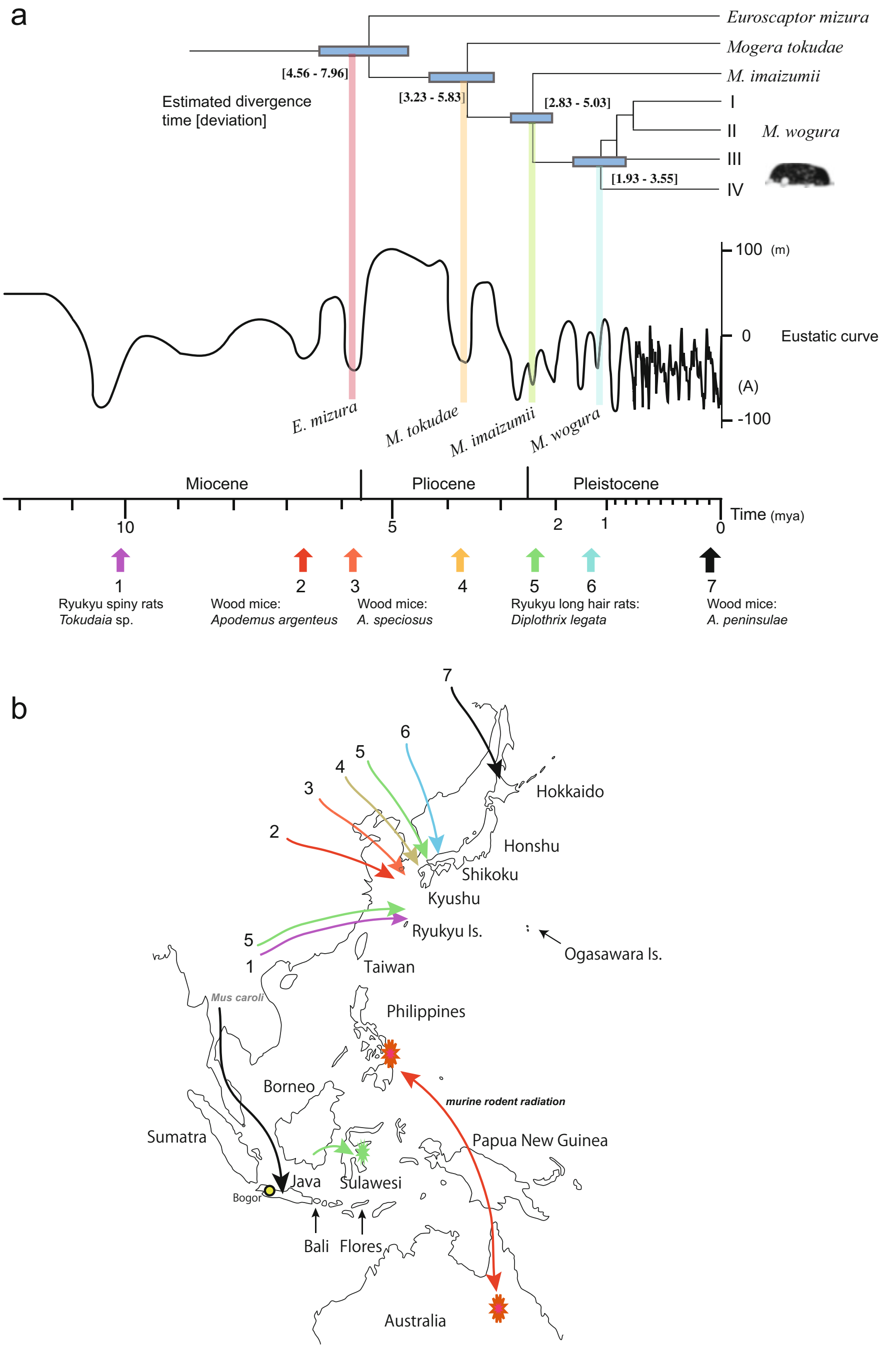
much higher than current estimations (Lohman et al. 2010), and many local lineages have been re-evaluated as endemic or cryptic species. This may also apply to other vertebrate taxa in hotspot regions in the area (Gorog et al. 2004; Lohman et al. 2011). However, why these geographic areas show such high levels of species diversity and endemism remains unclear. In this report, we provide basic information on Indonesian biodiversity. We also compare Indonesian biodiversity with the Japanese Islands, another biodiversity hotspot situated on the eastern side of the Eurasian Continent at a higher latitude that stretches from the humid subtropics to the boreal zone, resulting in a wide variety of climates and ecosystems (Mittermeier et al. 2004). This comparison highlights the extreme Indonesian biodiversity by comparing the insular domains to areas with high levels of biodiversity.

13.2 Evolutionary Consequences of Dispersal Events from the Continents

The appearance and disappearance of land bridges are important for the historical assemblage of insular ecosystems. Recently, Kirihara et al. (2013) performed phylogenetic inference using mitochondrial gene sequences, focusing on four Japanese mole species. The Japanese mole fauna is thought to have been structured by frequent dispersal events from the continent to Japan (Tsuchiya et al. 2000; Shinohara et al. 2004). It is believed that the fluctuating sea levels over time resulted in dispersal events across the deep seas (>100 m in depth; Kirihara et al. 2013); rapid, marked sea-level drops are thought to have occurred ca. 5.6, 3.5, 2.4,1.6, 1.3, and 0.9 million years ago (mya) (Haq et al. 1987; Woodruff 2003; Kitamura and Kimoto 2006). Based on this assumption, together with estimated divergence times from the cytochrome *b* gene (*Cytb*) sequences of mitochondrial DNA (mtDNA), the dispersal of ancestral lineages of the four Japanese moles of *Euroscaptor mizura*, *Mogera tokudae*, *M. imaizumii* and *M. wogura* are considered to have occurred 5.6, 3.5, 2.4, and 1.3 (or 1.6) mya, respectively (Kirihara et al. 2013; Fig. 13.1). The resultant phylogenetic tree implies that the dispersal event of the Taiwanese mole *M. insularis* may be coincident with *M. tokudae*. This assumption may be applicable to other insularlineages. For example, it is possible that the two Japanese wood mouse

→

Fig. 13.1 A zoogeographic view on the migration events of the ancestral lineages leading to endemic lineages in respective geographic regions, focusing on Indonesia, Philippines, Australia and Japan. Eustatic changes in the global sea level during the last 10 million years (Woodruff 2003; Berggren et al. 1995), which were suggestive of marked sea level decreases 5.6, 3.5, 2.4, and 1.3 mya (**a**). Estimated divergence times of the four Japanese endemic mole lineages (*vertical line*: means; *horizontal line*: confidence interval) are in good accordance with the worldwide sea level changes (See Kirihara et al. 2013 for details). Schematic representation of the inferred evolutionary history of small mammals in the eastern part of the Eurasian landmass and its adjacent islands (**b**)


a
Euroscaptor mizura
Mogera tokudae
M. imaizumii
I
II
III
IV
M. wogura
[4.56 - 7.96]
[3.23 - 5.83]
[2.83 - 5.03]
[1.93 - 3.55]
Estimated divergence time [deviation]
100 (m)
0
(A)
-100
Eustatic curve
E. mizura
M. tokudae
M. imaizumii
M. wogura
Miocene
Pliocene
Pleistocene
10
5
2
1
0
Time (mya)
1
Ryukyu spiny rats
Tokudaia sp.
2
Wood mice:
Apodemus argenteus
3
Wood mice:
A. speciosus
4
5
6
Ryukyu long hair rats:
Diplothrix legata
7
Wood mice:
A. peninsulae
b
7
6
5
4
3
2
Hokkaido
Honshu
Shikoku
Kyushu
5
1
Ryukyu Is.
Ogasawara Is.
Taiwan
Mus caroli
Philippines
murine rodent radiation
Borneo
Sumatra
Papua New Guinea
Java
Sulawesi
Bogor
Bali
Flores
Australia

species *Apodemus argenteus* and *A. speciosus* came to Japan across land bridges, which would have been built 6–7 and 5.6 mya, respectively (Fig. 13.1), based on the estimated divergence times from the molecular phylogenetic inference (Serizawa et al. 2000; Suzuki et al. 2003, 2008). The eustatic changes in sea level may have had a significant impact on faunal compositions of terrestrial animals found on the continent-associated islands, such as Japan and Taiwan, on which ancient migration events of terrestrial animals should be examined (e.g. Suzuki 2009; Hosoda et al. 2011). This may also be observed in Indonesia, as discussed below.

In the Northern Hemisphere, global climate change has shaped fauna composition; the climate has become cool and arid during the last 10 million years (Zachos et al. 2001) and assisted the expansion of temperate taxa 6–7 mya (Cerling et al. 1997) and subsequently boreal taxa 2–3 mya (Einarsson and Albertsson 1988). The Japanese Islands received continental lineages at different geological times; tropical or subtropical lineages came to Ryukyu Islands in ancient times, followed by temperate lineages to Honshu/Shikoku/Kyushu at moderately ancient times, and finally boreal lineages to Hokkaido rather more recently (Fig. 13.1; Suzuki 2009). The estimated divergence time for the Ryukyu Island endemic species, Ryukyu spiny rats *Tokudaia* sp. and Amami rabbits *Pentalagus furness*, is almost 10 mya (Suzuki et al. 2000; Yamada et al. 2002). Mammals found in the central landmass of Japan; namely, Honshu, Shikoku, and Kyushu, are thought to have come to Japan during the last 6–7 million years (Suzuki 2009). The northern-most island of Japan, Hokkaido, harbors both temperate and boreal lineages that originated recently (within the last 1 million years) from the continent and Honshu (e.g. *A. argenteus* and *A. speciosus*, respectively).

On the contrary, the most prominent geological event explaining the Indonesian fauna is the formation of the Indonesian Islands through collision between the Asian and Australian continental plates. The collision, which is thought to have occurred around 25 mya (Hall 2002, 2012), may explain the co-occurrence of both lineages from Asian and Australian components in the Indonesian biota, which are represented by eutherians (e.g. macaques) from the Asian side and marsupials (e.g. possums) from the Oceanian side. This may have facilitated the introduction of a large number of plant and animal taxa that originated in Asia into Australia over the past 20 million years (Byrne et al. 2011).

To explore the nature of the Indonesian ecosystem, murine rodents (subfamily Murinae) harboring a large number of species (approximately 500; 10 % of mammalian species that belong to this single subfamily) (Carleton and Musser 2005) should be examined since Indonesia and its neighboring regions are the primary geographic areas harboring the rodent taxon. In particular, the *Rattus* and its allele genera (tribe Rattini), the largest lineage of the murine rodents, is an ideal study group that includes more than 120 species. This group has three major subgroups, *Rattus*, *Niviventer*, and *Maxomys*, the first of which extended its descendent lineages to the Ryukyu Islands (*Diplothrix legatta*) and Australia. Recent molecular phylogenetic analyses revealed spatio-temporal patterns of the dispersal events of the Rattini lineages (e.g. Steppan et al. 2005; Jansa et al. 2006;

Rowe et al. 2008, 2011). The initiation of the radiation events of the murine rodents is rather old (10 mya), but migration of the rodents into the Philippines and Australia is estimated to have occurred 5 mya. The estimated times for migration of the Indonesian Rattini are 2–3 mya. This is in good accordance with the mouse taxon genus *Mus*. An ancestral lineage belonging to the subgenus *Coelomys*, with its homeland in Southeast Asia (Suzuki and Aplin 2012), extended its lineage to *Mus crociduroides* in Sumatra and *Mus vulcani* in Java approximately 2–3 mya. Oscillation of the Quaternary glacial and warm periods is thought to have contributed to the dispersal events from the Asian Continent to the Indonesian Islands. For example, molecular phylogeographic analyses indicated that the Southeast Asian mouse *Mus caroli* of the Java population shows a natural habitation. Intraspecies radiation of mtDNA in this species is known to have occurred half a million years ago, yielding several intraspecies local lineages that have extended from Myanmar to Vietnam, as well as to Java, in which the lineage is equally distinct from the continental lineages, contrary to the initial belief that the presence of this species in Indonesia is due to human-mediated introduction (Shimada et al. 2007). Overall, it is possible that the major assemblage of the Indonesian rodents (and perhaps the majority of other terrestrial animals) is young, dating back only 2–3 million years (see Esselstyn et al. 2013).

13.3 Speciation Processes

The number of murine rodent species in Indonesia exceeds 173 (Suyanto et al. 2002; Carleton and Musser 2005). An important feature of Indonesian fauna is the ability to promote the rapid speciation processes observed in murine rodents, as discussed above. For the Japanese Islands, the number of endemic murine rodent species is limited; only two species are found in the main areas of Japan (Honshu, Shikoku and Kyushu) (Fig. 13.2). Indonesia includes seven geographic areas; Sumatra, Kalimantan (most of Borneo), Jawa, Sulawesi, Lesser Sunda, Maluku, and Papua (the western half of Papua New Guinea). These islands harbor a large number of endemic species, indicative of promotion by specific systems of rapid speciation events, as seen in the murine rodents and shrews (Achmadi et al. 2013; Esselstyn et al. 2009, 2013). In particular, Sulawesi and Papua show high levels of endemicity in Rattini, excluding the six commensal species *Rattus argentiventer*, *R. exulans*, *R. nitidus*, *R. norvegicus*, *R. rattus* (and its related lineages) and *Mus musculus* (Suyanto et al. 2002; Fig. 13.2). Based on the phylogenetic tree of murine rodents, we observed several nested divergent clusters at various times from 1 to 3 mya, indicative of intermittent radiation events associated with the Indonesian Islands. Each of the clusters tended to include a Sulawesi endemic lineage. This is suggestive of unidirectional dispersal events toward Sulawesi, which fostered the migrant lineages to become indigenous species, resulting in the absence or limited migration of the Sulawesi lineages to other islands in the subsequent time period. In contrast,

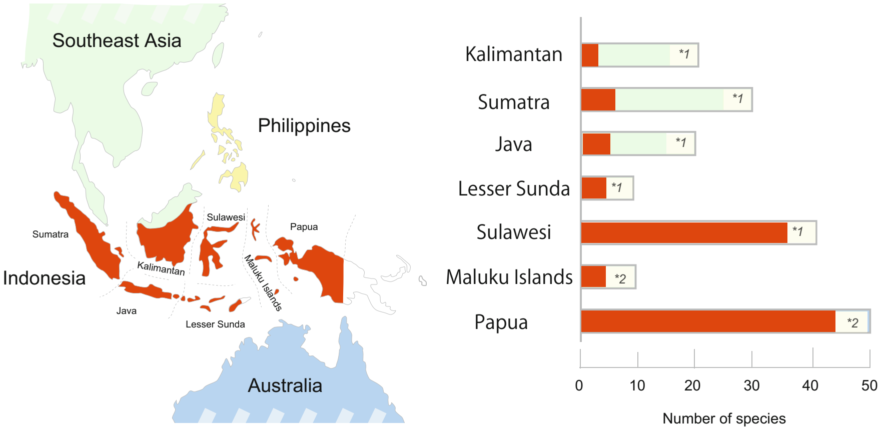


Fig. 13.2 Frequency histogram showing the number of species of Indonesian murine rodents described in the checklist published by Suyanto et al. (2002). Although the checklist requires revision, it can be used to characterize heterogeneous patterns in the endemic species (*red*) among the following seven geographic regions: Kalimantan, Sumatra, Java, Lesser Sunda, Sulawesi, Maluku Islands and Papua, as well as the distribution of species sets of invasive introduced rodents; *1: *Mus musculus*, *Rattus argentiventer*, *R. exulans*, *R. norvegicus* and *R. rattus*, and *2: species set *1 plus *R. nitidus*

the three islands Sumatra, Borneo, and Java showed limited numbers of endemic species, indicative of a strong influence of dispersal events among the three islands and the Asian continental region.

The several cycles of connection and disconnection of the landmasses during the late Pliocene to the early Pleistocene (e.g. 1–3 mya) would have affected lineage differentiation within the Sulawesi Islands, which can be divided into several insular-like landmasses (see Stelbrink et al. 2012). Sea level changes are thought to cause geographic isolation and hence mediate speciation processes, which can be seen in a variety of terrestrial animals, including *Rattini* rodents and macaques (Evans et al. 2003; Stelbrink et al. 2012). In the Japanese Islands, the genetic subdivision is thought to have been accelerated along with the insular domains of Honshu, Shikoku and Kyushu with the changes in sea level, which may also have affected the western Japanese mole, *M. wogura* (Kirihara et al. 2013).

The multiple separations and mixing of the Indonesian islands during the Quaternary may also have contributed to the extreme biodiversity in animal groups. Notably, the richness of the marine fish fauna of the East Indian region (Indonesia, New Guinea, and the Philippines) may be been caused by multiple cycles of sea level decreases and increases over the last 700,000 years (Randall 1998). Further investigations are required to explore the factors involved in speciation episodes using speciose animals such as bats (Maryanto and Yani 2003) and parrots (Astuti et al. 2006).

13.4 Specificity of the Ecological Features and Ongoing Phenotypic Evolution

Both the Japanese and Indonesian archipelagos, comprised of numerous islands, can contribute to evolutionary studies of natural selection and genetic drift. Rapidly changing species compositions due to frequent dispersal events would have forced rapid phenotypic changes due to adaptation to “new” environments, as well as interspecific (evolutionary arms race) and intraspecific competition (sexual selection), yielding phenotypic and functional variation within species.

The murine rodents, in particular Rattini rodents, show significant phenotypic evolutionary changes with respect to morphological characteristics. In fact, although the species lineages are young, many of the Rattini lineages that have different morphological appearances are classified as distinct genera. For example, in the Okinawan long-haired rat *Diplothrix legata*, the largest rodent in Japan, the divergence time from *Rattus* species dates back only 2–3 mya (Suzuki et al. 2000). One remarkable case is the Indonesian Rattini, the Flores giant rat, *Papagomys armandvillei*, with a head and body size of greater than 40 cm, whereas the small rat *Rattus exulans* has a head and body length of only 12 cm (Fig. 13.3). Rattini appears to be in a mid-period of phenotypic evolution in the ecosystems of Lesser Sunda, Sulawesi and Papua New Guinea, and a comprehensive view of the evolutionary patterns from both ecological and genetic perspectives is not yet available. The murine rodent evolved into the shrew-rat species with no cheek teeth, *Paucidentomys vermidax*, found in Sulawesi, which feeds on earthworms exclusively (Esselstyn et al. 2012). The newly discovered rodent *Waiomys mamasae* from Sulawesi represents a semi-aquatic and carnivorous rodent, which was previously found only on the continent of Sahul, showing a strong example of convergent evolution in the Indo-Australian Archipelago (Rowe et al. 2014).

Phenotypic variation in coat color is also a visible indicator of the evolutionary dynamics in each geographic area (e.g. Suzuki 2013). The Japanese Islands from north to south exhibit a number of coat color variations within species. A common example of coat color variation is seen in the Japanese hare, which shows apparent pelage color variation with the presence or absence of massive snowfall during

Fig. 13.3 Dorsal view of two skin specimens of rats, *Papagomys armandvillei* (*top*) and *Rattus exulans* (*bottom*), showing their markedly different size characteristics

the winter season (Nunome et al. 2010). The Japanese marten also shows spatial variation in the winter season based on hair pigmentation (Sato et al. 2009). On Hokkaido, the northern-most island, the sables show marked differences in body colors in the winter season, from bright yellow to dark brown (Hosoda et al. 2005). The five macaque species found in Sulawesi show remarkable interspecies phenotypic variation in coat color. Current studies are exploring the causative mutation of color variation (Nakayama et al. 2008).

The continuously changing ecosystems, such as are observed in Indonesia and Japan, will provide numerous opportunities to explore the factors shaping phenotypic changes. Genetically polymorphic states provide an opportunity to identify the responsible gene and causative mutation underlying phenotypic changes. In the Hokkaido sable, the causative mutation for the total yellow hair color is known to be replacement of a conserved cysteine residue at codon site 35 in the coat-color-related gene, melanocortin 1 receptor (Ogawa et al. unpublished). The identification of a causative mutation allows us to assess the involvement of natural selection by surveying accelerated rates of amino acid changes (e.g., Shimada et al. 2009) and the signatures of selective sweeps around a causative mutation.

13.5 Human Impact on Biodiversity

It is important to understand how human activity has altered the evolutionary patterns of wild life, including their geographic ranges, gene introgression, and phenotypic changes. In this context, the evolutionary dynamics of commensal rodents should be explored. Commensal rats are generally considered alien species, which are expected to harbor microorganisms related to a variety of zoonotic infections. Stowaway introduction of commensal rodents has now become a serious problem in ecosystems. However, commensal rodents provide valuable information on prehistoric human movements. In this section, we discuss the following two influential commensal rodents: the house mouse *Mus musculus* and the ship rat (or black rat) *Rattus rattus* or the *Rattus rattus* species complex.

The homeland (natural range) of the wild house mouse *M. musculus* is thought to have been a specific area of west Asia, and the historical human movements originating from Africa are thought to have mediated the global expansion of three subspecies groups of house mice onto the entire Eurasian Continent in prehistoric times (Bonhomme and Searle 2012). The three major subspecies that show long-range dispersal are *Mus musculus domesticus* (DOM), *M. m. castaneus* (CAS), and *M. m. musculus* (MUS), which are found in western Europe, southern Asia, and northern Eurasia, respectively. Molecular phylogenetic studies of the mitochondrial sequences revealed two subspecies lineages of CAS and MUS on the Japanese Islands with skewed distribution of CAS in the northern area; namely, Hokkaido and northern Honshu (Yonekawa et al. 1988; Terashima et al. 2006). The exact origins of the parental lineages remain unclear. A recent study using relatively long mitochondrial sequences revealed that Japanese CAS and MUS are closely related to haplotypes from South China, near areas of the Pearl River and the Korean Peninsula, respectively (Suzuki et al. 2013; Kuwayama et al. unpublished). This allows us to examine ancient movements of humans who propagated agriculture from the Asian continent to the Japanese Islands. The mtDNA analyses of Indonesian mice from five localities revealed CAS haplotypes unique to Indonesia that belong to a clade, designated CAS-1, with low nucleotide diversity and a wide distribution range in Southeast Asia, South China and Indonesia, and an estimated time for radiation of 8,000–4,000 years ago (Suzuki et al. 2013). This is suggestive of an ancient colonization event, spreading to Java, Bali, and Flores, which is somewhat concordant with the archaeological record of agriculture. Previous studies demonstrated the domestication of cereal crops, including rice and millet, by about 9,000 years ago in several parts of southern and eastern Asia (Khush 1997). This hypothesis requires verification, and the possible impact of Indonesian mice on the neighboring areas of the Philippines and Australia should be examined.

Meanwhile, nuclear gene analyses revealed relatively long DOM haplotypes of >2 Mb in some areas near ports and airports (Kushiro, Kyowa, and Atsugi), which is indicative of the introduction of eastern European lineages in modern times (Nunome et al. 2010; Kuwayama et al. unpublished). This so-called “stowaway introduction” is more common than initially believed. The western European lineage of the mtDNA, DOM, has been detected in Bogor. Mice collected from Bogor by 1990 contain CAS mtDNA haplotypes, while mice captured since 2000 are of western European type, DOM (Terashima et al. 2006; Suzuki et al. 2013). This unexpected occurrence of DOM haplotypes may be explained by long-distance dispersal events associated with human activities in somewhat modern times. This suggests that introgression of the DOM mtDNA is ongoing in this city. It is possible that the genetic structure of the house mouse is unstable over time due to stowaway introduction.

The evolutionary dynamics of the black rats (ship rats or roof rats), the *Rattus rattus* species complex, in ancient and present times should be explored. Black rats, the species complex, include two major members (*Rattus rattus* with $2n = 38$ and *R. tanezumi* with $2n = 42$). *Rattus rattus* is believed to have originated in western India (Yosida 1980), which is supported by recent mtDNA phylogeographic studies of *Rattus rattus* (sensu lato; Robins et al. 2007; Pagès et al. 2010; Aplin et al. 2011). In the Japanese Islands, two species can be found; the initial resident *R. tanezumi* and the new *R. rattus*. Molecular phylogenetic analyses revealed *R. tanezumi* haplotypes throughout the Japanese Islands, as expected, as well as the sporadic appearance of *R. rattus* haplotypes. In the northernmost island, Hokkaido, the *R. rattus* colony is confined to specific buildings, perhaps due to the unpleasant environment during the winter season. In Honshu and Kyushu, the *Rattus rattus* species is found in ports (e.g. Kagoshima) and shows urban habitation in large cities (e.g. Tokyo). In the Ryukyu Islands, represented by Okinawa and Amamioshima Islands, the introduction of *R. rattus* in the subtropical natural forests is not observed (Kambe et al. 2011, 2012, 2013), implying that the high-density habitation of *R. tanezumi* rats prevents introduction of the new *R. rattus*. In the Ogasawara Islands with subtropical climate, black rats inhabit areas, including numerous tiny islands, without human residency, contrary to the general belief that black rats always co-inhabit with humans. Subtropical natural forests lacking humans and congeneric competitors are likely the optimal habitats. Recent mtDNA studies revealed natural habitation of the black rat lineages in the Indonesian Islands and human-associated migration events during both prehistoric and historic times (Aplin et al. 2011). It is believed that alien lineages of black rats emerged from human-mediated introduction of established colonies, and may affect wildlife by eating seabird eggs. Further studies, including an intensive survey of the influence of colonization of black rats on the numerous Indonesian Islands, irrespective of human residency, are required.

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Chapter 14
Aquatic Communities in Peatland of Central Kalimantan

Sulmin Gumiri, Ardianor, Seigo Higashi, and Toshio Iwakuma

Abstract In the lakes of river flood-plain ecosystems of tropical regions, the dynamics of phytoplankton species are strongly affected by fluctuations in water level throughout the year. In Central Kalimantan Lakes, phytoplankton were dominated by heterotropic-flagellated species of Euglenophycea and Bacillariphyceae. Lakes that are frequently disturbed by flood pulses from the main river tend to have high abundance and diversity of phytoplankton, which is in line with the Junk's Intermediate Disturbance Hypothesis.

Several factors governed the dynamics of zooplankton communities in the studied lakes. On a monthly basis, the temporal variation of zooplankton density was induced by the lunar cycle, whereas the seasonal density and biomass were determined by the alternations of wet and dry seasons. Dilution and washout effects were observed to cause zooplankton dispersal in interconnected lakes with the main river due to the increase of water currents during the rainy season, whereas the penetration of dissolved oxygen appeared to be the ultimate factor in causing different patterns of zooplankton vertical distribution in water columns of the studied lakes.

Keywords Phytoplankton • Zooplankton • River flood-plain ecosystems • Peatland • Tropical region

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14.1 Introduction

A vast area of peatland forests cover the lowland areas of Southern Borneo (Central Kalimantan) with several large rivers meandering from north to south forming any number of oxbow and floodplain lakes alongside the rivers. The peatlands have been developed on oligotrophic kerangus soil, and are highly vulnerable to human activities.

One important factor in determining the diversity and production of the aquatic communities in the region is the hydrological dynamics in the connection of the main rivers and the lakes along the river courses the so called the "oxbow lakes". Since the river and oxbow lakes undergo large water level changes between the dry and wet seasons, the lakes are disconnected or connected to the main river according to the water level changes. The oxbow lakes are thus classified into the following three categories in terms of the hydrological connectivity to the main river: (1) lakes connected throughout the year at both inlet and outlet, (2) lakes connected at both inlet and outlet during the high water level period but disconnected at the outlet during the low water level period, and (3) lakes connected only at the outlet during the high water level period. The following describes details of the dynamics of aquatic community in the watershed basin of Central Kalimantan that have been studied since 1998.

14.2 Phytoplankton Community

Composition of phytoplankton species and its abundance in oxbow lakes in Central Kalimantan varied. At lakes, such as Lutan, Takapan, and Rengas which belong to the Kahayan River system, there were 54, 49, and 38 phytoplankton species, respectively (Sulastri and Hartoto 2000). The phytoplankton species were dominated by the class of Chlorophyceae, Bacillariophyceae, and Cyanophyceae. About 10 years later, Ardianor (2010) reported from different lakes in the Kahayan River system, Tehang, Batu, and also Lutan and found that Euglenophyceae, Bacillariophyceae, and Chlorophyceae were predominant among the eight classes of phytoplankton found there. Of 96 species identified only *Cryptomonas* sp. and *Trachelomonas volvocina* were abundant in all of the three lakes. When compared with studies made in tropical river systems of South America, the numbers of species of phytoplankton in these lakes were smaller than in the Parana River system of Argentina, where ca. 270 species were reported (Garcia de Emiliani 1993, 1997; Zalocar de Domitrovic 2003), and the about 580 in the Amazon River system (Melo and Huszar 2000; Melo et al. 2004; Nabout et al. 2006, 2007).

Phytoplankton abundance of the lakes in Central Kalimantan are strongly affected by hydrological conditions, mainly fluctuations of water levels during the dry and rainy seasons. The long-term surveys in Lakes Tehang and Batu exhibited seasonal trends of phytoplankton population dynamics. *Chlamydomonas* sp, *Cryptomonas* sp., and *Trachelomonas volvocina* occurred throughout the year,

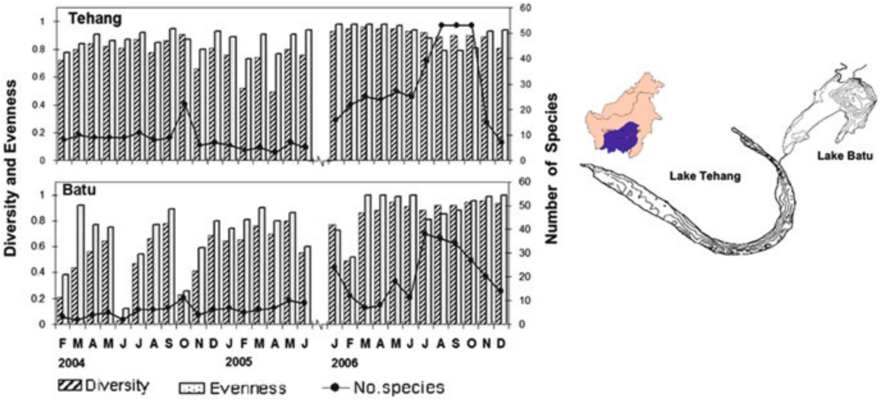

Fig. 14.1 Seasonal changes in diversity, number of species, and evenness in Lake Tehang and Batu. Simpson's diversity and Pielou evenness index were used as indices of diversity and evenness, respectively. Map showing Lake Tehang and Lake Batu in Central Kalimantan (After Ardianor 2010)

while *Peridinium* sp. and *Trachelomonas armata* were abundant only in the flood season and *Cymbella* spp., *Eunotia* spp., *Navicula* spp., *Euglena proxima*, *E. spirogyra*, *Phacus pleuronacles*, *Trachelomonas hispida*, and *Trachelomonas* spp. were abundant only in the dry season.

Species diversity was higher and more stable in Lake Tehang than in Lake Batu. In Lake Tehang, phytoplankton were more frequently disturbed by inundation of the Kahayan River, while in Lake Batu, they were sometimes monopolized by dominant species which considerably reduced the Pielou evenness specially in the low water level season when the lake was not disturbed by water currents from the Kahayan River (Fig. 14.1). This result seems to support the intermediate disturbance hypothesis accounting for high biodiversity in unsaturated communities (Junk et al. 1989).

Physico-chemical factors also exhibited seasonal fluctuations at both lakes. Multivariate statistical redundancy analysis, RDA, showed that chlorophyll-a and diversity indices of phytoplankton were significantly correlated with water temperature, electrical conductivity, and dissolved oxygen in Lake Tehang and with water temperature and water level in Lake Batu. Further, cannonical correspondence analysis (CCA) showed that abundant phytoplankton species were significantly affected by water temperature and water level in both Lakes Tehang and Batu (Fig. 14.2). According to CCA (Fig. 14.2), some species of phytoplankton, such as *Trachelomonas hispida* and *Eunotia* spp which are found slightly abundance during low water period, seemed to have negative correlation with pH at lakes. Meanwhile, *Navicula* sp., *Chlamydomonas* sp., and *Cryptomonas* sp. had more negative correlation with water trenparency (SD) than others. However, *Trachelomonas armata* looked strongly have correlation with both water temperature and pH. Among all abundant phytoplankton species found in lakes, *Trachelomonas volovocina* assumed mostly adaptive and cosmopolitan species.

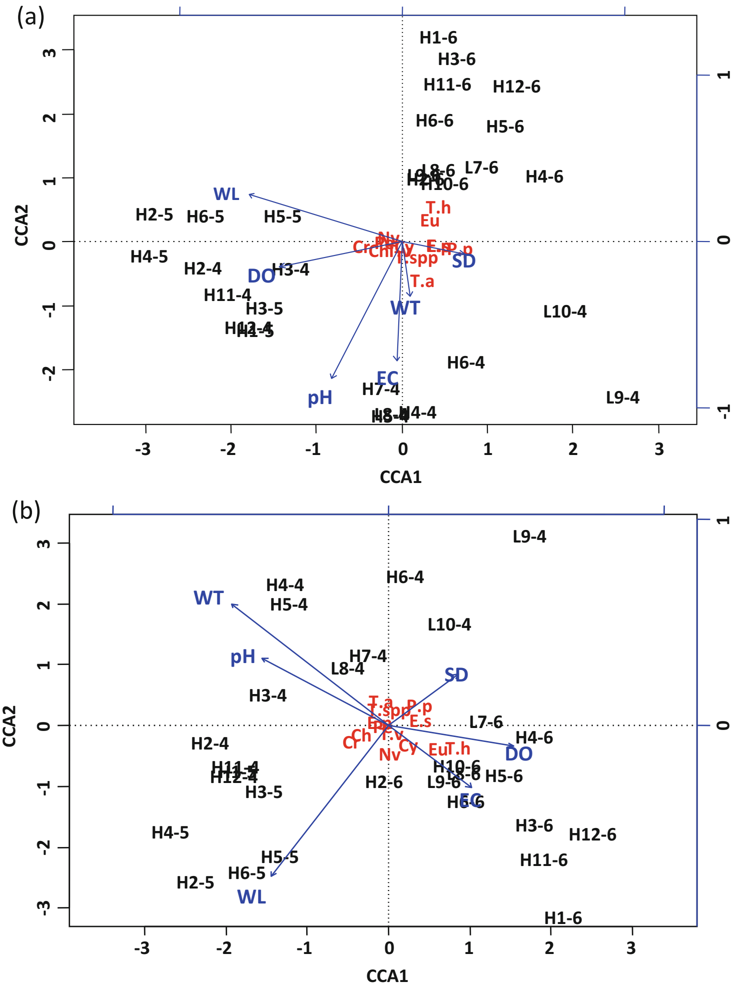

Fig. 14.2 Cannonical correspondence analysis (CCA) applied to abundant phytoplankton species and environmental variables in (**a**) **Lake Tehang** and (**b**) **Lake Batu**. For phytoplankton species, *Cy Cymbella* spp., *Eu Eunotia* spp., *Nv Navicula* spp., *Ch Chlamydomonas* sp., *Cr Cryptomonas* sp., *Pe Peridinium* sp.; *E.p Euglena proxima, E.s Euglena spirogyra, P.p Phacus pleuronacles, T.a Trachelomonas armata, T.h Trachelomonas hispida, T.v Trachelomonas volovocina, T.spp Trachelomonas* spp. For each position, *H* high water level, *L* low water level; first number: month; second number: year; e.g. *H6-4* high water level in June 2004. For environmental (constrained) variables, *WL* water level, *SD* Secchi depth, *WT* water temperature, *EC* electrical conductivity, *pH*, *DO* dissolved oxygen (After Ardianor 2010)

Overall, although the seasonal fluctuations in water temperature is much smaller than in rivers and lakes at high latitude, the temperature as well as water level still affects the phytoplankton communities in tropical oxbow and backwater lakes.

14.3 Zooplankton Community

The ecological characteristics of zooplankton community in tropical humic oxbow lake ecosystems are governed by the dynamics of the physico-chemical parameters in the aquatic ecosystem. The changing of physico-chemical parameters is due mainly to the seasonal changes in water hydrology in a region. Zooplankton communities can be classified into three major groups, rotifers, cladocerans, and copepods (Fig. 14.3). Among rotifers, several genera such as *Testudinella*, *Lepadella*, and *Lecane* were commonly found. Cladoceran communities consist mostly of *Bosminopsis*, *Alona*, and *Euryalona*, whereas copepod communities are dominated by *Mesocyclops*. The *thermocyclops brevifuracatus* species was the most common copepod species found. In all studied lakes, the number of identified rotifers was 119 species.

In all studied lakes, zooplankton communities exhibited considerable temporal and seasonal fluctuations in density and biomass. Over a 1-month period, larger-sized zooplankton in isolated lakes especially cladocerans, tended to decline in density during moonlight periods. Rotifers tended to increase in density during the decline of cladocerans. The density of cladocerans was correlated negatively with the rotiferan density (Fig. 14.4).

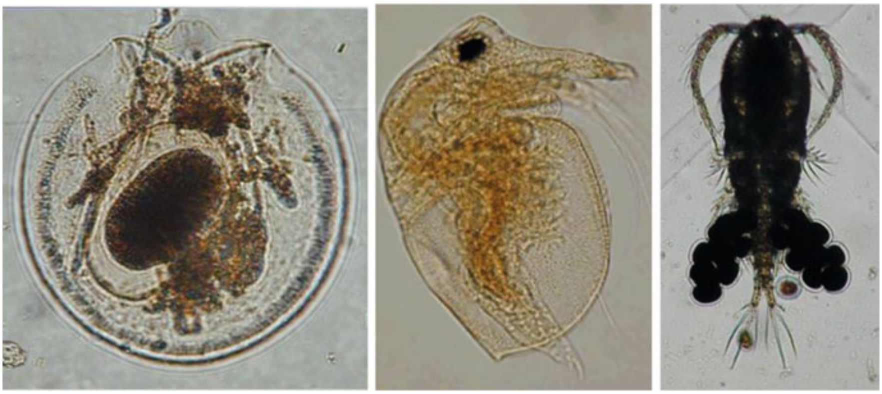

Fig. 14.3 Commonly found zooplankton in Central Kalimantan lakes: *Testudinella* (*left*), *Bosminopsis* (*centre*), and *Themocyclops* (*right*)

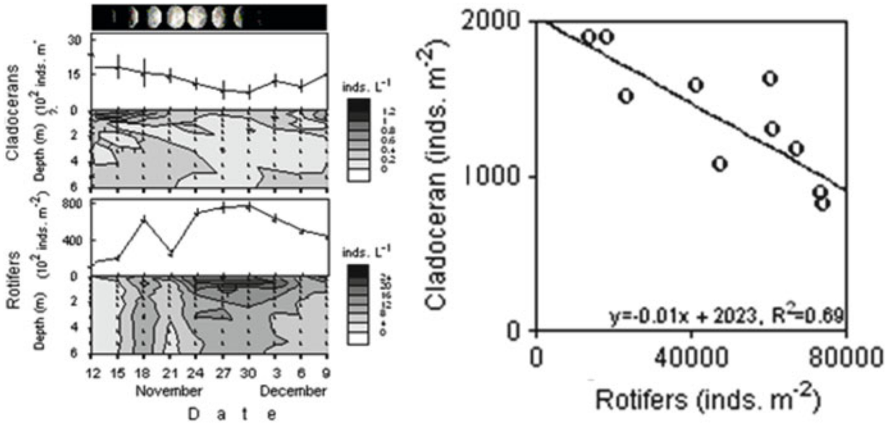

Fig. 14.4 Aerial population densities (10^2 individuals m^{-2}) and depth-time isopleths of densities of cladocerans plotted for three dominant rotiferan genera (individuals l^{-1}) at the center of Lake Tundai during 12 November to 9 December 1999. *Top panel* indicates the lunar cycle (*left*), and the relationships between the abundances of cladocerans (y axis) and rotifers (x axis) at the centre of Lake Tundai (*right*)

It is presumed that the inverse density relationship between cladocerans and rotifers is due to the effect of the lunar cycle on fish feeding intensities upon larger-sized zooplankton according to the size selective predation mechanism (Brooks and Dodson 1965). Since a lot of fish were also found in the lake (Doi et al. 2000) it is very probable that these fishes feed intensively on zooplankton. These fishes locate their prey visually and their predatory success is a function of prey size and underwater light intensity (Tilzer 2000).

Over a 1 year period, most lakes exhibited similar patterns of fluctuations in zooplankton density and biomass. Zooplankton density and biomass were very low during the rainy season, and then increased strongly during dry season from July to October (Fig. 14.5).

Although the seasonal fluctuations of zooplankton density were very similar, different mechanisms appeared to govern the dynamics and the successions of zooplankton in different lakes with different hydrological connectivity to the main rivers. In a lake which is completely isolated from the main river, the increase in zooplankton density during low water levels seemed to be induced by the increase of available food after the rainy season, as indicated by a significant positive correlation between rotiferan density and chl*a* or DOC (Table 14.1).

Previous studies by other workers (Mavuti 1990; Piyasiri and Chandrananda 1998) have reported that nutrient loading from surrounding areas during the rainy season is a common phenomenon in tropical lake systems. These nutrients could stimulate the growth of phytoplankton, which is in turn consumed by zooplankton for growth and reproduction.

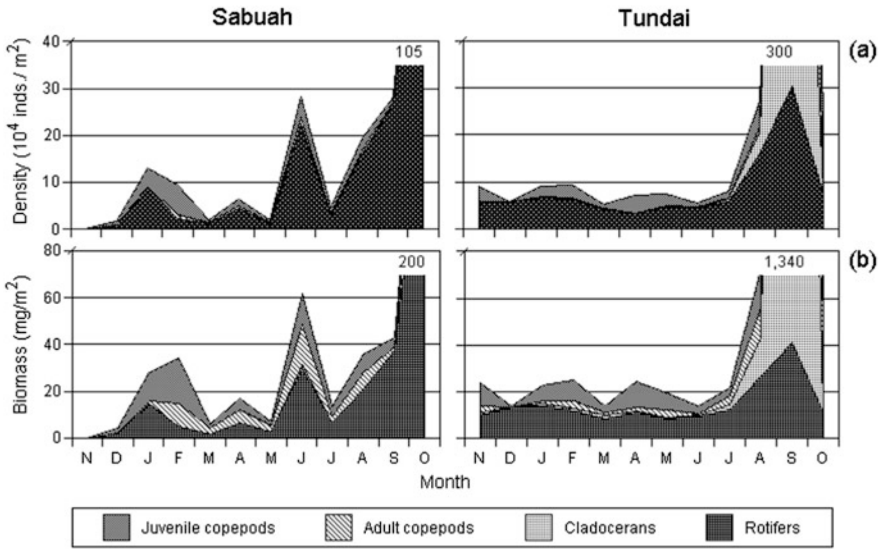

Fig. 14.5 Seasonal changes of total zooplankton density (**a**) and biomass (**b**) integrated for an entire water column of Lake Sabuah (*left*) and Lake Tundai (*right*) during November 1999-October 2000

Table 14.1 Results of stepwise regression analyses $[y = a\,(\pm\mathrm{SE}) + b\,(\pm\mathrm{SE})\,x]$ between zooplankton abundances and environmental factors as independent variables in Lake Sabuah, during the period from December 1999-September 2000

Multiple regression	R^2	F	P
$CL = 2450\,(\pm 1130) + (\pm 1130)\,WL$	0.45	6.54	0.03
$ROT = -1807000\,(\pm 306000) + 8000\,(\pm 1130)\,DOC +$ $252700\,(\pm 47544)\,\mathrm{pH} + 4810\,(\pm 2090)\,Chla$	0.89	17.06	0.002

CL cladocerans, *ROT* rotifers, *WL* water level, *Chla* chlorophyll-a, *DOC* dissolved organic carbon. For all regressions, $n = 10$

In lakes that were occasionally connected both in inlet and outlet to the main river, the mechanism is slightly different. During high water levels, water from the main rivers usually enters the lake from two different channels: inlet and outlet, and that leads to the increase in water currents in the lakes. This water current will lead to the dilution and washout effects that promote zooplankton dispersal from one lake to the main river or from one lake to other adjacent connected lakes. In four interconnected lakes along the Kahayan River (Fig. 14.6), these dilution and washout effects were clearly detected.

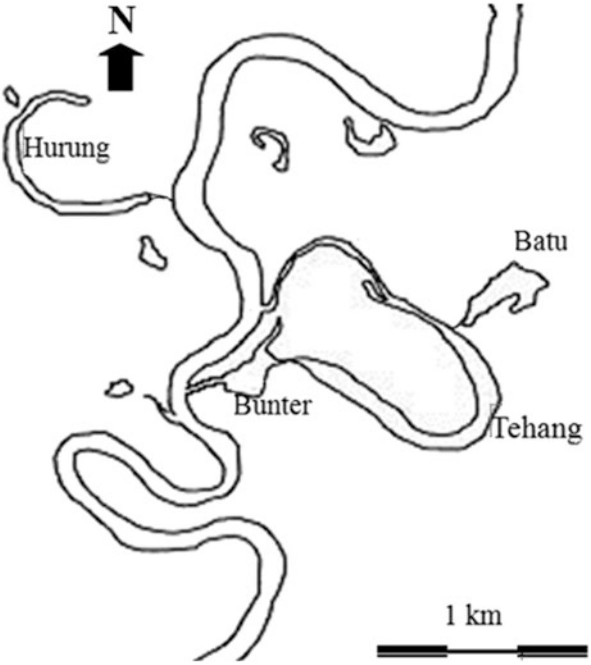

Fig. 14.6 The Kahayan River system showing the locations of lake Hurung, and the interconnected lakes: Batu, Tehang, and Bunter

Significant dispersal coefficient directions were found between the three interconnected lakes: Batu, Tehang, and Bunter. Between Lake Batu and Lake Tehang significant dispersal coefficients were observed during November ($\chi^2 = 8.0$, $P < 0.01$), December ($\chi^2 = 5.56$, $P < 0.05$), and July ($\chi^2 = 6.4$, $P < 0.05$) whereas those between Lake Tehang and Lake Bunter occurred in September ($\chi^2 = 9.0$, $P < 0.01$), November ($\chi^2 = 13.76$, $P < 0.01$), and January ($\chi^2 = 6.25$, $P < 0.05$).

Zooplankton communities in Kalimantan lakes could also exhibit very different patterns in the vertical distribution. In isolated lakes, zooplankton tended to be concentrated only in the layer from the surface down to 2 m depths throughout most of the year, whereas in open connected lakes, zooplankton was also found to be distributed vertically from the surface down to the bottom of the lake (Fig. 14.7). This difference in zooplankton vertical distributions was controlled by the lake mixing pattern and the distribution of dissolved oxygen in water columns between lakes.

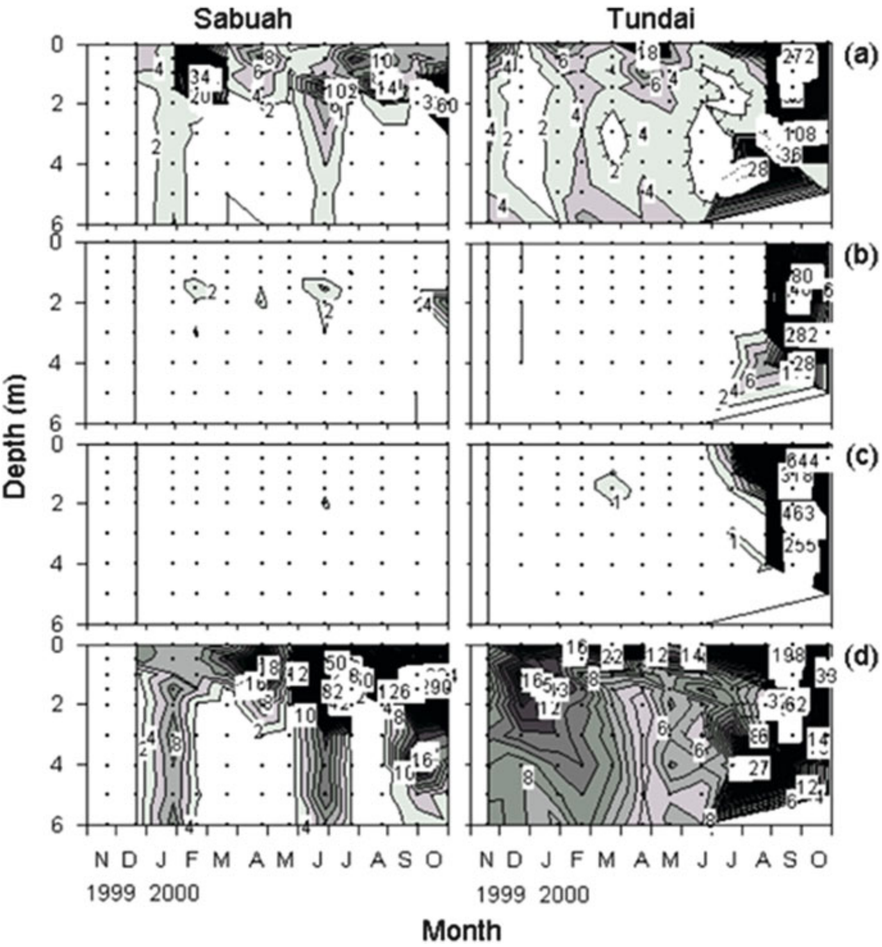

Fig. 14.7 Depth-time isopleths of zooplankton density in Lake Sabuah (*left*) and Lake Tundai (*right*) during November 1999-October 2000. **a** juvenile copepods, **b** adult copepods, **c** cladocerans, **d** rotifers. Figures in the panels indicate density (individuals/m^2)

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Chapter 15
Mycorrhizal Fungi in Peatland

Keitaro Tawaraya and Maman Turjaman

Abstract Peatland forest areas have been decreasing due to conversion of forests into farm land, the use of shifting cultivation on a large scale, illegal logging, opencast mining, and forest fires. Numerous studies of tropical forests have indicated that many native tree species were colonized by the arbuscular mycorrhizal (AM) and ectomycorrhizal (EM) fungi. Mycorrhizal fungal diversity is higher in tropical forests than in other forests, and colonization of mycorrhizal fungi improves plant growth of many tree species grown in the tropical forests. Survival rates of colonized seedlings of tree species are higher than those of non-colonized seedlings. Inoculation of mycorrhizal fungi at the nursery stage is a useful technique for large-scale remediation programs of degraded tropical forests. Selection of appropriate combinations of native tree species and mycorrhizal fungal species is also important for remediation of degraded peatland.

Keywords Arbuscular mycorrhizal fungi • Ectomycorrhizal fungi • Phosphorus • Remediation

15.1 Introduction

Tropical peatland forests are important both for their diverse bioresources and also as a significant carbon pool. Peatland forest areas have been decreasing due to conversion of forests into farmland, the use of shifting cultivation on a large scale, illegal logging, opencast mining, and forest fires. Degraded tropical peatland forests require wide scale remediation, and it is not simple to remediate degraded tropical peatland forests. A major obstacle in the remediation of tropical peatland forests is the slow growth and high mortality of seedlings in nurseries. It is also necessary to understand the physical, chemical, and biological factors of forest soils, in order to

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remediate degraded tropical peatland forests. Of these properties, the biological is the least known. Mycorrhizal fungi affect the maintenance of vegetation in various ecosystems, and may play an important role in remediation of degraded tropical forests. Mycorrhiza fungi were reported to increase the growth and survival rates of some tropical tree seedlings. There are expectations for remediation of degraded tropical peatland forests with inoculation of mycorrhizal fungi. The purpose of this chapter is to review the status of mycorrhizal fungi in tropical forests and the use of mycorrhizal fungi for remediation of degraded tropical peat land.

15.2 Arbuscular Mycorrhizal Fungi in Peat Land

Early studies of mycorrhizal fungi in forests focused primarily on temperate forests, but more recently, many studies have directed attention toward mycorrhizal fungi of tropical rain forests (Torti et al. 1997). The highest numbers of species and spores of AM fungi (arbuscular mycorrhizal fungi) were observed during the dry season, with a marked decrease during the rainy season in a tropical rain forest, Veracruz, Mexico (Guadarrama and Alvarez-Sanchez 1999). The introduction of *Plathymenia reticulata* Benth and *Eucalyptus camaldulensis* inoculated and mixed with *Tabebuia heptaphylla* promotes a higher AM fungal diversity, the percentage of AM colonization and plant growth compared with monocultures (Pagano et al. 2009). Rhizospheres of *Octomelaes sumatrana* recorded higher spore numbers of AM fungi than of *Anthocephalus chinensis* in Niah, Sarawak, Malaysia (Chubo et al. 2009).

Of the 142 species of trees and lianas surveyed in Guyana, 137 were exclusively AM (McGuire et al. 2008). Light microscopical investigation showed arbuscular mycorrhizas in 112 tree species from 53 families on mineral as well as pure organic soils in Ecuador (Kottke et al. 2004). A segment of fungal 18S rDNA was sequenced from the mycorrhizas of *Cedrela Montana*, *Heliocarpus americanus*, *Juglans neotropica*, and *Tabebuia chrysantha* in reforestation plots in Ecuador (Haug et al. 2010). Dual ectomycorrhizal and AM colonization was observed 4 of 14 ectomycorrhizal tree species belonging to Caesalpiniaceae and Uapacaceae from rainforests in Cameroon (Moyersoen and Fitter 1999). In total, 193 glomeromycotan sequences were analysed, 130 of these were previously unpublished. Some notable exceptions of tropical trees forming EM (ectomycorrhizal fungi) occur in the families Myrtaceae, Caesalpiniaceae, Euphorbiaceae, Fagaceae and Dipterocarpaceae.

Spores of AM fungi have been isolated from soils of tropical forests and their population and richness were affected by environmental conditions. Spore density and richness based on soil cores were higher in the dry season than in the rainy season in a tropical sclerophyllosu shrubland in the Venezuelan Guayana (Cuenca and Lovera 2010). Spore numbers of AM fungi were higher in young secondary forests and pastures and lower in pristine forest in the Amazon region (Sturmer et al. 2009). The AM fungal diversity is higher in tropical forests than in other forests (Wubet et al. 2009), and AM fungal spores in the soil decreased from an early plant succession to mature tropical forest in Brazil (Zangaro et al. 2008). The AM fungal types that were dominant in the newly germinated seedlings were almost entirely replaced by previously rare types in the surviving seedlings the following years (Husband et al. 2002a). As the seedlings matured in a tropical forest in the Republic of Panama, the fungal diversity decreased and there was a significant shift in population composition (Husband et al. 2002b). Based on spore morphology, 29 species of AM fungi were found in the rhizospheres of *Macaranga denticulate* (Youpensuk et al. 2004).

Moyersoen et al. (2001) reported that AM colonization was about 40 % in tree species in heath forests and mixed Diptercarpaceae forests in Brunei (Moyersoen et al. 2001). Tawaraya et al. (2003) collected seedlings of 22 tree species in 14 families grown in a peatland forest of Central Kalimantan, Indonesia and observed mycorrhizal colonization (Tawaraya et al. 2003). The AM colonization was observed for the first time in the roots of *Shorea teysmanniana*, *Shorea balangeran*, *Shorea uliginosa* (Dipterocarpaceae), *Calophyllum sclerophyllum*, *Calophyllum soulattri* (Guttiferae), *Cratoxylum arborescens* (Guttiferae), *Tetramerista glabra* (Tetrameristaceae), *Palaquium gutta* (Sapotaceae), *Melastoma melabathricum* (Melastomataceae), *Gonystylus bancanus* (Thymelaeaceae), *Hevea brasiliensis* (Euphorbiaceae), and *Campnosperma auriculatum* (Anacardiaceae). *C. soulattri*, *C. arborescens*, *G. bancanus*, *Acacia mangium*, *M. melabathricum*, and *H. brasiliensis* showed a percentage mycorrhizal colonization of 50 % or higher. No arbuscular mycorrhizal colonization was found in *Hopea mengarawan* (Dipterocarpaceae), *Koompassia malacensis* (Caesalpiniaceae), *Tristaniopsis whiteana* (Myrtaceae), *Combretocapus rotundatus* (Rhizophoraceae), and *Dyera costulata* (Apocynaceae).

The AM fungi in tropical forests represent a major sink of photosynthate, and AM fungal myceria in semi-evergreen moist tropical forest respired carbon at a rate of 1.4 t ha^{-1} year^{-1} accounted for 14 % of total soil respiration (Nottingham et al. 2010).

15.3 Ectomycorrhizal Fungi in Peat Land

Dipterocarpaceae, Fagaceae, Pinaceae, and some genera of Myrtaceae are known to form EM (Alexander and Lee 2005). All Dipterocarpaceae species surveyed to date are associated with EM fungi (Högberg 1982; Lee 1998; Smits 1994), and fungal families with the greatest abundance in Southeast Asian dipterocarps forests include Sclerodermataceae, Russulaceae, Boletaceae and Amanitaceae (Sims et al. 1997; Smits 1994).

15.4 Mycorrhizal Fungi Utilization for Remediation of Degraded Peatland Forests

15.4.1 Utilization of Arbuscular Mycorrhizal Fungi

Degradation of secondary forests and subsequent land conversion has global consequences, and the establishment of strategies for restoration and regeneration of degraded lowland rainforest is of paramount importance (Kettle 2010). The importance of mycorrhizal fungi for restoration of lowland dipterocarps rainforest is apparent.

The AM fungi have been reported to increase growth of some tropical trees, AM fungi increased seedling growth in 23 of 28 species from a lowland tropical rain forest in Costa Rica under nursery conditions (Janos 1980), and AM colonization of the tropical tree *Oubanguia alata* (Scytopetalaceae) was positively correlated with increased phosphorus (P) uptake despite low P availability in Cameroon (Moyersoen et al. 1998). The AM fungi improved the growth of the Brazilian pine *Araucaria angustifolia* (Araucariaceae) (Zandavalli et al. 2004) and there are also reports on the improved growth of non-timber forest product tree species following AM fungal inoculation in tropical forests. Muthukumar and Udaiyan (2010) reported that the inoculation of *Azadirachta indica* (Meliaceae) with AM fungi improved plant growth compared with control seedlings (Muthukumar and Udaiyan 2010).

Clusia minor and *Clusia multiflora* inoculated with *Scutellospora fulgida* in acidic soil had increased shoot and root biomass, leaf area and height, in comparison to the biomass of P-fertilized plants and non-mycorrhizal plants (Caceres and Cuenca 2006). Inoculation of AM fungus *Glomus geosporum* improved the growth, nutrient acquisition, and seedling quality of *Casuarina equisetifolia* seedlings under nursery conditions (Muthukumar and Udaiyan 2010). Seedlings of *Araucaria angustifolia* inoculated with *Glomus clarum* had higher shoot biomass, leaf concentrations of P, K, Na, and Cu and lower concentrations of Ca, Mg, Fe, Mn, and B than controls (Zandavalli et al. 2004). Inoculation with soil-containing AM fungi increased shoot growth nutrient contents when P was limited but N was applied (Youpensuk et al. 2004). Inoculation of AM fungi *Glomus clarum* and *Gigaspora decipiens* increased shoot N and P uptake of nontimber forest product species *Dyera polyphylla* and *Aquilarai filaria* under greenhouse conditions indicating that AM fungi can reduce the need for application of chemical fertilizer (Turjaman et al. 2006). Inoculation of mycorrhizal roots of the individual tree species or a mixture of the four trap species improved plant growth of 6-month-old *Cedrela moutana* and *Heliocarpus americanus* (Urgiles et al. 2009). The technique is much simpler to perform and incurs lower costs than spore production in tropical countries with limited facilities for storage of inoculum.

It has been reported that utilization of one AM fungal species increased plant growth of some host tropical tree species. The AM fungi increased plant growth of *Acacia nilotica* and *Leucaena leucocephala* (Leguminosae) at 12 weeks after transplantation under greenhouse conditions (Michelsen and Rosendahl 1990); AM fungi significantly increased plant growth of three multipurpose fruit tree species *Parkia biglobosa*, *Tamarindus indica*, and *Zizyphus mauritiana* at 2 months after inoculation (Guissou et al. 1998); AM *Glomus aggregatum* stimulated plant growth of 17 leguminous plants (Duponnois et al. 2001). *Glomus macrocarpum* increased plant growth of two different species *Sesbania aegyptiaca* and *S. grandiflora* (Giri et al. 2004) significantly.

Previous studies have shown that application of two or more AM fungal species led to differences in the increases in growth of one or more host tropical tree species. Two AM fungi *Glomus aggregatum* and *G. intraradices* increased early growth of 13 fruit trees of different provenance in Senegal (Ba et al. 2000). Three AM fungi *G. intraradices*, *G. mosseae*, and *G. caledonium* increased stem dry weight of 11 *Eucalyptus* at 20 weeks after inoculation (Adjoud et al. 1996). Nine AM fungi increased plant growth and plant nutrients of *Tectona grandis* under greenhouse conditions (Rajan et al. 2000).

The survival rate of seedling stocks in the field is vital to reforestation. The survival rates of AM- inoculated cuttings of *Ploiarium alternifolium* and *Calophyllum hosei* were 100 % after 6 months (Turjaman et al. 2008). These values were higher than the survival rates of two tropical tree species from Panama inoculated with AM fungi, *Ochroma pyramiddale* (97 %) and *Luehea seemannii* (52 %) (Kiers et al. 2000). Inoculation of AM fungi can reduce the cost of seedling production for reforesting vast areas of disturbed tropical forests. There are few reports on the effect of AM fungal inoculation on the growth of tropical tree species under field conditions. Recently, Graham et al. (2013) showed that inoculation of *Glomus clarum* and *Gigaspora decipience* increased N and P content of *Dyera polyphylla* under tropical peatland forest in Central Kalimantan, Indonesia (Graham et al. 2013).

The AM colonization also increased the nitrogen and phosphorus uptake and growth of Aloe vera L. under peat soil conditions (Tawaraya et al. 2007).

15.4.2 Utilization of Ectomycorrhizal Fungi

With EM (ectomycorrhizl fungi) colonization growth has been shown to be promoted for *Shorea curtisii* and *S. leprosula* (Lee and Lim 1989), *S. macroptera* (Turner et al. 1993), and *Hopea odorata*, and *H. helferi* (Yazid et al. 1994) under nursery conditions. *Pisolithus arhizus* and *Scleroderma columnare* promoted growth and survival rates of *S. pinanga* and *S. seminis* in peat soil under nursery conditions (Turjaman et al. 2005, 2006). However, little is known about the effect of EM fungal inoculation on the growth of dipterocarp species or *Shorea* species originating from peatland forests under nursery conditions.

In tropical forests, the use of *Pisolithus tinctorius* has been tested in *Pinus carribaea* under field conditions after 3 years on savannas in Liberia, Africa (Marx et al. 1985). Five EM fungi promoted the growth of hybrid eucalyptus (*Eucalyptus urophylla* x *E. kirtoniana*) 50 months after outplanting in a nutrient-poor acidic sandy savanna soil in Congo, Africa (Garbaye et al. 1988). This type of field experiment has been conducted in temperate areas as well, some examples of which are the inoculation of *Pseudotsuga menziesii* with four EM fungal species in northern Spain (Pera et al. 1999), and the inoculation of *P. menziesii* with EM fungi *Laccaria bicolor* in central France (Selosse et al. 2000). Turjaman et al. inoculated seedlings of *Shorea balangeran* with or without spores of *Boletus* sp., *Scleroderma* sp., and *Strobilomyce*s sp., transplanted seedlings into a degraded peatland forest and grew for 40 months. Shoot height, stem diameter, and survival rates were higher in inoculated seedlings than in controls 40 months after transplantation (Turjaman et al. 2011).

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Part IV

Water Condition and Management in Peatland

Hidenori Takahashi and Aswin Usup

Chapter 16
Characteristics of Watershed in Central Kalimantan

Tadaoki Itakura, Makoto Nakatsugawa, Hikaru Sugimoto, and Yasuharu Watanabe

Abstract The variation of the water level at Palangka Raya is well described by the Nearest Neighbor Method (NNM) and the prediction can be made with 1-month lead time. A rainfall runoff model, traditional Tank Model, is applied to analyze the rainfall runoff to predict the water level at Palangka Raya using the data of several rainfall gauging station. The water balance is evaluated at Palangka Raya from the rainfall, the discharge and the evaporation.

Keywords Rainfall runoff • Nearest neighbor method • Water balance

16.1 Introduction

Central Kalimantan Province is located in the area between 03°50′S 01°10′N and 110°20′E 116°00′E bording West Kalimantan, East Kalimantan and South Kalimantan Provinces. Geographically, the northern part of the province is characterized by mountainous topography, and the southern part is low lying area including a lot of peat swamp areas. Most of the forest land is classified into protected forests, forest reserves, tourism, permanent production forests, restricted production forest and convertible production forest. Other land use is largely for agriculture and settlement. Peatland area in Central Kalimantan is estimated to be 30,951 km^2

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Table 16.1 Major rivers in Central Kalimantan

No.	River	Catchment area (km^2)	Status	Authority	Remarks
1	Jelai	8,308	Across two provinces	Large River Basin Organization (BBWS: Abbreviation in Indonesian)	Partially located in West Kalimantan Province
2	Arut	6,634			
3	Lamandau	9,966			
4	Kumai	5,805			
5	Seruyan	11,625	National Strategic River	BBWS	
6	Mentaya	13,283	Inside the prefecture	Prefecture	
7	Katingan	21,576	Inside the prefecture	Prefecture	
8	Sebangau	6,649	National Strategic River	BBWS	
9	Kahayan	20,616			
10	Kapuas	no data	Across two provinces	BBWS	Partially located in South Kalimantan Province
11	Barito	29,884			

(Hojieer et al. 2006), which is almost 20 % of the total provincial area. The climate in the province is categorized into wet tropical, with an average annual rainfall of 2,700 mm. The rainy season is from October to March, while the dry season is from June to August.

Central Kalimantan Province has 11 major rivers as shown in Table 16.1 and Fig. 16.1. In 1996 the government of Indonesia commenced the One Million Hectare Mega Rice Project (MRP) for rice cultivation, linked to transmigration, The development of an area of 1 million hectares in Central Kalimantan, situated between the Sebangau River in the west, the Kahayan, Sungai Kapuas and Barito Rivers in the east, and the Java Sea in the south, was implemented. More than 4,000 km of channels were constructed. As a result, the peatland was drained severely due to the inappropriate plan. Out of the 11 rivers, mainly the Kahayan River is analyzed in the following sections.

The water levels at both ends of the cut-off canal, Kalanpangan Canal, (at the Kahayan River and at the Sebangau River) are necessary to analyze the movement of the ground water as the boundary conditions. The Kalanpangan Canal was constructed to lower the ground water level and dry up the land to cultivate for the agricultural use. On the other hand, the dry land which is mainly consists of the peat soil is suffered by the wild-fires very often which produce much CO_2 and cause several global problem of the carbon management. All the data used in the analysis were provided by the Department of Public Works, Central Kalimantan Province. And all the analysis are made by monthly averaged values.

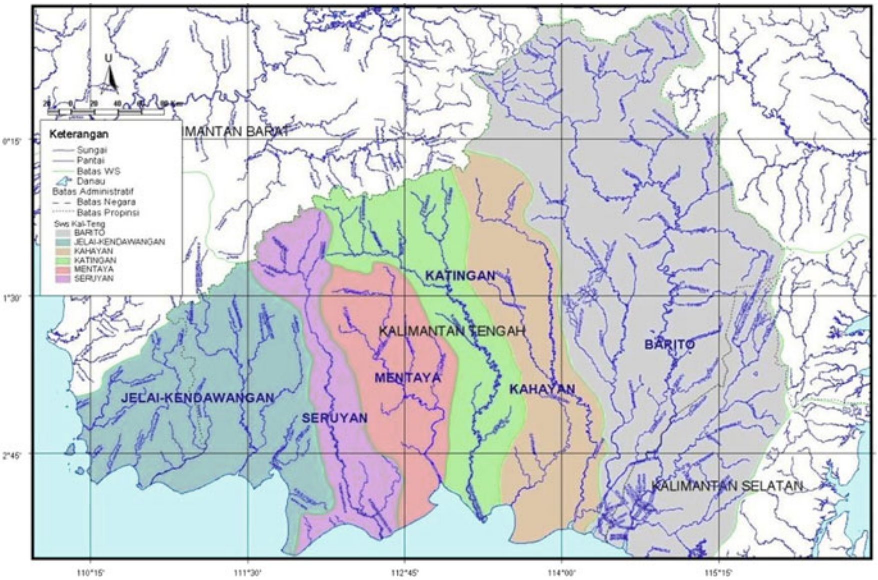


Fig. 16.1 Rivers and catchments in Central Kalimantan

16.2 Water Shed of Kahayan River

The Kahayan River is the largest river in the Central Kalimantan. Its drainage area is 20,616 km^2 and the length of the river course is 340 km. Palangka Raya, the capital city of the Central Kalimantan Province, is located at the center of the river basin and 130 km up-stream from the river mouth. The down-stream of the city of Palangka Raya is very flat and is the marsh covered by the peat soils.

The data used in the runoff analyses are the data of the water level at Palangka Raya (denoted H-34 in Fig. 16.2) and the rainfall is of Kuala Kurun (130 km up-stream of Palangka Raya, R-32). The data are of 1997–2010 for 14 years in which the period of “no data” is less. These data of the rainfall and the water level are all observed by Dinas PU Pripisi Kalimantan Tengah.

Six rainfall gauging stations and 14 automatic water level gauging stations were set by our JICA/JST Team for 2009–2010 as shown in Fig. 16.2.

The specific discharge (annual average runoff rate/drainage area) of the Kahayan River is 0.087 (m^3/s/km^2) and is very small compared to the world rivers. It is as small as the Chaopraya River in Thailand (0.03). It is concluded that the runoff of the Kahayan River is very small relative to its drainage area (Itakura et al. 2001, 2012; Itakura and Takahashi 2012).

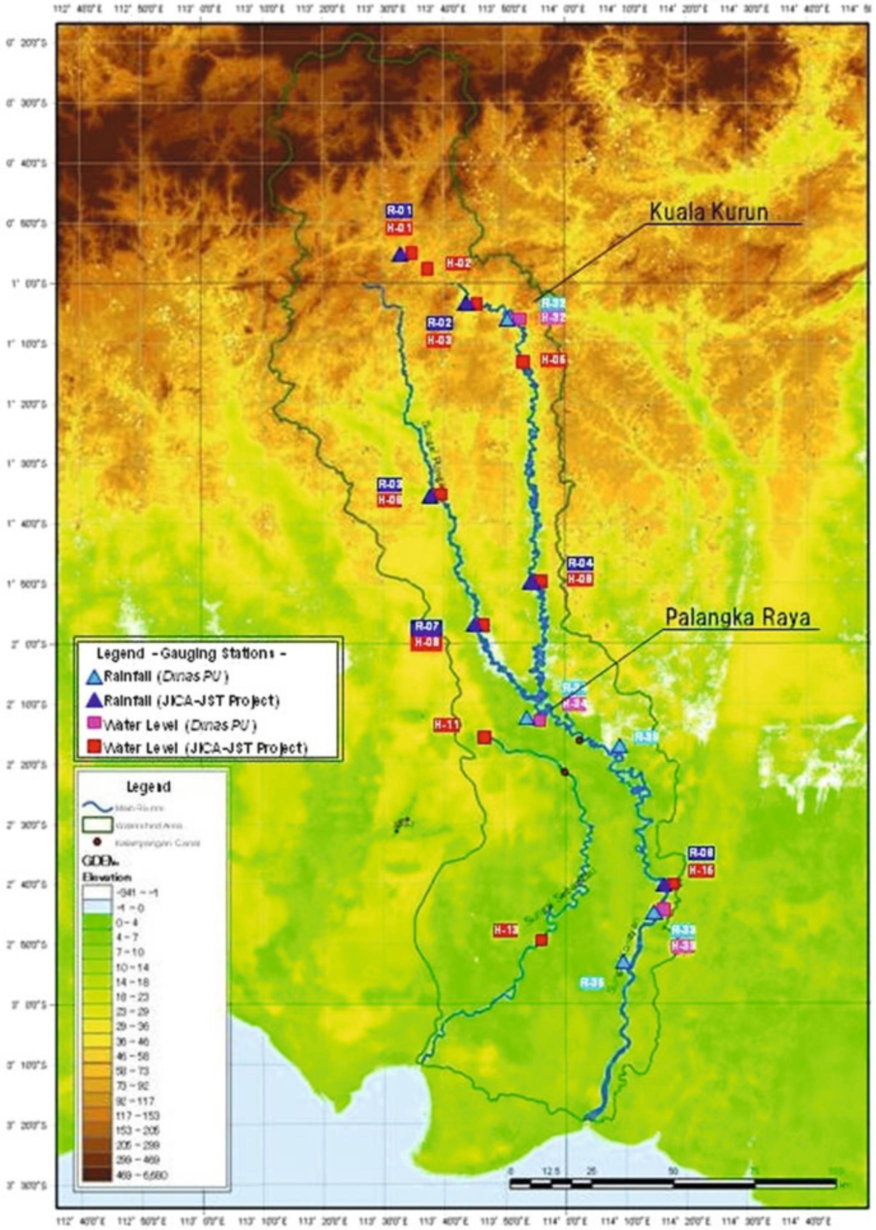


Fig. 16.2 Location of the river water level and rainfall observatory

Figure 16.3 shows the variation of monthly averaged and yearly water level at Palangka Raya. As far as the monthly average is concerned, it is very clear that from June to November is the dry season and the rainy season is from December

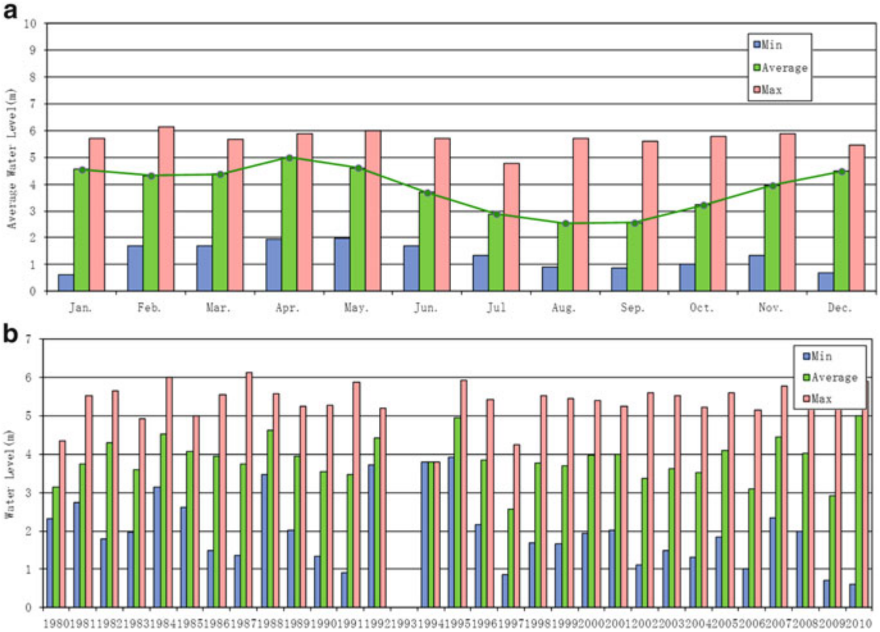


Fig. 16.3 (**a**) Annual change of monthly mean, maximum and minimum water levels (**b**) Yearly variation of annual mean, maximum and minimum water level from 1960 to 2010 at Palangka Raya

to May. But the variation of the water level of each month is very wide as much as 5 m. The maximum water levels are almost the same throughout whole the year. It is 5–6 m and an attention for the high water level is necessary for whole the year. This must be one of the reasons that people do not pay attention to the runoff analysis. This problem is classified to be “Prediction in Unguaged Basins” (PUB) in the committee of hydrology of the Japan Society of Civil Engineering.

16.3 Prediction of Water Level

16.3.1 Prediction Using Only Water Level Data

An attempt was made to forecast the water level with a focus on periods when it drops during El Niño events. We would like to prevent peatland drying by using water level forecasting and by the preliminary use of weirs to head up rivers or canals. However, when the practical use of such a measure for water level regulation on the Kahayan River basin is considered, the day-to-day operation of weirs is not important. Weir operation based on monthly forecasting is considered to be more practical for the subject area, and we conducted monthly forecasting in this study. In

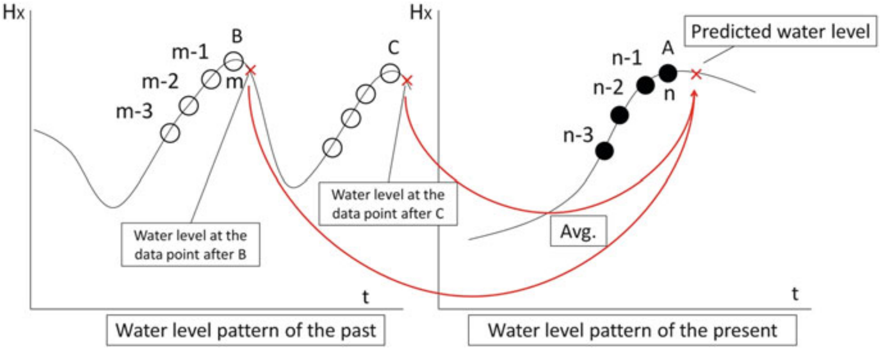


Fig. 16.4 Schematic figure of the NNM method for water level forecasting

addition, a common method of water level forecasting is done using rainfall and the resulting changes in river discharge. However, discharge observation has not been conducted periodically on the Kahayan River, so water level forecasting using the discharge data is difficult in the subject area. This study used the Nearest Neighbor Method (NNM), which is able to forecast the water level even when hydrological data are scant. The candidate for water level forecasting is the Palangka Raya observation site, which is distributed with peatland, agricultural land and urbanized land.

Outline of Nearest Neighbor Method (NNM) NNM is similar to pattern matching methods. Karlsson and Yakowits (1987) were the first to apply NNM to runoff prediction. Galeati et al. (1990) applied NNM to runoff prediction on a day-to-day basis at a river that has a snowmelt season. However, few studies have focused on the period of river water level decline. This method forecasts the water levels based on water level patterns in the present and past. In particular, in Fig. 16.4, when the water level at site X and at a time point right after A is forecasted, a water level pattern similar to the present pattern (black circles) is searched for in past data. The pattern of changes right before point B (white circles) is the most similar pattern, and the pattern right before point C (white circles) is the second most similar pattern. The predicted water level is the mean value of the values right after point B and point C. Furthermore, there are numerous combinations for the number of continuous data points (M) and the number of selected water levels from the past (K). Figure 16.4 schematically shows a case of $M = 4$ and $K = 2$. In addition, the pattern matching of the present and past data of hydrological data other than water level can be used together with the water level pattern matching. The data set used in the NNM is called a component.

The Euclidean distance in Eq. 16.1 was used to select the past water levels that were similar to the present pattern. The past water levels whose Euclidean distance is smallest are selected.

$$\text{Euclidean distance} = \sqrt{\left\{H_X(n) - H_X(m)\right\}^2 + \left\{H_X\,(n-1) - H_X\,(m-1)\right\}^2 + \cdots} \tag{16.1}$$

where $H_X(n)$ is the present water level at site X, $H_X(m)$ is the past water level at site X, and $H_X(n\text{-}1)$ and $H_X(m\text{-}1)$ are the immediately previous data points.

Results of Water Level Forecasting Using Hydrological Data In this section, we tried to forecast water level using the water level data at the Palangka Raya site and the average depth of rainfall over the watershed (called "rainfall" below) as hydrological data on the watershed. Various combinations of M of water level at Palangka Raya (MWp), M of rainfall (MR) and K are possible. Forecasts were calculated for several combinations, and the combination with the lowest error was selected. We used 2–5 for M, and 1–20 for K. Furthermore, the value of rainfall is about hundredfold the value of water level at Palangka Raya. Then, there is the problem that the Euclidean distance from water level and rainfall are not equivalent. The rainfall data are divided by 100.

Root mean square error (RMSE) was used for error evaluation. Forecasting calculation is considered to be accurate when the RMSE is small. The RMSE for the 3 months from July through September is called "Dry-RMSE" in this study.

$$\text{RMSE} = \sqrt{\frac{\sum (H_{cal} - H_{obs})^2}{N}} \tag{16.2}$$

where H_{cal} is predicted water level, H_{obs} is observed water level, and N is number of data. Prediction for 1 month later and calculation of the RMSE and Dry-RMSE were conducted from 2002 to 2003 on all combinations of the components, M and K. As a result, $MWp = 3$, $MR = 2$, $K = 2$ was selected (Table 16.2).

The results of water level forecasting are shown in Table 16.2 ("Forecasting pattern" from 1 to 4). The components are water level at Palangka Raya and rainfall. Lead times were from 1 to 4 months. The comparison between observed water levels, "forecasting pattern 1" and "forecasting pattern 5" (discussed below) is shown in Fig. 16.5. The forecasting period was from 2004 to 2007. The database period was from 1981 to 2003. By comparing "forecasting pattern 1" (Fig. 16.5) and observed water levels, predicted water levels indicated a tendency similar to the observed water levels. The results can be regarded as good agreement with observed data when considering that the lead time is 1 month.

Results of Water Level Forecasting that Incorporates SST In this section, we tried to introduce sea surface temperature (SST) data into NNM in order to increase the water level forecasting accuracy of the above section. Data of SST at NINO.3 (5N–5S, 150W–90W), which is the El Niño monitoring location used by the Japan Meteorological Agency (http://www.jma.go.jp/jma/index.html) for determining the occurrence of an El Niño event, were used; they are monthly data. SST is higher during El Niño events than during the same period of years without El Niño

Table 16.2 Measured water level and results of forecast patterns 1 and 5 (1 month lead time)

Forecasting pattern	Subject of forecast	Lead time	Components	Number of consecutive data (M)	Number of water level data (K)	RMSE	Dry-RMSE
1	Water level	1 month	Water level of the river, rainfall	$MWp = 3$	2	0.876 (m)	0.839 (m)
2	Water level	2 months		$MR = 2$		1.136 (m)	1.464 (m)
3	Water level	3 months				1.368 (m)	1.708 (m)
4	Water level	4 months				1.533 (m)	1.818 (m)
5	Water level	1 month	Water level of the river, rainfall, SST	$MWp = 3$ $MR = 2$		0.760 (m)	0.575 (m)
6	Water level	2 months		$MS = 2$		0.918 (m)	0.884 (m)
7	Water level	3 months				0.820 (m)	0.841 (m)
8	Water level	4 months				0.884 (m)	0.803 (m)
9	Rainfall	1 month	Rainfall	$MR = 2$	3	140 (mm month^{-1})	145 (mm month^{-1})
10	Rainfall	1 month	Rainfall, SST	$MR = 2$ $MS = 5$		99 (mm month^{-1})	65 (mm month^{-1})
11	Water level	1 month	The rainfall forecasting for pattern 10 was input in the tank model			0.890 (m)	0.734 (m)

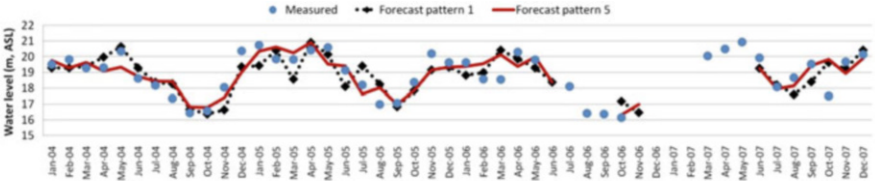


Fig. 16.5 Measured water level and results of forecast patterns 1 and 5 (1 month lead time)

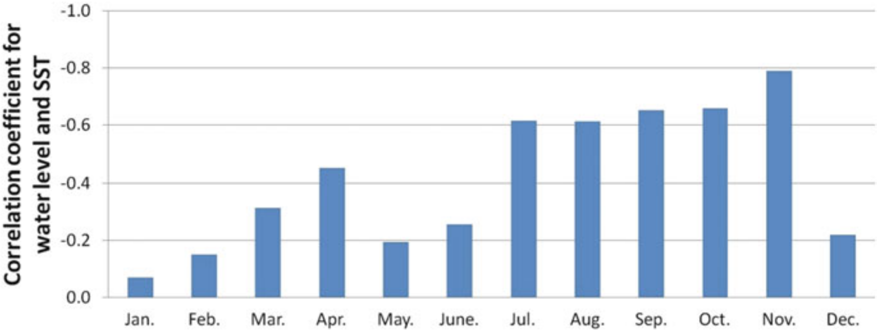


Fig. 16.6 Analysis of the correlation between SST and water level

events. The correlation between SST and water level was verified before SST was introduced into the NNM. The correlation coefficients for the monthly SST and water levels from 1980 to 2011 obtained by using the monthly data from the same period is shown in Fig. 16.6. From Fig. 16.6, it is shown that there is a considerable correlation between them from July to September, which is the dry season in Kalimantan. The relationship between the SST and water level at Palangka Raya is plotted as a regression line in Fig. 16.7, which shows that there is a negative correlation between them.

The relationship between the SST and water level was examined above. Water level forecasting that incorporates SST as a component of NNM was attempted in this section. Furthermore, water level forecasting with an extended lead time was also attempted, and the results are shown in Table 16.2 (Forecasting patterns 5–8). The MWp and MR values selected in the previous section were used, and MS (M of SST) = 2 was selected such that the smallest RMSE and Dry-RMSE values were produced in forecasting for 2002–2003. The period for forecasting and the period of database were the same as those used in the previous section.

Comparison between the Forecasting patterns 1 and 5 in Table 16.2 shows that the forecasting accuracy has been improved from the results of pattern 1 to that of pattern 5, with lowered RMSE, particularly Dry-RMSE. This improvement in accuracy can be explained by the water level drawdown in El Niño event, so that the high negative correlation between SST and water level in the dry season is found. From Forecasting patterns 2–4, it is found that the forecasting accuracy tends to

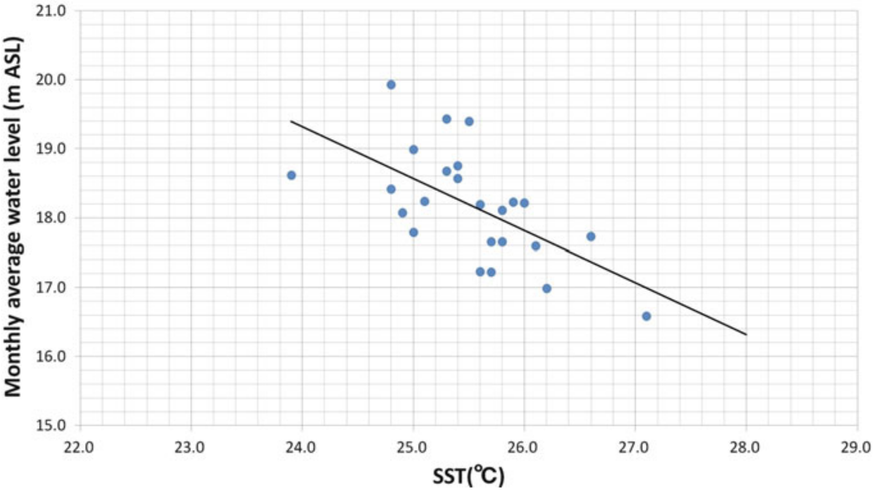


Fig. 16.7 Relationship between SST and water level in July

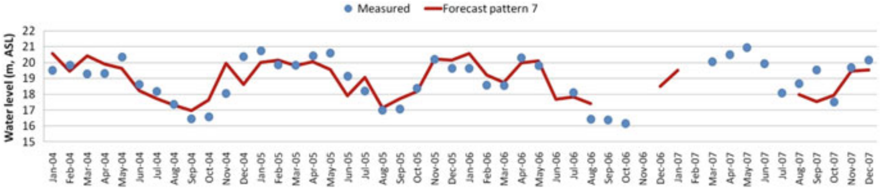


Fig. 16.8 Measured water level and the results of forecasting pattern 7 (3 months lead time)

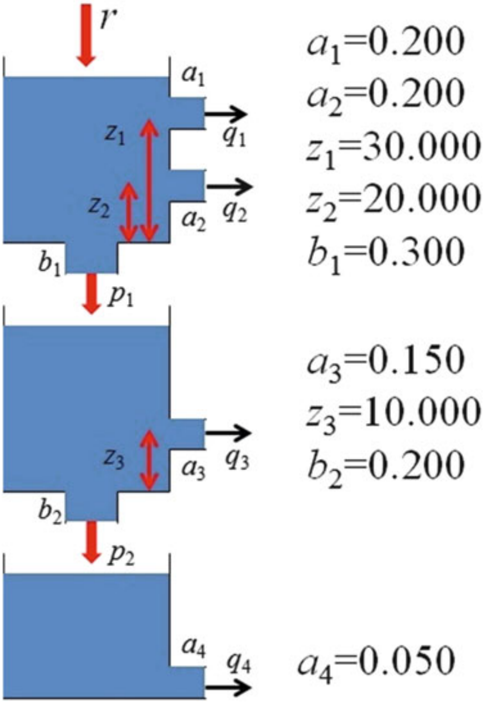
decrease with increases in lead time. From Forecasting patterns 6–8, however, the RMSE and Dry-RMSE undergo changes at about the same level for 2–4 months forecasting, regardless of the lead time. Although further examination is necessary to determine how many months the lead time can be extended while maintaining the forecasting accuracy, it was suggested that forecasting with extended lead time was possible by incorporating the SST as a component. In our example, it was possible to forecast the water level of 4 months ahead while maintaining the accuracy, after which the forecasting accuracy started to decrease. The comparison between measured water level and forecasting patterns 1 and 5 is shown in Fig. 16.5, and that between measured water level and forecasting pattern 7 is shown in Fig. 16.8. From Fig. 16.5, it is found that the results of forecasting pattern 1 tend to deviate often from the measured levels in 2005; however, that of forecasting pattern 5 shows a better result. Forecasting for the dry season in 2007, whose start was forecast to be later than the start of measured dry season in forecasting pattern 1, is also improved. The improved results are thought to be reflected in the RMSE and Dry-RMSE values. From Fig. 16.8, although there are some parts in which the forecasting accuracy shows decrease, the forecasting accuracy can be evaluated as sufficient even though the lead time is as long as 3 months.

16.3.2 Water Level Forecasting Using a Runoff Model and Forecasted Rainfall

The NNM is a pattern matching technique; therefore, it cannot continue forecasting when the procedure encounters a missing part in the measured water levels, which is proved in Figs. 16.5 and 16.8. To address this problem, we attempted to forecast the rainfall by the NNM and to use the obtained rainfall in the runoff model for forecasting the water level. To perform this procedure, construction of a runoff model was necessary.

Outline of Runoff Simulation A runoff simulation was done for the Palangka Raya gauging site. An integrated three-tank model, which has been applied in river basins of Japan, was used, and the calculation period was from 1981 to 2010. Simulation for daily rainfall runoff was done. The parameters used in this simulation were based on those by Tsuji et al. (2012), and the values were slightly modified as shown in Fig. 16.9, the unit is mm-d. Figure. 16.10 shows the monthly

Fig. 16.9 Model parameters



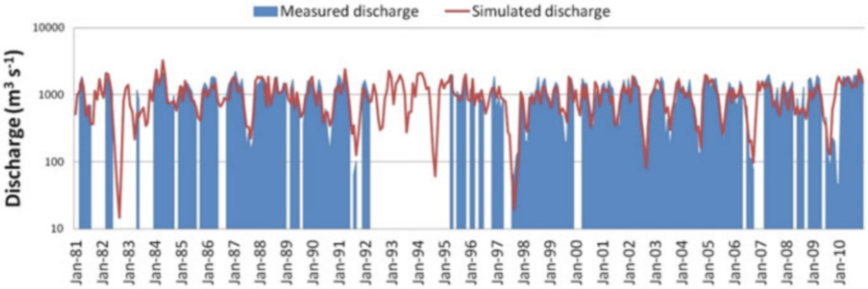


Fig. 16.10 Results of the runoff simulation

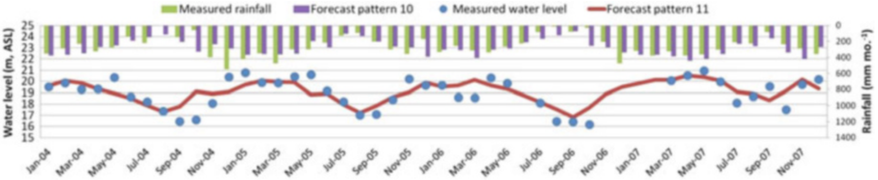


Fig. 16.11 Results of rainfall forecasting and of water level forecast using forecast rainfall (1 month lead time)

measured and simulated runoffs and it is found that the model roughly simulated the measured runoff. Furthermore, validity of the model can be confirmed by the Nash efficiency coefficient being 0.750 for the period from 2004 to 2007 for which water level forecasting will be done in the next section. We consider that the successful verification of the runoff model is the result of verification of the balance between the effective rainfall and runoff and appropriate selection of parameters.

Results of Rainfall Forecasting SST was also incorporated as a component in forecasting rainfall by the NNM. We created two patterns: one using rainfall as a single component, and the other using rainfall and SST as its components. Simulation was done for the two patterns (forecasting patterns 9 and 10 in Table 16.2). The values for M and K in forecasting the rainfall were selected so that they would produce small RMSE and Dry-RMSE for 2002 and 2003. Comparison between the RMSE and Dry-RMSE of forecasting patterns 9 and 10 shows that the accuracy of forecasting has improved remarkably by incorporating SST as a component, which demonstrates that it is necessary to consider the use of SST in hydrological analysis for the Kahayan River basin. The measured and forecasted rainfall amounts in Fig. 16.11 show that the forecasted rainfall simulated the measured rainfall well. For water level forecasting in the next section, we used the rainfall forecasted by forecasting pattern 10.

Estimation of Water Level Forecasting from Forecasted Rainfall The tank model that was examined in the previous section and the forecasted rainfall were used in an attempt to forecast water levels in this section. For performing simulation using a tank model, daily rainfall data were obtained by dividing the forecasted monthly rainfall by the number of days. The obtained daily runoff was converted to daily water level by using the H-Q equation. Then, the monthly average water level was obtained by using the obtained daily water level. The results of water level forecasting are shown in Table 16.2 (forecasting pattern 11) and comparison between the forecasted and the measured water levels is shown in Fig. 16.11. Table 16.2 shows that the values of RMSE and Dry-RMSE are inferior to those obtained by forecasting pattern 5. It is thought that forecasting which uses water level data produces more accurate results than water level forecasting using rainfall forecasting. However, when Fig. 16.11 is carefully examined, it can be determined that the forecasting sufficiently expresses the pattern of the changes in the water level. Furthermore, even if water level data are not available for a certain month for which a rainfall data are available, it is possible to forecast the water level for the following month by using the water level forecasting from rainfall forecasting. The forecasted water level has no missing portions for the period from 2004 to 2007, because there were no missing portions in the rainfall data for the subject period (Fig. 16.11). We were able to demonstrate a water level forecasting technique that can be effectively used even when portions of the measured water level data are missing. When the validity of the above described technique is examined based on the fact that this study focuses on water level forecasting during the dry, low-water season, the changes in daily rainfall are thought to have little influence on the water level. Therefore, the forecasting results of the technique in this study, which focuses on water level forecasting in the low-water season, are thought to be sufficient. To use this technique for water level forecasting for the rainy season, it is necessary to further improve it by devising ways to consider daily changes in rainfall.

16.3.3 Relationship Between River Water Level and Canal Water Level

This section analyzes the relationship between river water level and canal water level in order to obtain knowledge of the information on river water level that can be applied in controlling the canal water level. River water level is that observed at the PalangkaRaya site. Canal water level is that observed at the Lg1 site (Fig. 16.12). The relationship between the water level at the PalangkaRaya site and the water level at Lg1 is plotted in Fig. 16.13. The daily data were used, and the data period was from March 1, 2011 to April 29, 2012. 340 days of data observed at both observation sites were used. Figure 16.13 shows that there is a direct relationship between the water levels at the PalangkaRaya site and the Lg1 site. This finding can be used as basic information when the water level information is used in controlling the canal water level.

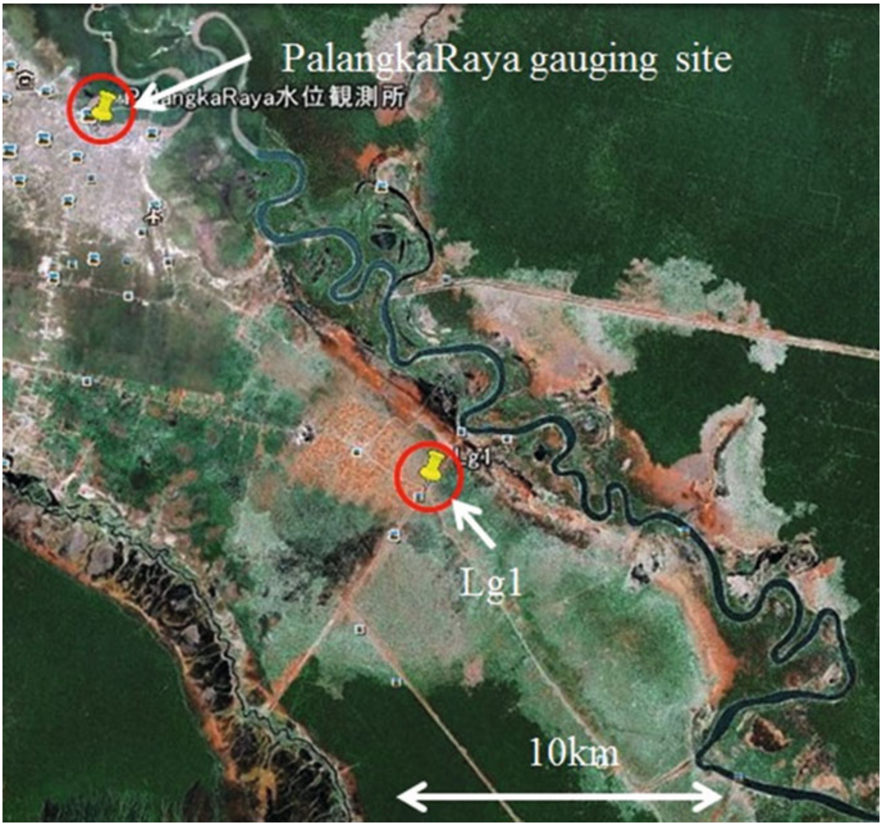


Fig. 16.12 Palangka Raya site and Lg1 site

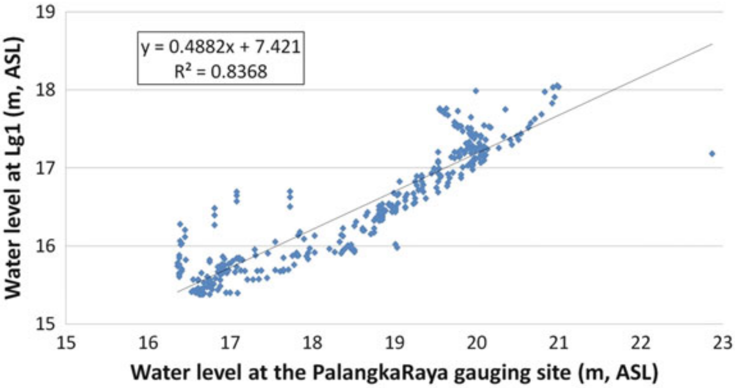


Fig. 16.13 Relationship between water levels at Palangka Raya and at Lg1

16.4 Water Balance in the Kahayan River Basin

In this section, the water balance is quantified by comparing the effective rainfall and the runoff height for the basin of the Palangka Raya gauging site. Effective rainfall is the average depth of rainfall over the watershed area minus the amount of evapotranspiration. The calculation method for the amount of evapotranspiration is shown below. According to the estimation by Budyko et al. (1977), the ratio of actual evapotranspiration amount and potential evapotranspiration amount is approximately 2:3 in the vicinity of Indonesia. Then, after the calculation of the potential evapotranspiration amount using the Hamon method (Hamon(1961)), the actual evapotranspiration amount is calculated by multiplying the potential evapotranspiration amount by 2/3. Air temperature data for calculating the potential evapotranspiration amount was measured at PalangkaRaya Airport (Fig. 16.14). Palangka Raya Airport is the only gauging site in the basin that measures air temperature on a long-term basis.

The average depth of rainfall over the watershed is the arithmetic mean of two values:rainfall measured at the Palangka Raya gauging site and at the Kuala Kurun gauging site. In addition, this study used 0.5° grid data from the Global Precipitation Climatology Project (GPCP) of the World Meteorological Organization provided by the website of German Meteorological Service (http://www.dwd.de/). Five grid points were extracted from the basin (Fig. 16.14), and the average depth of rainfall over the watershed was the arithmetic mean of the five values (GPCP rainfall). Effective rainfall was estimated by using actual evapotranspiration amount and the average depth of rainfall over the watershed, which was calculated from the above.

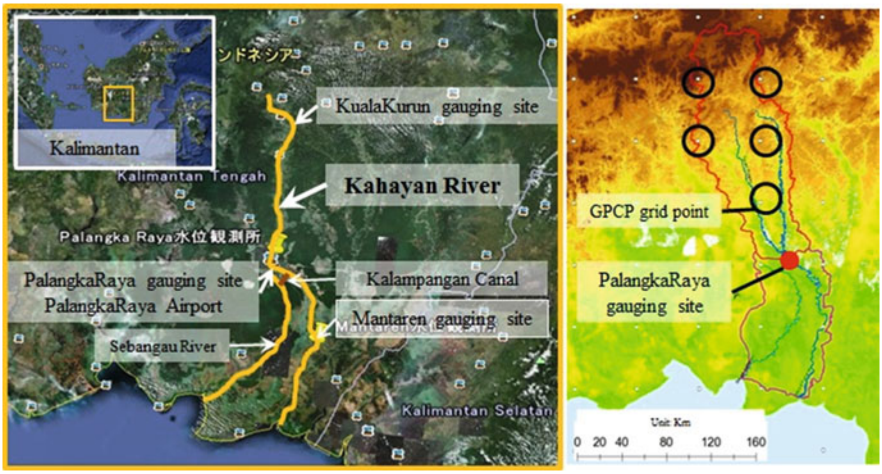


Fig. 16.14 Location of gauging points, boundary of the basin and the GPCP grid points in the Kahayan River

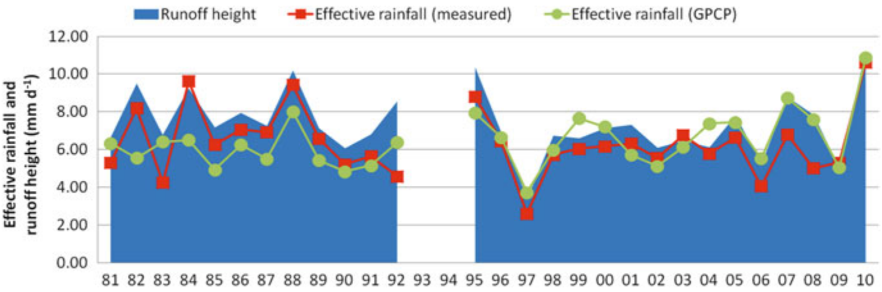


Fig. 16.15 Verification of water balance (1993 and 1994 are regarded as missing data)

Table 16.3 Daily and annual average of water balance (mm)

	Avg. from ’81 to ’10	Daily avg. (mm day^{-1})	Annual avg. (mm $year^{-1}$)
1	Measured rainfall	8.83	3,223
1′	GPCP rainfall	8.84	3,226
2	Measured evapotranspiration	2.43	886
3	Effective rainfall (1–2)	6.4	2,337
3′	Effective rainfall (1′–2)	6.41	2,340
4	Runoff height	7.28	2,656

Discharge is not measured periodically in the Kahayan River. The runoff height was estimated according to the method of Tsuji et al. (2012). First, an relationship between water level and discharge (H-Q) was formulated as H-Q equation using hydrological data measured irregularly. Next, the H-Q equation was applied to the continuous water level data. Finally, continuous discharge data were obtained. The developed H-Q equation is $H = 0.13Q^{0.5} - 0.15 + 15.15$ (m, ASL) where 15.15 is the value used to convert the water level of the Palangka Raya gauging site to the water level above sea level and ASL is the elevation from mean sea level.

To conduct long-term verification, the period for verification was set from 1981, which is the year that the water level and rainfall at the Palangka Raya site started to be measured, to 2010. The annual fluctuations in effective rainfall and runoff height are shown in Fig. 16.15. They are shown as daily mean values because it was impossible to calculate the annual amount due to missing values of measured data. In addition, we hypothesized that approximate values of annual amounts could be estimated by using long-term data despite the missing values. The daily mean value for 30 years was calculated using the data from 1981 to 2010, and yearly mean value was obtained by multiplying the daily mean value by 365. It is shown in Table 16.3. In Fig. 16.15, it be said that effective rainfall based on the rainfall measured by ground rain gauge is in balance with runoff height. This result shows that the effective rainfall calculation is valid. In addition, the effective rainfall calculated based on “GPCP rainfall” for the term before 1992 is underestimated relative to that for after 1995. However, that imbalance has been declining since 1995, and the balance has been very accurate since 2005. This result shows the accuracy improvement for "GPCP rainfall". The results of the above examination show that we will be able to conduct sufficiently accurate verification of annual water balance for a local area by using the global precipitation data. For the yearly mean of effective rainfall and runoff height (Table 16.3), it is shown that the runoff for the Kahayan River is approximately 2,300–2,700 (mm year^{-1}), although the margin of error is about 300 (mm year^{-1}).

Acknowledgement Results shown in this paper were mainly obtained from SATREPS (Science and Technology Research Partnership for Sustainable Development) project entitled as "Wild fire and carbon management in peat-forest in Indonesia" founded by JST (Japan Science and Technology Agency) and JICA (Japan International Cooperation Agency).

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Chapter 17
Groundwater in Peatland

Yoshiyuki Ishii, Ken Koizumi, Hiroshi Fukami, Koichi Yamamoto, Hidenori Takahashi, Suwido H. Limin, Kitso Kusin, Aswin Usup, and Gatot E. Susilo

Abstract In a tropical peat-forest in Central Kalimantan, Indonesia, massive drainage canal excavation led to a significant groundwater table decrease and to peatland degradation due to wildfires. To assess how to maintain a high groundwater table in tropical peatlands, groundwater levels and canal water levels were monitored by drilling 32 shallow wells, 6 deep wells and 13 canal sites in the Block-C North area of the Ex-Mega Rice Project area. A static GPS survey was done to determine the altitudes of all observation sites, and contour maps of the ground surface and of the shallow groundwater table were made at three different times. From these results, the regional characteristics of the shallow and deep groundwater movements were clarified. Furthermore, to examine the present and the past groundwater condition in this area and also to predict a future one, we established a numerical simulation model based on the MODFLOW. According to the calibrated model, the groundwater level in the peat layer dropped to more than 2 m below the surface near Kalampangan Canal during the 2009 drought period when a severe wildfire occurred. Before the Mega Rice Project (MRP), the

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groundwater potentials were higher than they are at present. If several proposed dams are constructed along the Kalampangan Canal, the dam efficiency needed to maintain a high water level in the peat layer is estimated to be more than 10 cm within 400 m of the canal in the 2009 drought period.

Keywords Tropical peatland • Groundwater level • Canal water level • Groundwater simulation model • Dam efficiency

17.1 Introduction

In a tropical peat-forest in Central Kalimantan, Indonesia, massive drainage canal excavation performed during the Mega Rice Project (MRP) in the late 1990s caused a significant groundwater level decrease and soil drying within the surface peat layer (Page et al. 2002; Wösten et al. 2008). Many severe wildfires occurred, and their range expanded in every dry year, leading to peatland degradation, which causes irreversible damage to the peatland pedology and ecosystem (Siegert et al. 2001; 2002). To protect the peatland from wildfires, it is necessary to maintain a high groundwater level in the peat layer due to the construction of suitable dam array in the canal. However, knowledge of the regional groundwater flow system around the Ex-MRP area has been quite limited. The main objectives in this study are to clarify the hydrological characteristics of the peatland groundwater in the Block-C North area of the Ex-MRP area and to evaluate the dam and canal efficiency for maintaining a high groundwater level in the peatland. These can be done through both field observation and model simulation.

17.2 Regional Groundwater Movement

The area between the Kahayan River and the Sebangau River is called 'Block C' of the Ex-MRP area. Our study site is located 20 km southeast of Palangka Raya in the Block-C North area. There are two main canals, the Kalampangan Canal, which crosses the area from the Kahayan River to the Sebangau River, and the Taruna Canal, which starts at the junction of the Kalampangan Canal in the southeast direction.

We installed an automatic weather station at the Base Camp of the University of Palangka Raya, located at the intersection of the national road and the Kalampangan Canal (Fig. 17.1). We used the precipitation data of the station.

To determine the present groundwater condition, we constructed 32 observation wells for shallow groundwater (5 m deep), 6 wells for deep groundwater (20 m deep) and 13 canal water level measuring sites in 2010 as shown in Fig. 17.1, and installed water level loggers (S&DL Mini, OYO Corp., Japan; DL/N70, STS AG, Switzerland) at all sites. Most data recording started in July 2010, except at the Lg 9 and Lg 11–13 sites (Ishii et al. 2012). As the water levels of the Kahayan and the Sebangau Rivers were unusually high, even in the dry season in 2010, we could not install the iron tubes and the data loggers at Lg 11–13. Therefore, we installed them

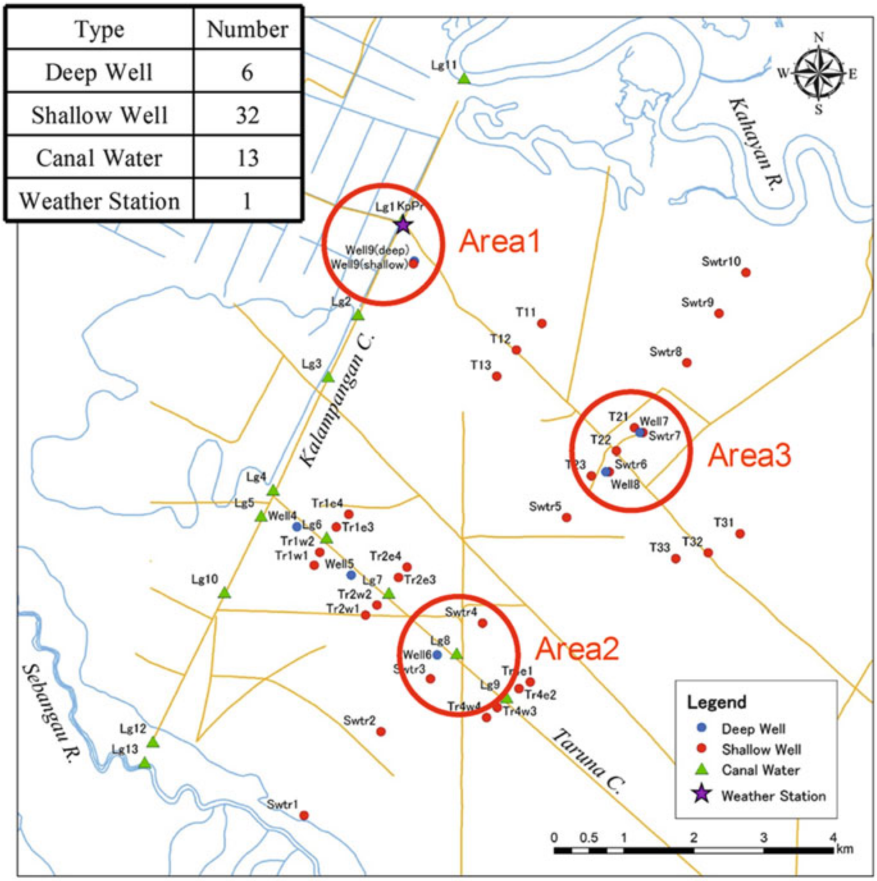

Fig. 17.1 Observation site in Block-C North area

in September 2010 at the Lg 11 site and in July 2011 at the Lg 12 and 13 sites. Also, to determine the altitude of the water level, we performed a static GPS survey for all sites in 2010 and 2011, using the Trimble 5,700 L1/L2 as reported in Yamamoto et al. (2011).

Based on these field activities, we analyzed the seasonal changes in the shallow/deep groundwater levels and the canal water level. In addition, we made water level contour maps of the shallow groundwater within the peat layer at three different times: namely, November 2010, March 2011 and May 2011.

17.2.1 Groundwater Level Fluctuation

Figure 17.2 shows the changes in the shallow/deep groundwater levels at Areas 1, 2 and 3, with the changes in the adjacent canal/river water level and daily precipitation. The shallow groundwater level showed clear increases in response

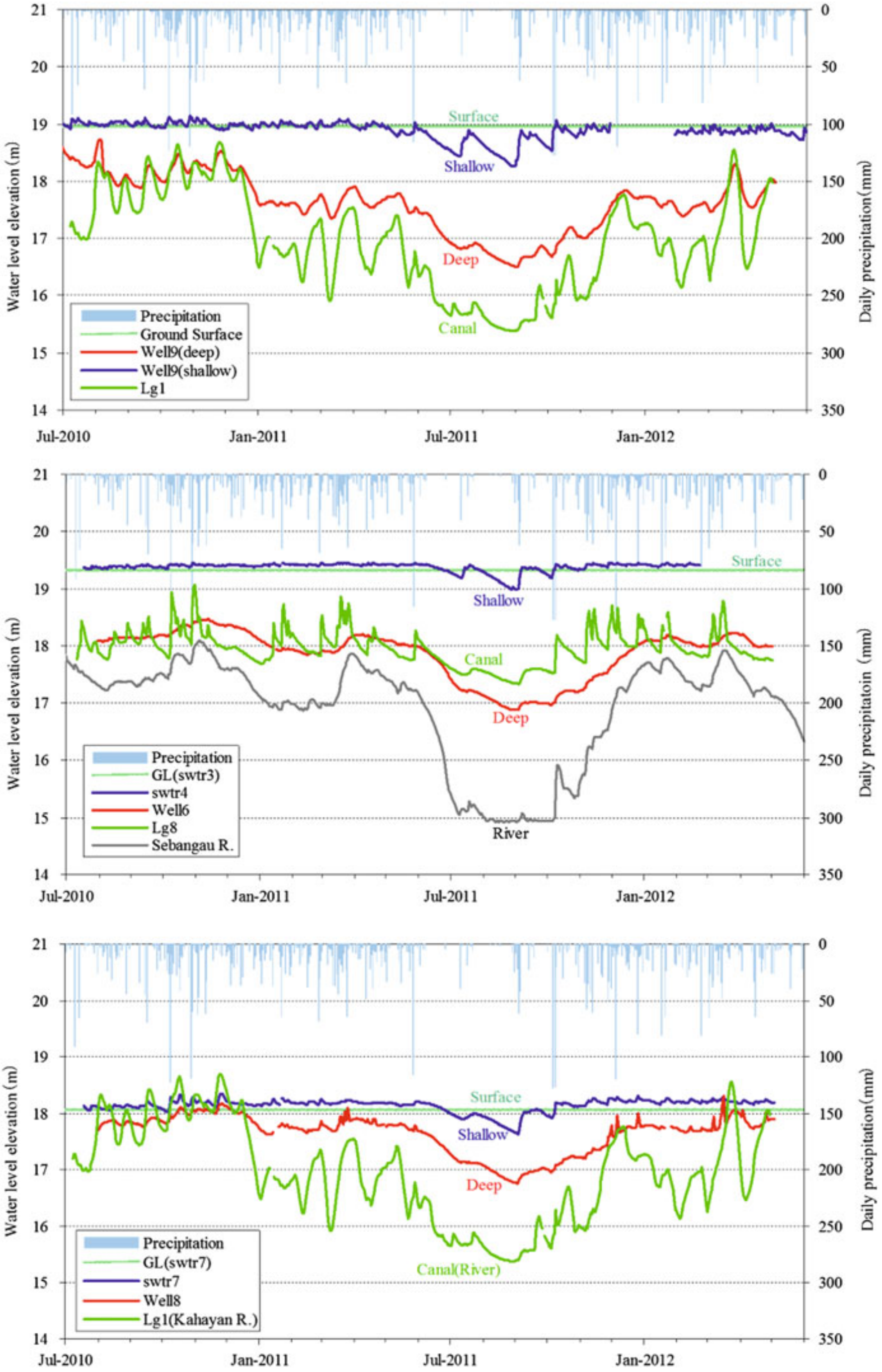

Fig. 17.2 Water level changes in the shallow/deep groundwater at Areas 1–3 with the changes in the adjacent canal/river water level and daily precipitation

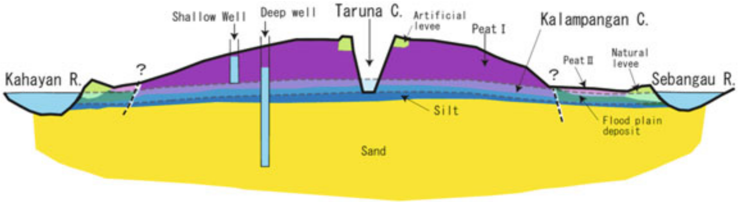

Fig. 17.3 Schematic diagram of hydrogeology in the study area

to significant rainfall events. All 32 shallow groundwater levels showed nearly the same fluctuation tendency as these sites. Meanwhile, the deep groundwater level showed slower changes, similar to those of the canal water level. This tendency was recognized in almost all study areas, and it means that there is an aquitard between the upper peat layer and the lower sand layer, which separates the shallow aquifer from the deep aquifer. Drilling data in this area support the existence of the aquitard.

Based on analysis of field survey and previous studies, we considered a hydrogeological model as schematically shown in Fig. 17.3. There are two aquifers (one shallow and one deep) and one aquitard up to 50 m in depth. The shallow aquifer composed of Peat I/Alluvial (Peat II) and the deep aquifer composed of sand are separated by an aquitard of silt. The deep aquifer has sufficient capacity for pumping usage, and has good water quality. Its specific electrical conductivity is around 1.5 mS/m, which is nearly the same as that of the Kahayan River water. Deep groundwater exists in the lower white sand layer under a confined or semi-confined condition. On the other hand, the shallow aquifer exists in the surficial peat layer and is as deep as 5 m, with the water table usually maintained near the ground surface. This groundwater is a chocolate-like color, and its electrical conductivity ranges from 5 to 6 mS/m. Peatlands in this area are dome shaped, with an elevation that increases from sea level at the coast to only some 20 m above sea level 200 km inland. Sand, gravel and clay deposits of fluvial origin underlie these peatlands (Sieffermann et al. 1988).

17.2.2 Regional Groundwater Movement

Figure 17.4 shows the contour map of ground surface elevation based on the results of a static GPS survey. This area originally formed a typical dome-shaped cross section between the Kahayan and Sebangau Rivers, as mentioned in Hooijer et al. (2010). However, two major canal excavations gave rise to severe changes in the surficial topography of the peatland. Ground surface levels are decreasing in the direction of the canal. As the Taruna Canal was constructed to cut through the highest part of the peat dome, the ground surface decline is steep along the canal.

Shallow groundwater contour maps are shown in Fig. 17.5 for three different points in time. The water level condition was comparatively high in November 26,

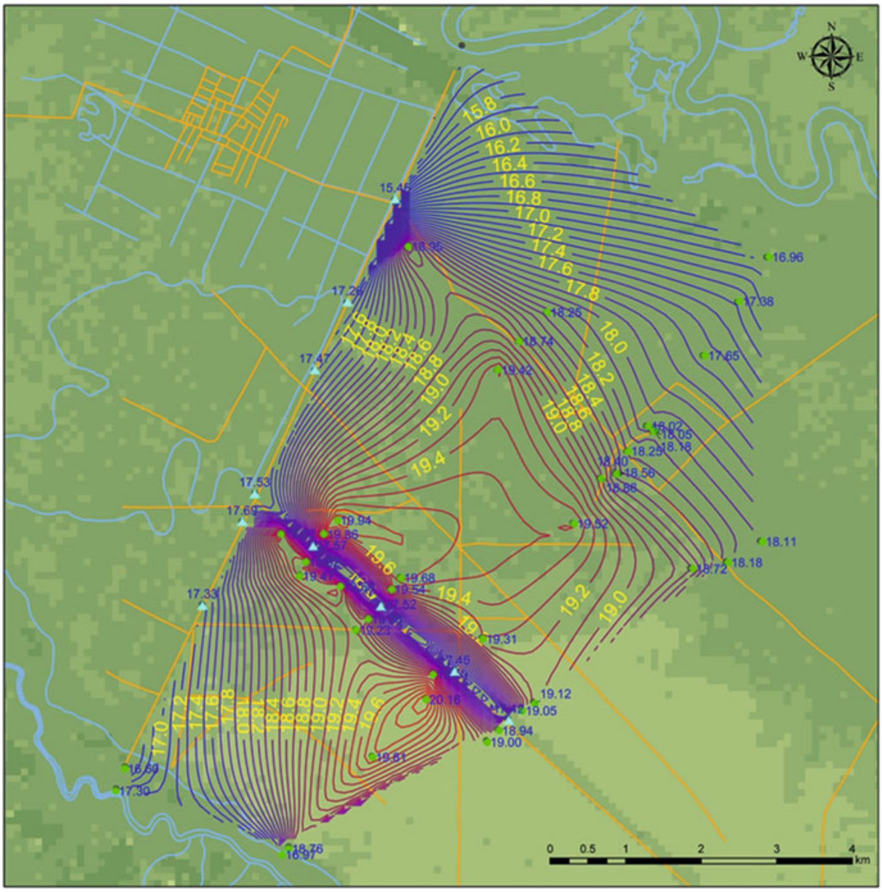

Fig. 17.4 Ground surface contour map

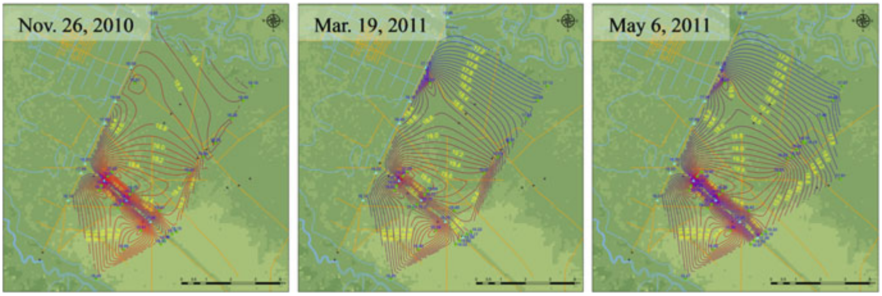

Fig. 17.5 Contour maps of the shallow groundwater table on November 26, 2010; March 19, 2011; and May 6, 2011

Fig. 17.6 Water flow directions within the Kalampangan Canal and the Taruna Canal

2010, and low in March 19 and May 6, 2011. Each contour map shows a steep water level decline along the Taruna Canal. The groundwater levels were always higher than the canal water levels, and those fluctuation ranges were relatively small as compared with the canal. Therefore, the water level gradient near the canal became large when the canal water level was low, and became small when it was high.

17.2.3 Flow Direction of the Canal Water

Figure 17.6 shows the water flow direction within the canals for the same three times shown in Fig. 17.5. When the water levels in both the Kahayan and Sebangau Rivers were high, the flow of the Kalampangan Canal was directed from the rivers to the center of the peat dome. In contrast, when the river water levels were low, the flow direction changed to run from the canal to the rivers. However, the water level at Lg 3 was often the lowest among the 13 canal water level measuring sites. There is a possibility of some water leakage from the Kalampangan Canal to the northwest-facing peat-swampy area through the bank. In the Taruna Canal, the water level was always highest at Lg 7, and the canal flow direction ran from this site toward the northwest and southeast directions. These flow directions of the canal water have to be considered during the planning of a suitable dam array construction scheme.

17.3 Past and Future Groundwater Movement

The code selected to simulate the regional groundwater flow condition in the study area was MODFLOW; a saturated modular three-dimensional finite difference groundwater flow model developed by the U. S. Geological Survey. The application used for pre-/post-processing was Visual MODFLOW (Waterloo Hydrogeologic, Inc.). The unsaturated zone is of considerable importance to wetland hydrology because it provides the link between net surface flux and water table response

(Boswell and Olyphant 2007). However, unsaturated zone dynamics are simplified by the tank model, and the result from the tank model supply to the groundwater model as recharge, because the information for the unsaturated zone in the study area is limited, and the main objective was to estimate the dam efficiency required to keep the shallow groundwater level high in the peat layer.

The tank model for the study area was composed of two vertical tanks (Fig. 17.7). The first tank represents the surface and unsaturated layers. The second tank represents the shallow aquifer and can simulate the water level in the shallow aquifer. Daily recharge can be estimated from the vertical outlet of the first tank. The precipitation data at the Base Camp were used as the input, and the daily evapotranspiration in peatland was assumed to have a constant value of 4.0 mm/d based on previous studies (Hooijer et al. 2008) and empirical formulas. The tank model structure shown in Fig. 17.7 could sufficiently recreate the water level change in Well 9 (shallow).

The area selected for the groundwater model is shown in Fig. 17.8. The horizontal range contains the whole region of the study area along 21.4 km in the X direction, 17.2 km in the Y direction and 389.48 km^2 in area. The model domain was discretized with a uniform 100 × 100 m^2 grid. The developed groundwater model consists of two aquifers and one aquitard. The model grid is formed by 116,844 cells (214 columns × 172 rows × 3 layers), including the inactive area.

The interpolated elevation data from a static GPS survey, the Airborne Laser Scan (Kalteng Consultants 2009) and Shuttle Radar Topography Mission (SRTM) data were imported to the top layer of the model. The basement of the model was set at minus 200 m above sea level so as to have sufficient thickness for minimizing the impact to the model calculation and to be able to evaluate the regional groundwater movement in the deep aquifer. It was assumed that the silt layer was 3 m below the surface based on the survey data and was distributed over the whole area in the

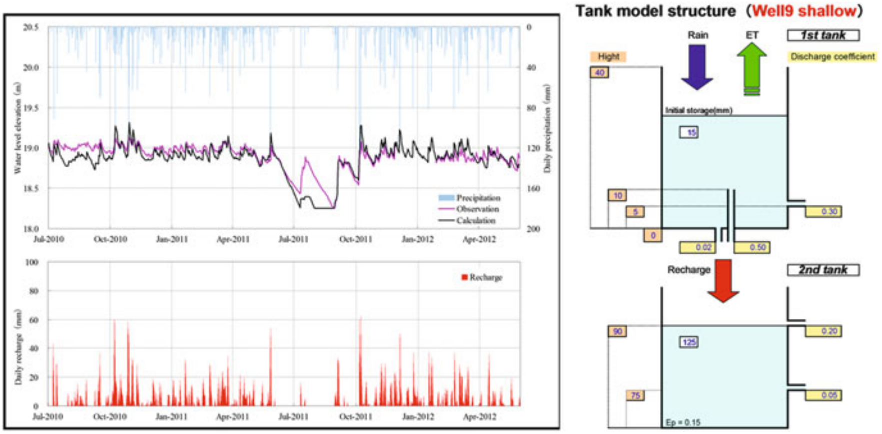

Fig. 17.7 Tank model structure and example of the tank model calculation results

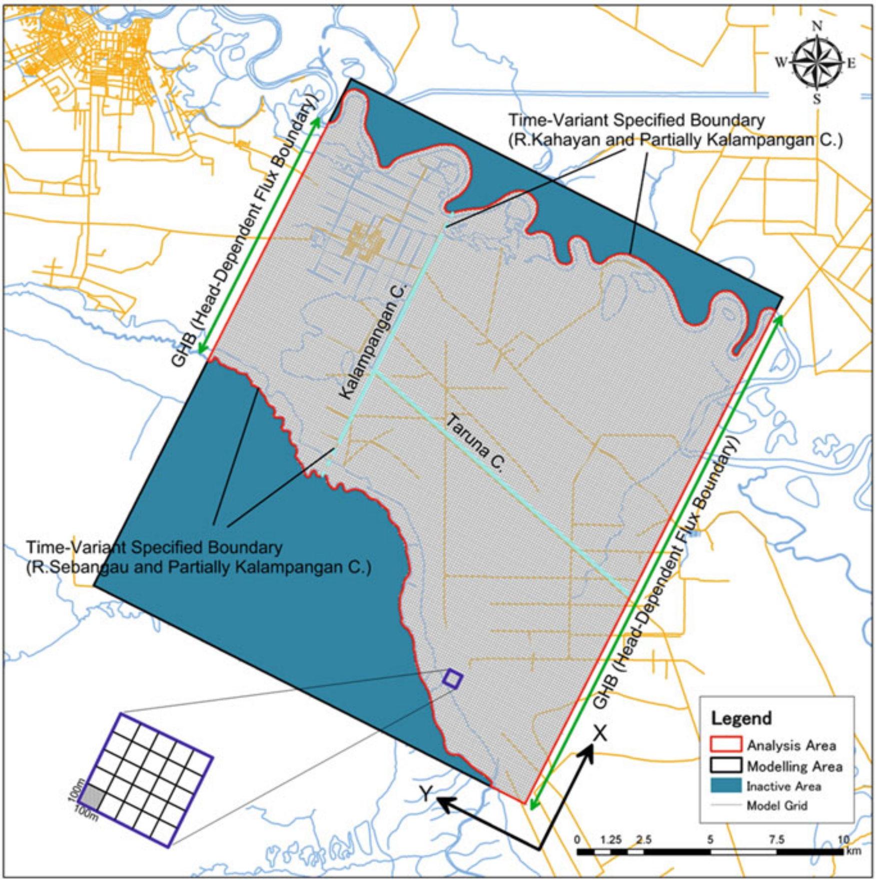

Fig. 17.8 Model grids of the calculation area with boundary conditions

model, and the bottom of the silt layer was flat because the information for the thin silt layer acting as an aquitard was limited. Hence the silt layer became thinner in accordance with the lowering of the surface elevation.

The analytical area was bounded to the northeast by the Kahayan River and to the southwest by the Sebangau River. The model simulations employed time-variant specified head boundary conditions for these two river boundaries. However, there were no hydrologic divides such as rivers or canals in the southeast and northwest boundaries, and the groundwater could flow into/out through them. General Head Boundaries (GHB), which are head-dependent flux boundaries, provide a way to simulate the effects of a distant boundary in a small model domain. The water level at the GHB of the model cell has to be specified, but this water level is actually representative of the head at a defined distance. For the southeast and northwest boundaries, GHBs were introduced. The constant values as hydraulic heads at the boundaries extrapolated from the results of the field survey were specified in this case.

Table 17.1 Analytical condition for model calibration

Application (Code)	Visual MODFLOW (Schlumberger water services) (MODFLOW: finite difference method)
Simulation method	Transient simulation
Analysis period	2010.7–2012.5
Time step	1day
Boundary conditions	Canal and river water level, GHB
Recharge	Estimated value from tank model
Initial condition	Steady state groundwater potential distribution
Calibration target	Water level changes in observation wells

Table 17.2 Hydraulic parameters used in the model

Layer	Horizontal conductivity kx,ky (m/s)	Vertical conductivity kz (m/s)	Specific yield Sy (−)	Specific storage Ss (1/m)
Peat I	1×10^{-5}	1×10^{-6}	0.2	1×10^{-5}
Alluvial (Peat II)	5×10^{-4}	5×10^{-5}	0.35	1×10^{-5}
Silt	1.5×10^{-7}	1.5×10^{-8}	0.2	1×10^{-5}
Sand	7×10^{-4}	7×10^{-5}	0.15	5×10^{-5}

The analytical condition for model calibration is summarized in Table 17.1. Transient simulation was carried out from July 2010 to May 2012. The groundwater model was calibrated to fit the measured water levels in observation wells to improve the precision of the model.

17.3.1 *Model Validation to the Present Groundwater Movement*

Based on previous studies as reported by Wösten et al. (2008), initial hydraulic conductivity was assigned to each layer. Final hydraulic parameters, after calibration, are listed in Table 17.2. The hydraulic conductivity in the sand layer turned out to be one order higher than that in the Peat I layer. The vertical conductivities were set to one-tenth of the horizontal conductivities in all layers.

The results for the repeatability in time series for each aquifer in Area 1 are shown in Fig. 17.9, as an example. The observed groundwater level for each aquifer showed a seasonal variation from July 2010 to June 2011 and declined during the drought period until Sep 2011. The water levels gradually recovered to almost the same level observed before they dropped. The model can represent these seasonal variations and long-term tendencies very well. The lowering of the groundwater level in the drought period could be recreated using the appropriate recharge and boundary conditions.

Planar distributions of the groundwater potentials in each layer for the rainy period and drought period are summarized in Fig. 17.10. The groundwater potentials in both aquifers were generally affected by the shape of the ground surface.

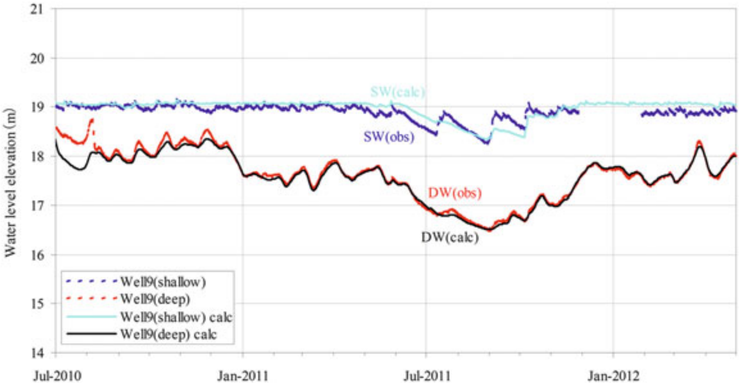

Fig. 17.9 Results of the repeatability in time series for each aquifer in Area 1

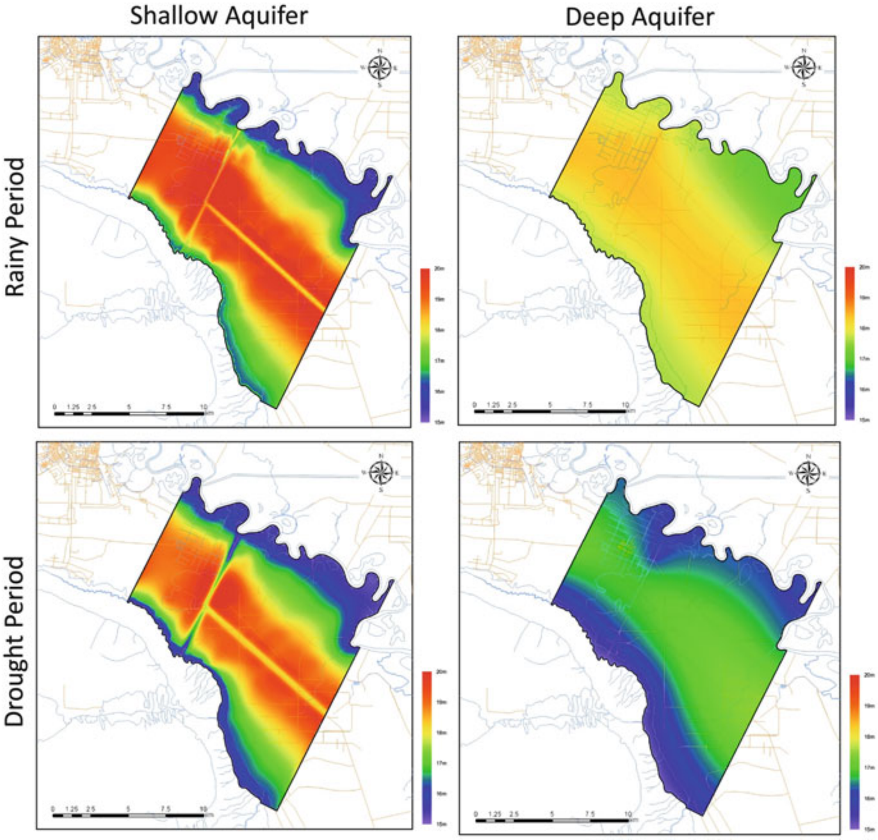

Fig. 17.10 Planar distributions of groundwater potentials in each layer for rainy and drought periods

The calculated data showed that the groundwater potential in the shallow aquifer was always higher than that in the deep aquifer, and that the potential gradually decreased to the rivers or the canals. That is, the shallow groundwater in the peat layer was recharged by rain, horizontally moved along the ground surface to the rivers or drainage canals and vertically penetrated through the silt layer to recharge the deep groundwater. Meanwhile, the groundwater in the deep aquifer flowed toward the rivers affected by the water levels of the rivers and drainage canals.

17.3.2 MRP Impact and Dam Efficiency After Proposed Dam Array Construction

Using the calibrated model, predictive numerical studies of the groundwater condition in severe drought conditions were carried out for the following two cases; before the MRP and after the proposed dam construction. In the "before MRP" case, neither the Kalampangan nor the Taruna Canal existed. The groundwater movement was dominated by the shape of the ground surface and the natural boundary conditions. To perform the calculations for this case, the grid cell elevations corresponding to the canals in the groundwater model were modified to represent the ground surface before the canals were dug. After MRP, two main canals were dug and many dams were constructed along the canals to prevent the peatland water from draining. However, plenty of dams were destroyed by floods, and only three effective dams remained. "Present" represents the case in which the change in groundwater conditions after the MRP was evaluated, which is essentially the same as the calibrated model. The Carbon Management 1-1 group planned eight new dams along the Kalampangan Canal (Fig. 17.11). "After proposed dam construction" represents the case in which the dam efficiency required to keep the shallow groundwater level high in the peat layer was estimated.

For convenience, we refer to the calculation results for "before MRP", "present" and "after proposed dam construction" as Cases 1, 2 and 3, respectively. The predictive studies were carried out from Jan 2009 to Mar 2010, including the 2009 drought period when severe wildfires occurred.

In 2009, severe wildfires occurred in central Kalimantan including the Block-C North area. To determine the shallow groundwater conditions under such circumstances, the time series for three cases at Well 9 (located in the wild fire area) are compared in Fig. 17.12. The model prediction shows that the groundwater in the shallow aquifer might drawdown to more than 1 m below the surface (Case 2). However, if there were no canals, the water level might remain at only 40 cm below the surface even in a severe drought period (Case 1). After the proposed dam construction, the water level might drawdown to around 90 cm below the surface (Case 3). However, as Well 9 was located more than 400 m away from Kalampangan Canal, it was difficult to evaluate the dam efficiency. Figure 17.13 shows the planar

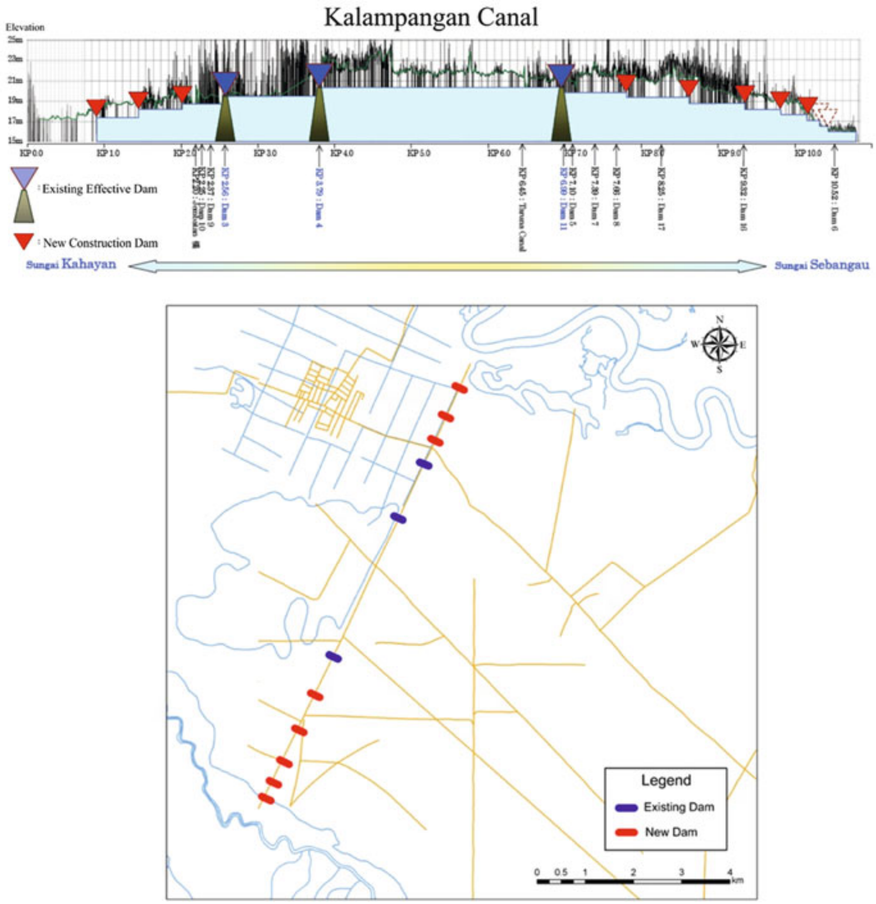

Fig. 17.11 Locations of proposed dam construction by CM 1-1 group

distributions of the groundwater potential in the three cases at the time of evaluation. The lowest water level occurred in Case 2. Cases 1, 2 and 3 show clearly different distributions of groundwater potentials, especially in the vicinity of the drainage canals. The groundwater potentials in Case 1 were higher than those in Cases 2 and 3, and eventually, near the Kalampangan Canal, the heads remained near the surface. The heads in Cases 2 and 3, near Kalampangan Canal dropped more than 2 m below the surface. The head distributions in Cases 2 and 3 were quite similar except in the area in the vicinity of Kalampangan Canal. The Case 3 heads were higher than in Case 2 near the Kalampangan Canal, thus resulting in greater dam efficiency.

To confirm the details of dam efficiency, a heads difference map between Cases 3 and 2 was drawn at the time of evaluation (Fig. 17.14). X–X′ is the cross-section passing Well 9. The dam efficiency to maintain a high water level in the peat layer was estimated at more than 10 cm within 400 m from the Kalampangan Canal in the 2009 drought period.

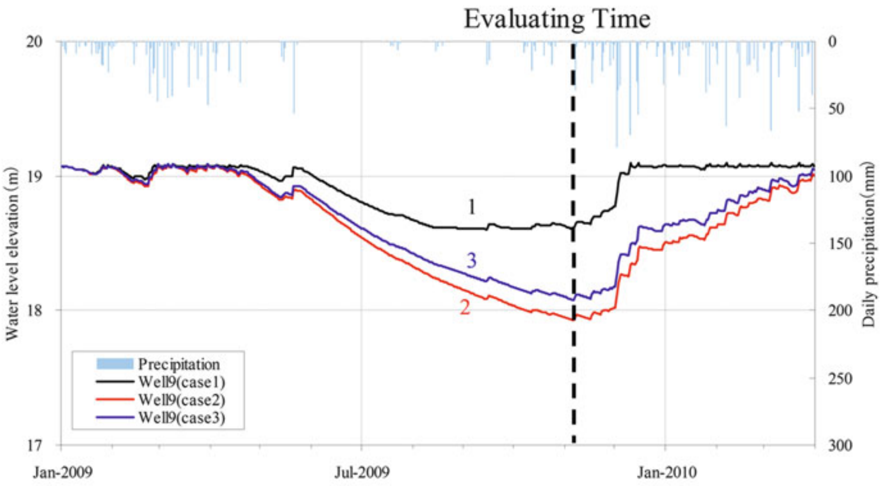

Fig. 17.12 Time series for three cases at Well 9

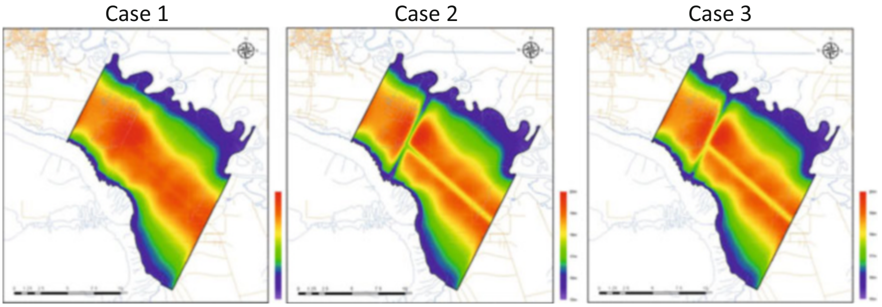

Fig. 17.13 Planar distributions of groundwater potential in three cases at the time of evaluation

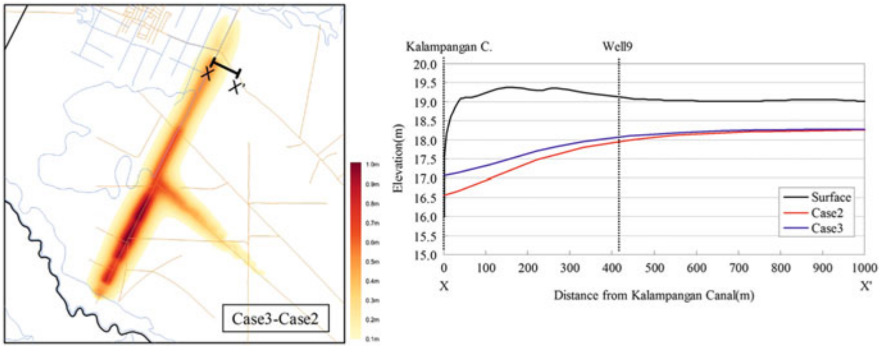

Fig. 17.14 Heads difference map between Case 3 and Case 2 at the time of evaluation (*left*) and cross-section diagram at X–X′ (*right*)

Acknowledgement Results shown in this paper were mainly obtained from SATREPS (Science and Technology Research Partnership for Sustainable Development) project entitled as "Wild fire and carbon management in peat-forest in Indonesia" founded by JST (Japan Science and Technology Agency) and JICA (Japan International Cooperation Agency).

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Chapter 18
Peat Fire Impact on Water Quality and Organic Matter in Peat Soil

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Abstract The impacts of peat fire on the water quality were investigated by comparing the water quality of the Sebangau River and the Canal Kalampangan. pH and DOC are important parameters related to the specific properties of water in Central Kalimantan. The pH value of the Sebangau River and the Canal water are about 4. The average concentration of DOC in the Sebangau River was about 43.8 mg/L, while that in the Canal was about 37.2 mg/L. The DOC concentration in the Canal was lower than that in the Sebangau River, it was supposed that peat soil around the Canal had been burnt, and therefore the supply of dissolved organic matters to the Canal decreased. In this chapter, it is also shown that DOC concentration of soil collected from burnt area was lower than that from unburnt area. It was found that the tap water in Palangka Raya contained high concentration of NH_4-N and DOC, including humic substances. Polyaluminium chloride (PAC) with $CaCO_3$ was one of the effective coagulants that could reduce humic substances contained in tap water in Palangka Raya, to more than 91 % removal. The assessment of the toxicity of humic acid using the trypan blue exclusion method is also discussed in this chapter. The peat fire also influenced

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the chemical characteristics of aquatic humic substances (fulvic acid and humic acid), especially in the H/C and O/C value from elemental analysis data, molecular weights, and 3DEEM fluorescence spectra. The effect of peat fire on the properties of soil organic matter was investigated, and it was clarified that the peat fire affected not only on surface soil but it reached into the subsurface soil until 30–50 cm depth.

Keywords Humic acid • Fulvic acid • Dissolved organic carbon (DOC) • Tap water • 3-DEEM spectra • TG-DTA curve • Soil organic matter (SOM) • Toxicity

18.1 Introduction

Commonly in Indonesian forests, agricultural development of thicker tropical peats has failed because planners considered peatlands to be simply another type of land and did not take into account the special physical and chemical properties of this peat. A glaring example was the Mega Rice Project (MRP: 1996–1999) in Central Kalimantan where long irrigation canals were constructed to convert about 1 million hectares of wetland (mostly peatland) into rice fields (Muhamad and Rieley 2002). However, the MRP was discontinued because of the low pH of the water around the MRP area, and the long irrigation canals still remain. These canals might impose a large impact on the environment, for example, a decrease in the tropical forest lowering of the water table and consequently an increase in the dryness of the peat soil in the dry season. The oxidative properties of the soil which result from lowering the water table may facilitate the decomposition of the organic matter stored in the soil by chemical and biological process and sometimes cause peatland fires. A portion of the decomposed organic matter is exhausted to the atmosphere as CO_2 and other portions are eluted into the aquatic environment as dissolved organic matter (DOM). This may lead to the disappearance of the function of the peatland as a carbon sink. The impact of drainage construction and peatland fire on the water quality including DOC has been discussed.

18.2 DOC and pH of the Sebangau River and Canal Water

In this section, DOC (Dissolved Organic Carbon) and pH changes in the Sebangau River and the canal and also the characteristics of humic substances extracted from these waters are shown. The water quality including temperature, pH, DO, redox potential and DOC at several points in the Sebangau river and the canal has been measured in order to observe the impact of peatland fire on the water quality in the burnt and unburnt areas. In addition, it is important to understand the characteristics of humic substances extracted from these waters followed by purifying in order to know peatland condition in Central Kalimantan.

The water samples were collected at several points along the Sebangau River and the canal in the Mega Rice Project (MRP) area in Kalampangan and Sebangau

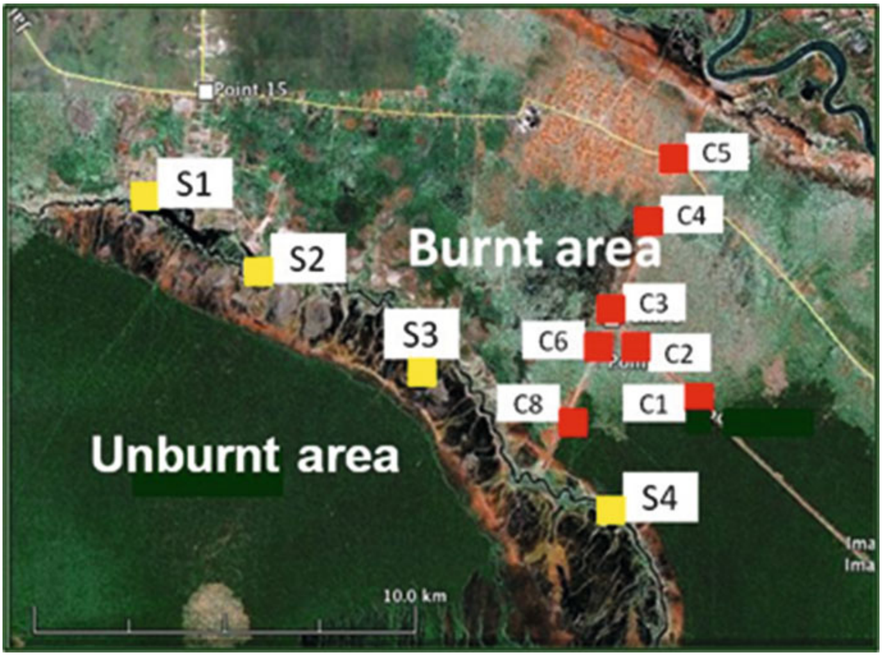


Fig. 18.1 Sampling and monitoring sites of waters in Central Kalimantan, Indonesia

National Park in Central Kalimantan Province, Indonesia. The Mega Rice Project area showed extremely high fire density (hotspots), 0.188 hotspots/km^2/year as reported by Yulianti et al. (2012). Therefore, the MRP area was selected as the representative of the burnt areas. In this area, a long canal had been constructed by MRP and peatland fires have often occurred. However, some parts of the unburnt area have been recovered by growing plants. A segment of the Sebangau River located in a peat swamp forest conservation area was chosen as the unburnt area. In our project, the monitoring and sampling of waters carried out in the Sebangau River and the canal are shown in Fig. 18.1.

During the 4 years from 2008 to 2012, the water quality of the Sebangau River and the canal were investigated. Almost all water quality data were measured in the dry season and the water levels of the river and canal were low. The 2010 data was obtained between the dry and rainy seasons, and the water level at that time was relatively high. The pH and DOC data are shown in Figs. 18.2 and 18.3.

The pH of the Sebangau River was around pH 4 at three sampling sites. The low pH of this river might be due to the presence of humic substances (humic acid and fulvic acid) in the water. As will be described later, most of the dissolved organic matter in the river and canal were humic substances, especially fulvic acids. The presence of these organic acids resulted in the lower pH of the water. The pH of the canal was slightly lower than that of the Sebangau River in 2009. The pH values of the canal water in 2009 and 2010 were lower than pH 4 even though there was a

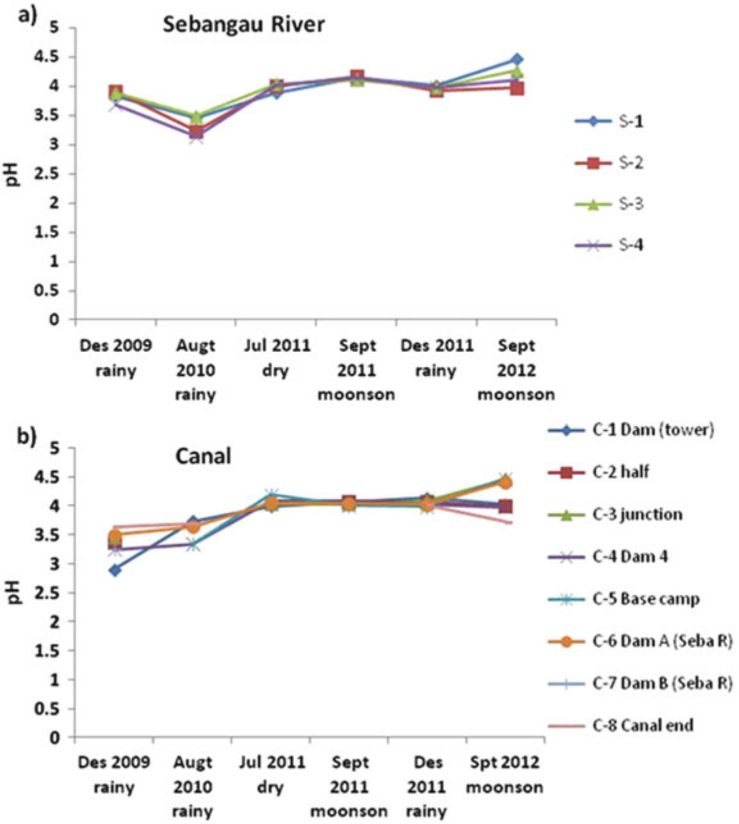


Fig. 18.2 pH of the (**a**) Sebangau river and (**b**) the canal

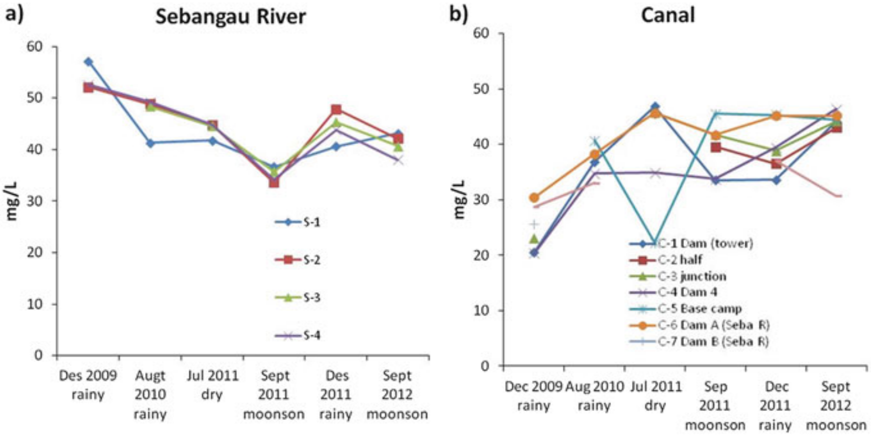


Fig. 18.3 DOC of the (**a**) Sebangau river and (**b**) the canal

smaller amount of DOC in these years. The big difference in pH between the dry and rainy seasons was not observed in the river and canal water.

The DOC concentrations of the Sebangau River were in the range of 33.6–57.1 mg/L with the average concentration of 43.8 mg/L, while in the canal was in the range of 20.4–46.9 mg/L with the average concentration of 37.2 mg/L. Some variation in the DOC values was observed in the canal and the canal DOC in 2009 was lower than that of the later years. There were big differences in 2011 DOC between the monitoring sites. On the other hand, the Sebangau River DOC was stable at every monitoring site. The water flow in the canal depends on the location, that is, it is fast in some places but slow or standing in other places. The difference in the duration of time the canal water contacts soil might cause the variation of the amount of organic matters in the water at each site. The chemical characteristics of dissolved organic matter will be described in the next section.

Aquatic Humic Substances (AHS) are a major fraction of dissolved organic material in natural water, especially in peatland areas. According to the report by Frimmel (2001), humic substances enter to the hydrosphere from two main sources, one is from terrestrial plants and soil (allochthonous substances) and the other is from biological activities within the water body itself (autochthonous substances). On the basis of their solubility in acid-base media, humic substances can be divided in three fractions: humic acid is a fraction of AHS, that is soluble when the pH is high but insoluble when the pH is low. The other fractions of AHS are humin, a fraction which is insoluble at any pH; and the last is fulvic acid, a fraction which is soluble at any pH (Greenberg et al. 1992). The chemical characteristics of humic substances generally depend on their origin and the environment where they have been traced. There are many impacts of peatland fire on the chemical characteristics of humic substances extracted from the Sebangau River and canal water in peatland areas.

The DOC concentration of the Sebangau River as a natural river was around 40 mg/L and was almost similar to that of the Kalampangan canal. The amounts of purified humic acid and fulvic acid extracted from 40 L of the canal water were 0.69 g and 2.21 g, respectively and these values correspond to 8.6 and 19.8 mg C/L, respectively. Around 70 % of the DOC of the canal water was at least from AHS, this means main part of the dissolved organic matter in the canal water is AHS. The carbon content of the HAs from both the rivers and canal was higher than that of fulvic acid. On the other hand, the oxygen content of the fulvic acid was higher than that of the humic acid. The higher value of H/C and O/C estimated from the ratio of the elements in AHS indicated that the AHS has more aromaticity and more functional groups containing oxygen. The Van Krevelen diagram for the AHS extracted from the river and canal water is shown in Fig. 18.4. The O/C value of humic acid from the canal water was higher than that of the humic acid from the Sebangau River. The O/C value of the fulvic acid from the canal water was also higher than that of the fulvic acid from the Sebangau River. This result was opposite to that of the humic substances extracted from the soil. That is, the humic substances in non-burnt sites have relatively higher O/C than that from burnt sites (Yustiawati et al. 2014). This evidence suggested to us that the moiety of humic substances,

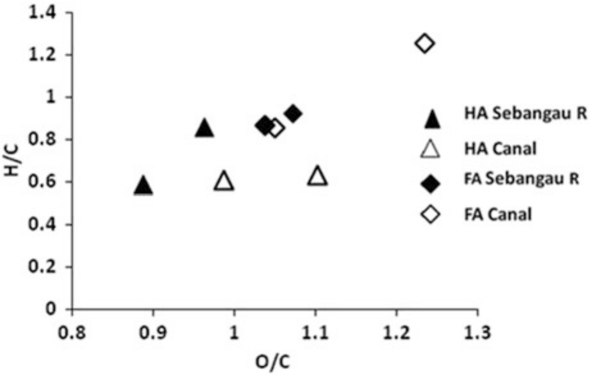


Fig. 18.4 H/C and O/C values of humic acid and fulvic acid extracted from river and canal water (By Yustiawati and Shunitz Tanaka)

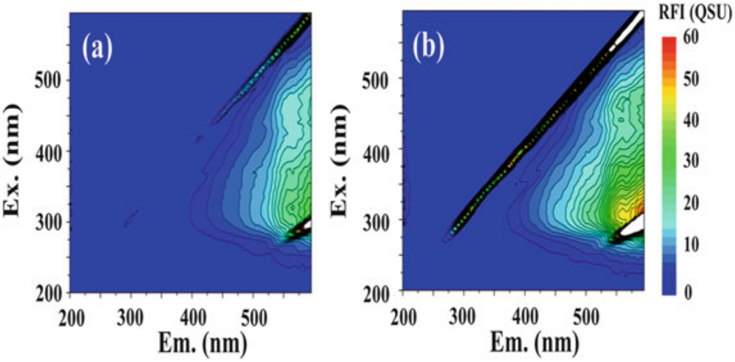


Fig. 18.5 The 3DEEM fluorescence spectra of humic acid from Sebangau river (**a**) and Canal water (**b**)

which have more functional groups containing oxygen, has been eluted to the canal due to the impact of peatland fire.

The 3DEEM fluorescence spectra of humic acid from the Sebangau River (a) and Canal water (b) is shown in Fig. 18.5. The fluorophore compounds such as phenolic compound that contained in humic acid could be observed using this method. The bar chart next to the graph indicates the contour intervals of the relative fluorophore intensity (RFI) normalized with the quinine sulfate. Humic acid from canal water had higher RFI value than that from the Sebangau River. It indicates canal water contained more phenolic compounds that might be originated from peat burnt soil.

The molecular weight of the humic acid extracted from the Sebangau River (4,242–4,360 Da) was higher than that from the canal in Kalampangan (3,664–3,738 Da). Fulvic acid also showed similar behavior; the molecular weight of the fulvic acid from the Sebangau river was 3,883–4,348 Da and from the canal in Kalampangan it was 3,248–3,303 Da. This might be the evidence that the humic substances in the canal have been affected by peatland fires.

18.3 The Quality of Tap Water in Palangka Raya and the Removal of DOC for Drinking Water

Samples of tap water were collected from Bogor, Cibinong, Jakarta and Palangka Raya and were tested for water quality. Table 18.1 shows the concentrations of nitrate-nitrogen (NO_3-N), ammonium-nitrogen (NH_4-N) and DOC found in the tap water and their respective fluorescence properties. As a reference, the parameters for the quality of water taken from the rivers flowing through these cities are presented in Table 18.1. These rivers have been used as the primary source of drinking water for these cities. The fluorescente properties were evaluated from a three-dimensional excitation-emission matrix (3DEEM) spectrum which is the result of sequential and simultaneous determination of excitation wavelength (Ex.), emission wavelength (Em.) and relative fluorescence intensity (RFI). The RFI values are described quinine sulfate units (QSU; 1 QSU = 1 μg/L of quinine sulfate monohydrate at Ex./Em. = 355/450 nm). The fluorescence peak T (Ex./Em. = 220/300 nm) and C (Ex./Em. = 330/440 nm) are for protein-like and humic-like components, respectively (Sazawa et al. 2011). The tap water in Bogor, Cibinong and Jakarta showed lower concentrations of NO_3-N and NH_4-N than river water, whereas the tap water DOC concentration when compared to river water did not show any differences. The RFI value obtained from 3DEEM spectrum indicated a lower peak C value for tap water but a higher peak T when compared with river water. The prominent feature in the tap water sample from Palangka Raya is the high concentration of NH_4-N and DOC. The concentration level of NH_4-N is much higher than the river water from cities located on Java Island. Figure 18.6 shows a comparison of the 3DEEM fluorescence spectra for the tap water collected from (a) Jakarta and (b) Palangka Raya. Peak C which was clearly observed in Palangka Raya's tap water indicates the existence of a high concentration of dissolved humic substances (DHS) which is at the same level of river water.

Table 18.1 The parameters for water quality and the relative fluorescence intensity of protein-like substances (Peak T) and humic-like substances (Peak C) in river and tap water collected from Bogor, Cibinong, Jakarta and Palangka Raya, Indonesia

		NO_3-N	NH_4-N	DOC	Peak T	Peak C
		(ppm)			(QSU)	
Bogor	River water	9.9	0.04	2.9	180.9	23.4
	Tap water	3.0	N.D.	2.7	294.8	8.2
Cibinong	River water	11.8	0.06	2.0	131.7	20.3
	Tap water	5.0	0.05	4.4	336.2	5.4
Jakarta	River water	16.7	>0.6	5.1	374.7	52.6
	Tap water	3.2	0.04	3.5	340.1	9.7
Palangka Raya	Tap water	N.D.	>0.6	11.6	190.1	134.5

N.D. no detection

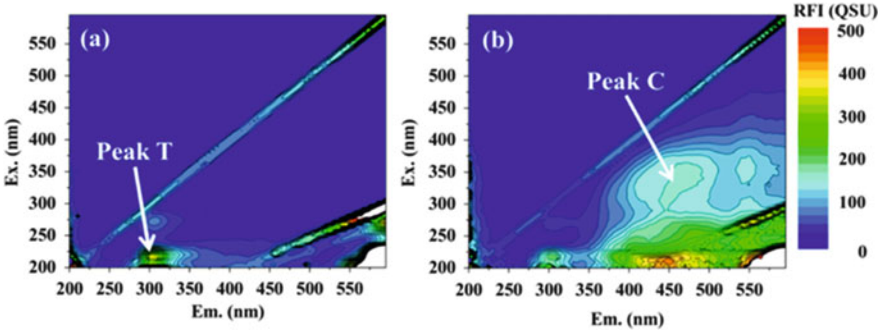


Fig. 18.6 The 3DEEM fluorescence spectra of tap water in (**a**) Jakarta and (**b**) Palangka Raya. The bar chart next to the graph indicates contour intervals of the fluorescence intensity in quinine sulfate normalization (By Hideki Kuramitz, Kazuto Sazawa and M. Suhaemi Syawal)

The daily intake of high concentrations of humic acids (approximately 200 mg/L) contained in artesian well water is thought to be the root cause of Blackfoot disease which prevails in the Southwest of Taiwan (Cheng et al. 1999). Taking this into consideration, we carried out further investigation by removing humic substances from the water through a coagulation method using polyaluminum chloride with $CaCO_3$ as a neutralizer and coagulant aid. The removal of humic acid was achieved for 96.6 and 91.6 % which was calculated from absorbance at 260 nm and the concentration of DOC when $CaCO_3$ was used as an alkaline chemical with PAC. Since $CaCO_3$ behaves as a coagulant reagent, the sedimentation velocity was significantly high and the sludge volume (SV) was reduced to about half compared with the existing method using NaOH as a neutralizer. It can be said that $CaCO_3$ is efficient because it is able to function both as an alkaline chemical and coagulant aid. The demonstration was performed using Sebangau River water which consists of 33.4 mg/L of DOC. The lowest residual DOC concentration of 4.5 mg/L was lower than the water quality standards for drinking water in Indonesia.

18.4 The Effect of Wild Peat Fire on the Properties of Soil Organic Matter

As described in the previous section, the river and canal water in Central Kalimantan, Indonesia demonstrates a low pH and a high concentration of dissolved organic matter (DOM). Three DEEM observation results suggest that the major components of DOM in river and canal water are terrestrial humic substances. Namely, this indicates that the changes in the existing components of the soil are strongly influenced by water content, i.e., water quality. Therefore, it is necessary to conduct a qualitative and quantitative assessment of the soil to further understand the changes in SOM due to the impact of peatland fire in Central Kalimantan.

Our findings indicate that lignin and hemicelluloses started to degrade at 130–190 °C, whereas the carbonization process (dehydration and decarboxylation) starts above 200 °C (Chandler et al. 1983; Freitas et al. 1999). An earlier study reported that water soluble SOM such as fulvic and humic acids are transformed into insoluble substances such as humin and black carbon by accelerated dehydration and decarboxylation from the heating caused by wild fire (Almendros and Leal 1990). From this, we can assume the soil and river ecosystems are strongly influenced by peatland fires. However, the current information available regarding the quantitative and qualitative changes of SOM in tropical peat is still limited. In the following paragraphs, a summary introduction of the findings on the impact of wild peat fires in Central Kalimantan on the physical and chemical properties of SOM is presented.

The physicochemical properties of peat soil collected from unburnt and burnt areas near Palangka Raya city were compared. In the case of peat soil collected from the surface layer (0–20 cm), a drastic increment in pH and particle density was observed. The pH values of unburned and burned soil were 3.1–3.4 and 4.7–5.8, respectively. After the burning, the particle density increased from 1.05–1.22 to 1.39–1.58. On the other hand, such differences between burned and unburned were not clearly seen in the soil collected from the subsurface (30–50 cm) area.

Thermogravimetry-Differential Thermal Analysis (TG-DTA) curves for the peat soil collected from the subsurface in the unburnt area are shown in Fig. 18.7. The two curves in this figure are thermogravimetry (TG) and the different thermal analysis (DTA) curve. Both these curves show the weight loss and the rate of heat released from the soil sample during the pyrolysis process. For this experiment, approximately 10 mg of the sample was heated from 20 to 500 °C at a rate of 3 °C min^{-1}. The TG curve shows that this peat soil is mostly composed of organic matter (ca. 98 wt.%). From the obtained DTA curve, the ignition temperature (*Tv*), combustible gas release (peak A), and the combustion of carbide (peak B) were determined to be at 186 °C (*Tv*), 306, and 425 °C, respectively. The combustion characteristics of the soil which was collected from the burnt area were also

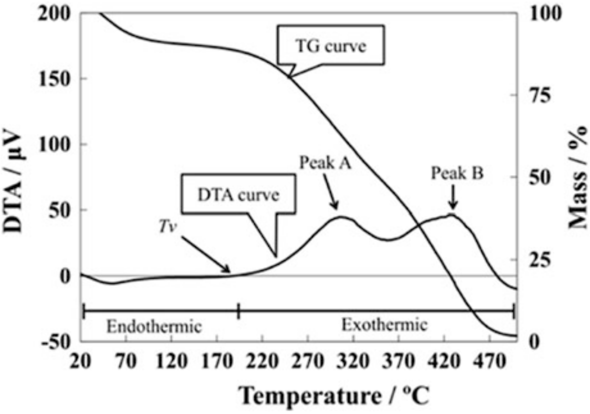


Fig. 18.7 TG-DTA curves of the Indonesian peat soil collected from the subsurface (30–50 cm) in the unburnt area. *Tv* ignition temperature of the volatile matter, *peak A* combustible gas release, *peak B* combustion of carbide (Sazawa et al. 2013)

evaluated. The peak values for A and B obtained from the surface layer of soil collected in the burnt area were lower than that of the unburned soil. In the case of the subsurface layer of burned soil, the peak A value drastically decreased, whereas the peak B value was 56 % higher than the unburned soil. Moreover, the ignition temperature increased up to 220 °C. The results of the TG-DTA observations suggest that the production of charred material occurred in the burned soil at the subsurface layer. Charred material is highly resistant to heat and biological degradation, thus, the transformation of SOM in burned soil has a potential to affect the soil and river ecosystems.

In addition, a decrease in the atomic ratios for H/C and O/C which shows carbonization of SOM was observed from an elemental analysis of the subsurface soil collected from the burnt area. This finding supports the result obtained from TG-DTA. The elemental analysis was performed to evaluate the heating temperature of the subsurface soil in the burnt area by thermally treating the samples at different temperatures. The results indicated that the atomic ratios of H/C and O/C for the soil samples collected from the subsurface layer in the burnt area showed similar values for the heated peat soil sample at a slightly lower ignition temperature. It has been commonly reported that forest fires mainly affect only the soil surface layer. In fact, some researchers have even concluded that the heat from the fire does not reach a depth of 20–30 cm from the surface of the soil, even if the surface temperature exceeds 500–700 °C (Neary et al. 1999; DeBano 2000). The findings from this investigation suggest that subsurface layer SOM was carbonized from the burning and this is said to be a key characteristic of tropical peat soil damaged by forest fire. The most obvious difference observed in the aftermath of forest fire between peat land and forest soil is that heat more easily reaches the subsurface level of peat land soil than forest soil. The penetration of heat to the subsurface area damages SOM by changing the characteristics of organic components contained in the subsurface layer. Because of the nature of the heat transfer, peatland faces a greater risk of damage from forest fire due to the sensitive nature of the soil and the serious consequences of the recovery process. The question remains if peatland soil can ever return to the pre-fire condition it once had in years to come? Moreover, we have also found that C/N ratios of peat soil in the burnt area have a tendency to increase greatly compared with those of unburned peat soil. Some soil samples from the burnt area exhibited an intriguingly high ratio of C/N = 100, creating a serious concern about the restoration potential of peat soil productivity. It could take at least 4 years to restore the C/N ratio to its original pre-fire state (C/N = 30–48).

The DOC in soil is strongly linked to the storage of carbon in catchment soil. The concentration of DOC including SOM in soil contributes to the carbon balance of terrestrial ecosystems and serves an important role in controlling the quality and quantity of organic components in aquatic ecosystems. The DOC concentrations and fractionations of soil water-extracted solutions for the Indonesian peat soil samples collected in Oct., 2010 from unburnt (UB 1, 2, 3) and burnt (B 1, 2, 3) areas at the subsurface layer are shown in Fig. 18.8a. The DOC components of water-extracted soil were fractionated using DAX-8 resin. Generally, DAX-8 resin is often used for hydrophobic-hydrophilic separation of DOC fractionations in river and lake

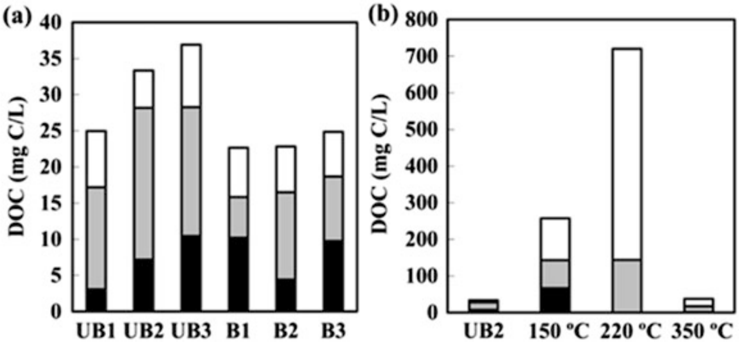


Fig. 18.8 (**a**) The DOC concentrations and fractionations of soil water-extracted solution for the Indonesian peat soil samples collected from unburnt (*UB 1, 2, 3*) and burnt (*B 1, 2, 3*) areas at the subsurface layer (30–50 cm) and (**b**) thermally treated Indonesian peat soil samples (150, 220 and 350 °C for 30 min). *White bar* = Hydrophilic and Hydrophobic bases fraction (Hp + HoB), *Gray bar* = Hydrophobic acids fraction (HoA), *Black bar* = Hydrophobic neutrals fraction (HoN)

water. In this study, the DOC soil fractions extracted by water were divided into three groups based on the affinity of DAX-8 resin: hydrophilic and hydrophobic bases, hydrophobic acids, and hydrophobic neutrals. In the hydrophilic (Hp: fatty acids, sugar acids, hydroxyl acids, polysaccharides etc.) and hydrophobic bases (HoB: aromatic amines) fraction, (Hp + HoB) is not absorbed. The hydrophobic acids (HoA: humic and fulvic acids) fraction, and the hydrophobic neutral (HoN: large cellulose polymers, hydrocarbons, carbonyl compounds etc.) fraction, are both absorbed by the DAX-8 (Leenheer 1981).

The HoA fraction can then be extracted from the DAX-8 with an alkaline solution, while the HoN fraction cannot be extracted. The DOC concentrations in soil collected from the burnt area are found to be lower than that of unburned soil. Furthermore, the DOC of each fraction was as follows: Hp + HoB = 16–31 %, HoA = 48–63 %, HoN = 12–28 % in unburned soil and Hp + HoB = 25–30 %, HoA = 25–53 %, HoN = 19–45 % in burned soil. These data conclude that fire contributes to reduction of DOC especially in the hydrophilic fractions. One possible reason for this phenomenon could be the denaturation of SOM from the heat caused by fire. We also investigated the changes in concentrations and fractionations of DOC in the peat soil by thermally treating it at various heating temperatures in a laboratory setup. Figure 18.8b shows the experimental results obtained by thermal treatment at 150, 220 and 350 °C for 30 min. The concentration of DOC, especially in the hydrophilic and hydrophobic fractions increased drastically from heat treatment at 150 and 220 °C, which is around the ignition temperature of peat soil. In this case, it was observed by means of size exclusion chromatography and spectrophotometric analysis that the molecular weights of DOC components extracted from the soil measured lower than before heating.

The results from the investigations conducted both in field and by laboratory experiments reveal that peat fire causes transformations of SOM on the lower molecular and hydrophilic organic compounds at the subsurface layer of the soil. The denaturation of SOM caused by the heat from the fire accelerates the exodus of organic carbon from peatlands, which have a huge accumulation of carbon storage.

18.5 Toxicity of Humic Substances

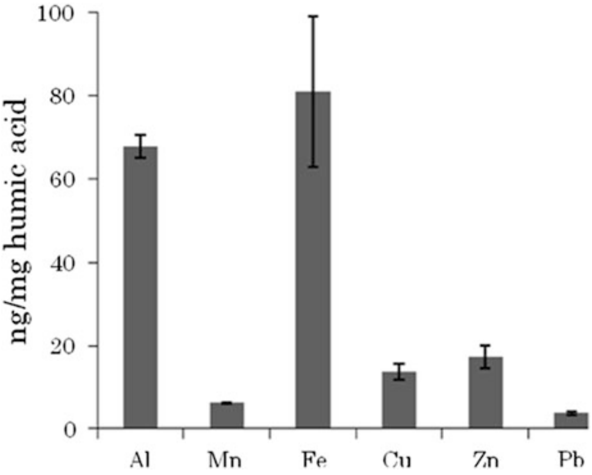
A portion of the people living in the Sebangau River catchment used the river water for drinking (Haraguchi et al. 2007). Humic acid has been known as a major component of DOC making up to 70–90 % of brown colored river water (Mills et al. 1996). It contains aromatic rings, phenolic hydroxyl and carboxyl groups, which act as binding sites for metal ions (Von Wandruszka 2000). Therefore, humic acid easily forms complexes with Fe, Zn, Mn and/or Cd (Lu 1990). Since humic acid, a major component of DOC, has been shown to damage human endothelial cells (Hseu et al. 2002), the effect on human health of consuming Sebangau River water should be investigated.

Humic acid which causes Blackfoot disease was detected in the well water using infrared spectrophotometry and atomic absorption spectrometry (Liao et al. 2011; Selim Reza et al. 2011). The impairment of vascular endothelial cells at an early stage has been shown to be an important aspect of the vascular disease. While humic acid has previously been shown to mediate damage to human vascular endothelial cells (Yang et al. 1996), the mechanisms of these effects are still unknown.

In this section, to assess the risk of humic acid to human health in the tropical peatlands of Indonesia, a basic characterization of the humic acid in the peatlands, the risk of oxidative stress caused by humic acid in the tropical peatlands in Indonesia, and the mechanism by which humic acid elicits these effects were discussed.

Metal concentrations in the humic acid sample are shown in Fig. 18.9. The high concentrations of Al and Fe in the humic acid are shown, and that of Cu was

Fig. 18.9 Metal concentration of humic acid



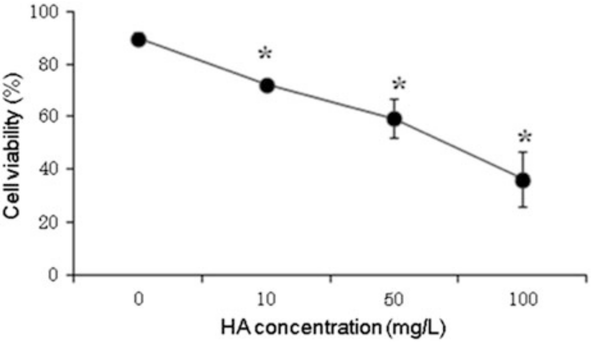


Fig. 18.10 Cell viability of HUVECs exposed to humic acid. HUVECs were treated with or without 0–100 mg/L humic acid for 72 h in the medium. Values are expressed as means ± S.E.M in the triplicate experiments. *means $p < 0.05$ as compared with the cell viability of untreated cells

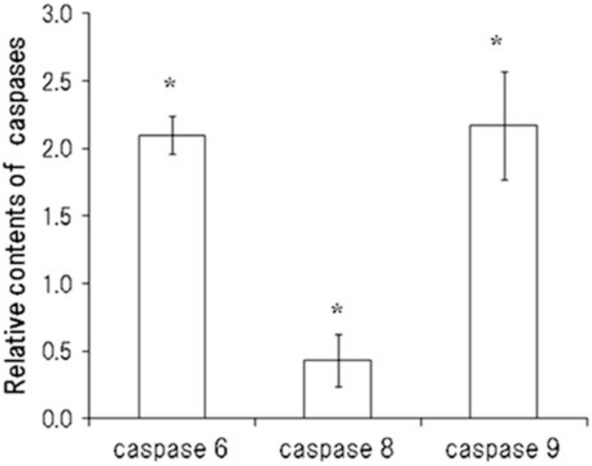


Fig. 18.11 The effects of humic acid on expression of caspase 6, 8 and 9. HUVECs were treated with 0 and 50 mg/L humic acid for 24 h. The contents of caspases were expressed as relative changes in the ratio of caspase against that in control cells. Values are expressed as means ± S.E.M ($n = 3$). *means $p < 0.05$ as compared with ratio of caspase expression of untreated cells

13.6 ng/mg. Since the humic acid sample used in the cell experiments went through a purification process, humic acid in natural water is considered to have higher traces of metals than those of the purified humic acid.

To determine whether humic acid affects cytotoxicity, the cell viability of human umbilical vein endothelial (HUVEC) cells treated with humic acid using the trypan blue exclusion method was usually employed. The viability of humic acid-treated cells decreased with an increase in humic acid concentration (Fig. 18.10). Especially, it was observed that the cell viability decreased more than 40 % with a 50 mg/L humic acid treatment. This humic acid concentration was almost equivalent to that in the water used for drinking by a portion of the residents in the Sebangau River catchment in Central Kalimantan.

To confirm whether the cytotoxicity depending on humic acid causes apoptosis, expressions of caspases 6, 8 and 9 in the cells exposed to humic acid were investigated using the RT-PCR method. As illustrated in Fig. 18.11, a significant increase of the caspase 6 and 9 contents were observed in the cells exposed to 50 mg/L humic acid. On the other hand, the content of caspase 8 was significantly decreased about 50 % by humic acid administration. On the mechanisms underlying

Table 18.2 The change of eNOS and Hsp90β levels by humic acid treatment

Humic acid concentration (μg/ml)	eNOS±SE	Hsp90β±SE
0	100 ± 3.7	100 ± 7.8
25	179 ± 15.4*	183 ± 16.2*
50	173 ± 19.2*	173 ± 1.79*
100	102 ± 26.5	140 ± 16.5

$n = 3–4$, *denotes $p < 0.05$ vs control

apoptotic cell death, caspases 8 and 9 are thought to be relevant to death receptor mediated apoptosis and mitochondrial mediated apoptosis, respectively. Hence, it is estimated that the apoptosis induced by humic acid is not related to the death receptor pathway but the mitochondrial pathway. One reproducible inducer is mild oxidative stress. Oxidants including ROS, lipid hydroperoxides and NO are believed to be widely involved in oxidative stress-induced apoptosis (Forrest et al. 1994). The production of oxidants in the cells may relate to the high concentrations of Fe and Cu bound to humic acid (Fig. 18.9).

To examine whether NO is one of the responsible factors in HUVEC apoptotic cell death, the level of eNOS was measured using western blot analysis described by Miyajima et al. (2013). eNOS content of HUVECs treated with 25 μg/ml humic acid was higher than that of control cells (Table 18.2). This upregulation may cause the increased level of Hsp90β. Hsp90β levels in HUVECS treated with 25 and 50 μg/ml humic acid increased significantly as compared with those in the control (Table 18.2).

These results showed that humic acid induced upregulation of eNOS. It has been reported that Hsp90β induces eNOS phosphorylation at Thr495. eNOS phosphorylation at Thr495 produces NO and superoxide anions, respectively (Cortes-Gonzalez et al. 2010). It was suggested that the humic acid increases the production of NO and/or some reactive oxygen species in HUVECs via changes in the protein levels of eNOS/Hsp90β during the apoptotic status. These changes caused by humic acid may lead to endothelial dysfunction.

Acknowledgement The results shown in this paper were mainly obtained from SATREPS (Science and Technology Research Partnership for Sustainable Development) project entitled as "Wild fire and carbon management in peat-forest in Indonesia" founded by JST (Japan Science and Technology Agency) and JICA (Japan International Cooperation Agency).

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Chapter 19
Discharged Sulfuric Acid from Peatland to River System

Akira Haraguchi

Abstract In this chapter I first give an overview of environmental problems due to contamination by sulfuric acid of surface water systems. Then I specially focus on the sulfuric acid discharge from the acid sulfate soils in tropical peat swamps occurring after agricultural land development in Central Kalimantan, Indonesia. Pyrite-containing sediments can be found in several parts of the world ranging from tropical to Arctic and Antarctic regions. As long as these pyrite-containing sediments remain waterlogged or covered with other sediments without pyrite, the presence of pyrite does not constitute any danger to the environment. Drainage of water or removal of covering layers for agricultural or industrial purposes, however, enable oxygen to enter the pyrite-containing sediments, and subsequently pyrite is oxidized to produce sulfuric acid. One of the regional environmental problems caused by human activities affecting tropical peat swamp forests, especially destruction of peat soil due to agricultural land development, is the oxidation of pyrite within the sediment underneath the peat layer. In order to estimate the range of the area that is affected by the sulfuric acid pollution, the water chemistry of some rivers in Central Kalimantan was surveyed. The sulfuric acid loading from pyrite oxidation appeared from the river mouth up to 135 km upstream. The discharge of pyritic sulfate from peat soil to the limnological system is much higher in the high water table season (October to March) than in the low water table season. Control of pyrite oxidation is indispensable for maintaining sustainable land use of the tropical peat land.

Keywords Acid sulfate soil • Basin • Canal • Peat swamp • Pyrite oxidation • Sulfuric acid discharge

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19.1 Introduction

Peat swamps in tropical regions are areas endangered by sulfuric acid contamination by pyrite oxidation. Most of peat layers in tropical peat swamps deposited on pyrite-containing sediments. Most of these sediments have been formed in coastal areas influenced by tides, such as coastal marshes, and hence environmental problems caused by pyrite oxidation after agricultural peatland development usually appear in coastal peat swamps. As long as these pyrite-containing sediments remain waterlogged or covered with peat, the presence of pyrite does not constitute any danger to the environment. Drainage of water or removal of peat layers for agricultural or industrial purposes, however, enable oxygen to enter the pyrite-containing sediments, and subsequently pyrite is oxidized to produce sulfuric acid. Sulfuric acid causes the formation of acid sulfate soils and contamination due to sulfuric acid in underground or surface water systems.

Tropical peat, most of which belongs to the category of coastal peat, is deposited over the maritime sediments. The pH of tropical peat is usually 3.0–4.5 (Anderson 1983; Haraguchi et al. 2000) and that value is lower than the pH of temperate herbaceous peat (Clymo 1983). The high acidity of tropical peat is considered to be due to the high content of humic and fulvic acids from decomposing wood materials in the peat, compared to that in temperate *Sphagnum* peat (Anderson 1983). The soil of the upper basin of the Sebangau River in Central Kalimantan, Indonesia, is characterized by Spodosols with thick bleached horizons composed of quartz sand (Djuwansah 1999). Development of the Spodosols in this area is due to the high acidity of the tropical peat (MacKinnon et al. 1996). Destruction of peat in this area results in poor vegetation in the *kerangas* heath forest because of the quartz sand's extremely low water- and nutrient-holding capacity. The pH tended to increase with the increasing depth of the peat in Lahei in the upper basin of the Mangkutup River, a tributary of the Kapuas River (Fig. 19.1; Haraguchi et al. 2000, 2005, 2006). Temperate peat also shows the same increasing profile of pH with increasing depth in each peat layer (Clymo 1983).

It is evident that the pH of the bottom layer of the Paduran core in the lower basin of the river maintained a lower pH value than that for the peat cores in the upper basin of the river (Haraguchi et al. 2006). Sulfuric acid produced from pyrite oxidation could lower the pH of the bottom peat layer of the Paduran peat to a value lower than that of the bottom peat layer in Lahei. The effect of pyrite oxidation on the acidification of peat was evident only at the bottom layer of the coastal Paduran peat mire (Fig. 19.1). The concentration of SO_4^{2-} in the peat pore water at the bottom layer of peat was 0.98 mgL^{-1} (450–500 cm depth) and 4.07 mgL^{-1} (650–700 cm depth) in the Lahei peat core, and 262 mgL^{-1} (90–100 cm depth) and 1626 mgL^{-1} (110–120 cm depth) in the Paduran peat core. This implies that the bottom layer of the Paduran core is strongly affected by the sulfuric acid originating from pyrite oxidation within the mineral sediment under the peat layer.

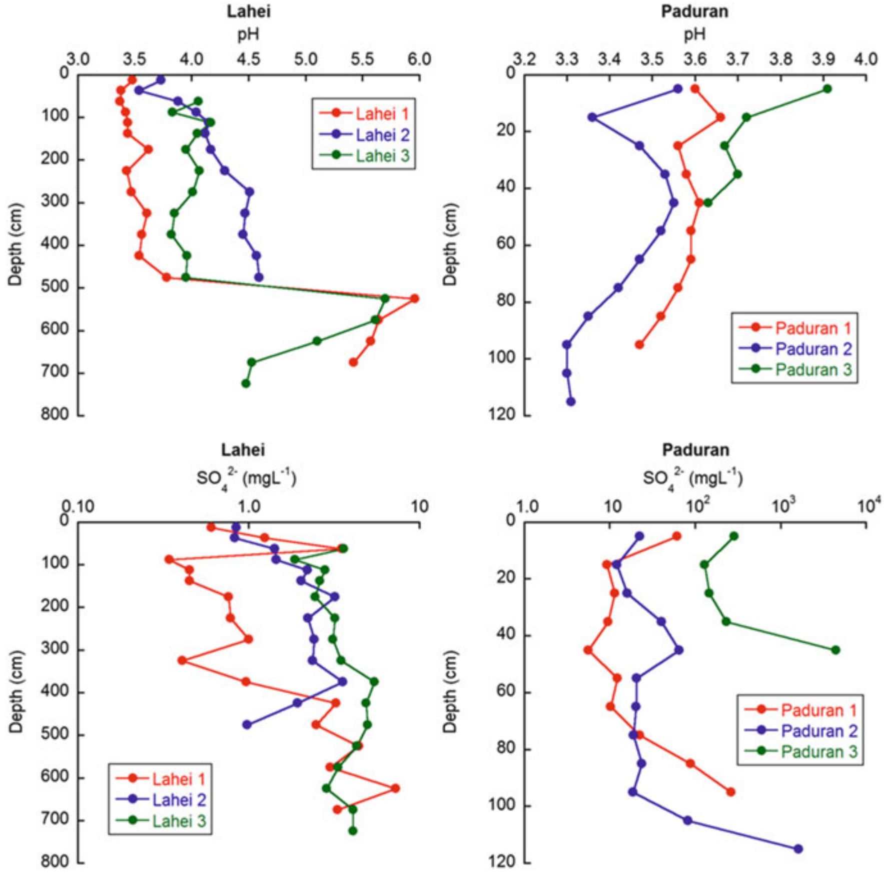


Fig. 19.1 Vertical profile of the pH and SO_4^{2-} concentration of the peat pore water in Lahei, upper basin of the Mangkutup River and Paduran, lower basin of the Sebangau River in Central Kalimantan, Indonesia (Haraguchi et al. 2000)

19.2 Formation of Pyrite

Pyrite (FeS_2) is formed in a reducing environment with a continuous supply of sulfur and iron in the presence of easily decomposable organic matter (Howarth and Giblin 1983; King 1983). The formation of pyrite via bacterial sulfate reduction in marine systems is well known, and pyrite is the solid phase end product of bacterial sulfate reduction in marine sediments. According to the chemical equilibrium of the solution system for iron and sulfur, pyrite deposits occur between Eh (redox potential) = −0.4–0.0 (V vs. NHE) and pH = 4.0–9.0 at 25 °C (Zuoping et al. 1998).

The predominant reduced sulfur species formed in salt marsh sediments is pyrite and there are many reports on the sulfur reduction and formation process of pyrite in salt marsh sediments (e.g. Luther III et al. 1982; Lord III and Church 1983; Howarth and Merkel 1984). The chemical status of sulfur compounds in salt marsh sediments usually relates to the above- and below-ground biomass and the primary production of vegetation in a given salt marsh community (King 1988; Miley and Kiene 2004). In the sediment of salt marshes, the plant root system controls the redox property of the sediment and the consequent redox status of sulfur compounds. Crowded vegetation of *Juncus* or *Spartina* spp. in a salt marsh community causes the oxidation of rhizospheres, and the reduction of sulfate is restricted (Hsieh and Yang 1997; Caçador et al. 2000). However, Hines et al. (1989) reported that the dissolved organic matter which is released from roots only during active growth of *Spartina alterniflora* and *S. patens* works as the electron donor for the reduction of sulfate, and hence the rate of sulfate reduction in sediment is highest during the active growth of *Spartina* spp. and in a crowded community.

Pyrite-containing Tertiary sediments distribute in some areas in Europe, e.g. Lusatia, Zwenkau Garzweiler in Germany (Ludwig et al. 1999; Meyer et al. 1999; Balkenhol et al. 2001), Nieuwkoop in The Netherlands (Ritsema and Groenenberg 1993), The London Basin in the UK (de Haan et al. 1994), Romania (Schippers et al. 2000) or Jutland (Rasmussen and Willems 1981). During the process of open-cut mining of brown coal in these areas, pyrite-containing Tertiary sands intercalated between brown coal layers appear at the land surface and cause environmental pollution after pyrite oxidation. Coal contains both organic and inorganic sulfur in high quantity (0.5–6.0 % (w/w); Kargi and Robinson 1982). Pyrite is the major sulfur-bearing inorganic mineral in coal and the oxidation of pyrite causes the production of sulfuric acid during the burning of coal (Wu et al. 1990).

Pyrite is sometimes locally included in mineral rocks. In the Green Tuff region in northern Japan, for example, a bedrock of Miocene andesite, dacite and pyroclastic rocks which contains secondary minerals such as pyrophyllite, kaolinate, and pyrite is present in various locations (Igarashi et al. 2003).

19.3 Oxidation of Pyrite

When pyrite is exposed to air and water, it is expected to oxidize easily. Oxidation of pyrite occurs both by thermo-chemical processes and by microbiological processes. As summarized in Evangelou and Zhang (1995), pyrite is microbiologically oxidized as follows:

$$\begin{aligned}
&\mathrm{FeS_2} + 7/2\mathrm{O_2} + \mathrm{H_2O} \rightarrow \mathrm{Fe^{2+}} + 2\mathrm{SO_4^{2-}} + 2\mathrm{H^+}\\
&\mathrm{Fe^{2+}} + 1/4\mathrm{O_2} + \mathrm{H^+} \rightarrow \mathrm{Fe^{3+}} + 1/2\mathrm{H_2O}\\
&\mathrm{Fe^{3+}} + 3\mathrm{H_2O} \rightarrow \mathrm{Fe(OH)_3}\ (s) + 3\mathrm{H^+}\\
&\mathrm{FeS_2} + 7\mathrm{Fe_2(SO_4)_3} + 8\mathrm{H_2O} \rightarrow 15\mathrm{FeSO_4} + 8\mathrm{H_2SO_4}
\end{aligned}$$

Thiobacillus ferooxidans is a common pyrite-oxidizing obligate chemoautotrophic and acidophilic bacteria (Rawlings et al. 1999), and the reaction has been most widely studied for use in coal desulfurization, water treatment of metal ore leaching, and bacterial leaching of metals from sulfide ores. The sum of the bacteria-induced pyrite oxidation reaction by O_2 is as follows.

$$4FeS_2 + 15O_2 + 2H_2O \rightarrow 2Fe_2(SO_4)_3 + 2H_2SO_4$$

Thibacillus thiooxidans, *Leptospirillum ferooxidans*, *Sulfobacillus thermosulfidooxidans*, *Sulfolobus acidocaldarius*, *S. solfataricus* and *Acidianus brierleyi* are commonly involved in the oxidation process of pyrite and are generally detected in pyrite-containing mine waste. It is known that the addition of organic substances such as sewage sludge or compost accelerates the pyrite oxidation by microorganisms (Larsson et al. 1990; Tsaplina et al. 1992).

Thiobacillus thioparus, *T. neapolitanus*, *T. novellus*, and *Thiomonas intermedia* are also known as sulfuric acid-producing microorganisms (Arkesteyn 1980). Arkesteyn (1980) summarized the pyrite oxidation process by thiobacilli. *T. ferooxidans* directly oxidizes pyrite under acidic conditions ($pH < 4.0$) after the non-biological pyrite reduction process. *T. thioparus* and *T. thooxidans* do not directly oxidize pyrite, but utilize reduced sulphur compounds that are formed during the non-biological oxidation of pyrite. *T. thooxidans*, *T. thiparus*, *T. intermedius* and *T. permetabolis* increase in the pyrite-containing media; however, they did not accelerate the pyrite oxidation.

In wetland soils with large quantities of sulfur, such as soils in salt marshes, pyrite and other reduced sulfur compounds (hydrogen sulfate and elemental sulfur) can be biotically oxidized to produce sulfate and thiosulfate through the oxidizing power of diffused oxygen via soil pores and marsh grass roots (aerenchyma) in salt marsh sediments (Caçador et al. 2000). The pyrite oxidation rate in wetland soils and sediments is usually determined by the oxidation-reduction status of the below-ground portion controlled by the plant root system and the accompanying community of microorganisms in the rhizosphere. Crowded plant communities transfer oxygen from atmosphere to the area below the ground surface, and then the sediment becomes rather more oxic than the non-vegetated sediment. Similar oxidation phenomena in reduced sulfur compounds have been observed in creek waters at low tide or in the surface layer of peatlands during the low water table season.

Pyrite oxidation proceeds also in anaerobic conditions with the presence of Fe(III) via a redox reaction such as:

$$FeS_2 + 14Fe^{3+} + 8H_2O \rightarrow 15Fe^{2+} + 2SO_4^{2-} + 16H^+$$

Furthermore, some kinds of bacteria (e.g. *Desulphobacter propionicus*) can oxidize S^0 to sulfate under anaerobic conditions using Fe(III) (Bottrell et al. 2000).

19.4 Environmental Problems of Pyrite Oxidation

Pyrite is distributed widely throughout the sediments and bedrocks around the world. One of the serious environmental problems caused by pyrite oxidation is the generation of acid mine drainage (AMD) from mine site spoils. Mining operations produce large amounts of waste tailings, which are usually deposited in open-air impoundments. Waste tailings containing metal sulfates such as pyrite lead to the production of acid rock drainage which contaminates the environment with heavy metals and sulfuric acid. Many reports describe the effect of sulfuric acid from mine wastes on vegetation destruction and ecosystems (e.g. Meyer et al. 1999; Bachmann et al. 2001; Werner et al. 2001).

Acid mine drainage containing a high concentration of sulfuric acid causes aquifer pollution with a high groundwater sulfate concentration, a low pH and enhanced heavy metal contents e.g. Ni, Co, Cu, Pb, As or Zn (Andersen et al. 2001).

In former open-cut brown coal mining areas dating from the early twentieth century, for example in The Lower Lusatian lignite mining district in Germany, there still remain many open mining casting lakes with high concentrations of sulfuric acid and extremely high acidity ($\text{pH} = 1.5\text{–}2.5$). Sulfuric acid comes from the mine spoils surrounding the lakes, and the continuous supply of sulfuric acid to the lake accelerates the acidification of the lake water. Furthermore, at this point most of the areas have not been reclaimed. An advanced method of open-cut mining of brown coal using a conveyer bridge dump can prevent the pyrite oxidation by keeping the stratigraphy of the Tertiary strata to the greatest degree (Wisotzky and Obermann 2001). However, the rehabilitation of vegetation after open mining area is difficult because of the contamination by pyrite of the topsoil.

19.5 Effects of Pyrite on Limnological Ecosystems

Sulfuric acid produced by pyrite oxidation affects not only the soil itself but also river and lake water systems after discharge from acid sulfate soil (Monterroso and Macías 1998; Blunden et al. 2001). It is reported that pyrite-containing rocks such as volcanic rocks affect the sulfate ion concentration in stream water discharged from the pyrite-containing rocks (Igarashi et al. 2003).

Sulfuric acid pollution in open mining casting lakes after coal mining is a serious environmental problem in some areas of Europe. Surface mining of brown coal may have severe impacts on the quality of surface and underground waters due to the possible formation of acid mine drainage. Pyrite oxidation and secondary reactions may result in a solution $\text{pH} < 2$ and large concentrations of SO_4^{2-}, Fe and Al in the leaching water. At sites with low proton buffer capacity, there is a concern that the toxicity of Al and heavy metals may restrict reforestation efforts (Schippers et al. 2000). When carbonate is distributed in the basin, H^+ formed by pyrite oxidation is rapidly buffered by $CaCO_3$. However, pyrite oxidation accompanied by carbonate weathering forms gypsum and it affects the hydrological properties of the aquifer (Ritsema and Groenenberg 1993).

Human activity affecting tropical peat swamp forests, especially destruction of peat soil due to agricultural land development, leads not only to global warming by emission of green house gases but also to various serious regional environmental problems. One of the regional environmental problems caused by the destruction of tropical peat is the oxidation of pyrite within the sediment underneath the peat layer in coastal areas. In the Sebangau River, the pH of the river water tended to decrease from Kya (uppermost stream of the Sebangau River) to the 60–80 km point from the river mouth (Fig. 19.2). However, the pH increased downstream to the river mouth

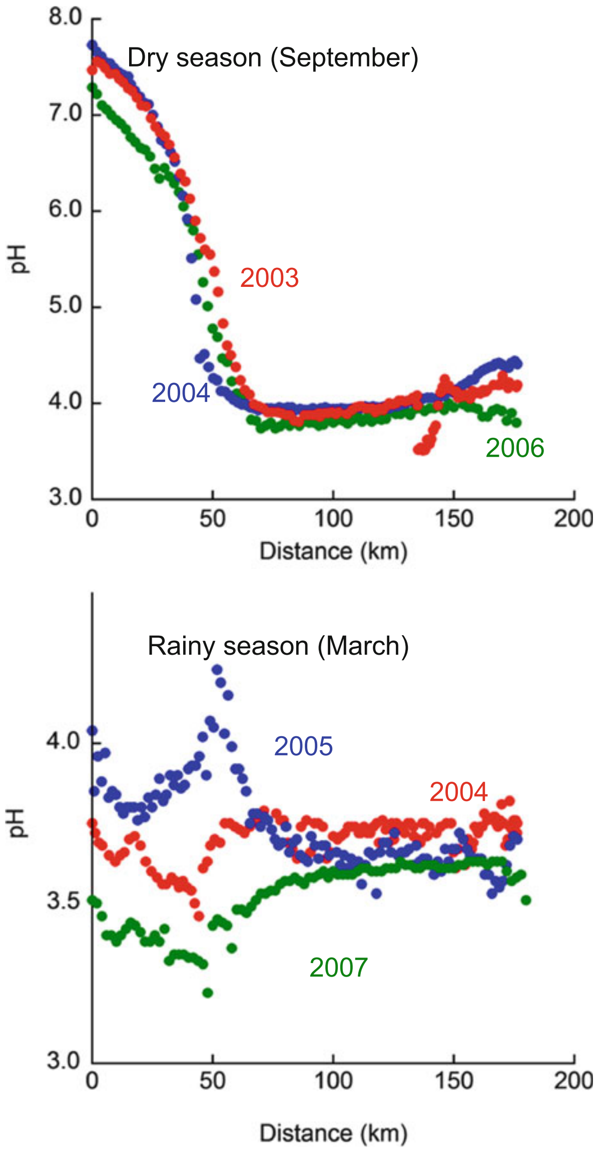


Fig. 19.2 Surface water pH of the Sebangau River in Central Kalimantan, Indonesia in the dry season (September 2003, 2004 and 2006; *upper*) and in the rainy season (March 2004, 2005 and 2007; *lower*) (Parts of the data appeared in Haraguchi (2007))

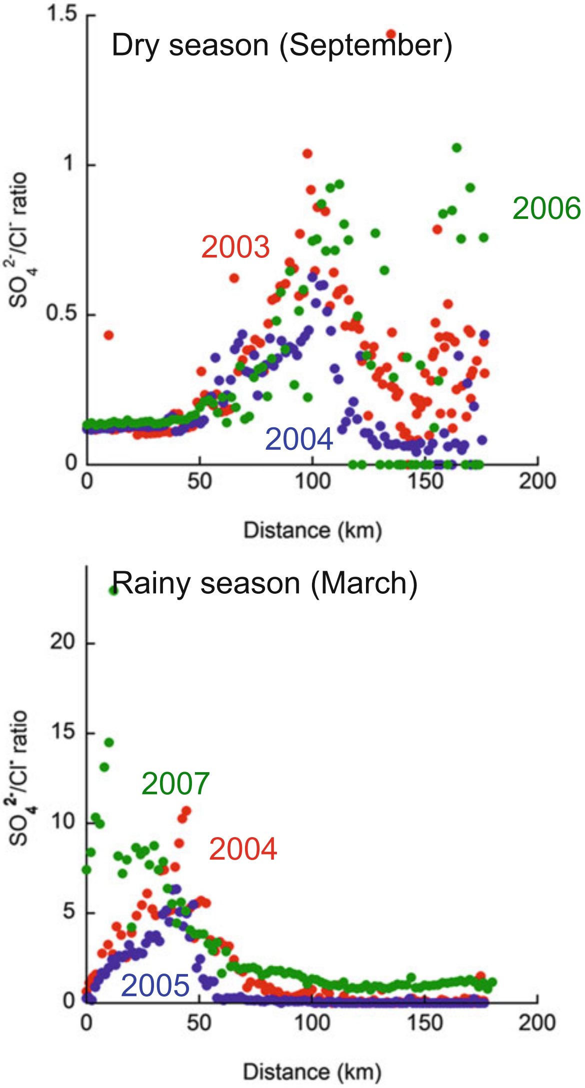
in the dry season; and the pH tended to decrease to the river mouth in the rainy season (Fig. 19.2). The pH in the Paduran canal in the lower basin of the river was almost the same or lower than in the main stream of the Sebangau River in the dry season; however, the pH in the Paduran canal exhibited a value 0.6 units lower than in the main stream of the Sebangau River in the rainy season.

We estimated the range over which sulfuric acid originating from pyrite oxidation affects the water chemistry of the river. Sulfate ions come both from sea water and from water discharged from pyrite-containing soils. Sulfate ion concentration in the water discharged from soils in which pyrite oxidation occurs is usually much higher than the chloride concentration, and so the ratio of SO_4^{2-}/Cl^- (w/w) can be used to evaluate the effects of sulfuric acid from pyrite oxidation on the river water chemistry (Fig. 19.3). In the dry season, the SO_4^{2-}/Cl^- ratio in the Sebangau River decreased from the uppermost stream of the river to the ca. 130 km point, and it increased from the 130 km point to the 90–100 km point (Fig. 19.3). The ratio decreased from the 90–100 km point to the ca. 45 km point and it fluctuated around 0.18, the same value found in the sea water, from the ca. 45 km point to the river mouth. Increases of SO_4^{2-}/Cl^- ratio downstream from the ca. 130 km point implied that the effect of pyrite on the river water chemistry appeared downstream from the ca. 130 km point from the river mouth (maximum value ca. 1.0). In the rainy season, the ratio showed the same tendency as in the dry season; however, the ratio was much higher than during the dry season. The SO_4^{2-}/Cl^- ratio started to increase from 130 to 140 km from the river mouth; however, the maximum was 10–45 km from the river mouth (maximum value ca. 7.0–15.0), 45–90 km downstream in comparison to the result during the dry season. This implies that the effect of sea water appeared only in the lower basin in the rainy season because of the high water level of the river.

Water of the mainstream of the rivers as well as water discharged from canals into the mainstream in the rainy season showed much higher acidity and a higher ratio of sulfate ion/chloride ion than during the dry season (Figs. 19.3 and 19.4). This implies that discharge of pyritic sulfate from peat soil to the limnological system is much higher in the rainy (high water table) season than during the dry (low water table) season. Anisfeld and Benoit (1997) reported that the rate of pyrite oxidation in salt marshes increased due to the tidal flow restriction to salt marshes and that sulfuric acid accumulated in salt marsh under desiccation-induced oxic conditions in the sediments. The re-connection of salt marsh sediments to tidal flow caused the severe acidification of surface water. This would be controlled by the same mechanism observed in the tropical peat swamp in Central Kalimantan, Indonesia.

Vertical profile of water chemistry of the Sebangau River clearly showed higher discharge of sulfate from peat soil in the rainy season (Figs. 19.4 and 19.5). Water at the river mouth showed constantly higher pH in the dry season due to inundation of sea water. Water column at the river mouth showed clear stratification in the rainy season because of the surface flow of the discharged fresh water and inundation of sea water at the bottom of water column. Surface water of the river basin in the rainy season, however, showed lower value of pH and higher SO_4^{2-}/Cl^- ratio compared to the lower part of the water column due to the effect by fresh water flowing over

Fig. 19.3 Ratio of sulfate and chloride ions (weight ratio) of the surface water of the Sebangau River in Central Kalimantan, Indonesia in the dry season (September 2003, 2004 and 2006; *upper*) and in the rainy season (March 2004, 2005 and 2007; *lower*) (Parts of the data appeared in Haraguchi (2007))



the sea water. Surface water at Paduran canal, lower basin of the river, showed lower pH in the rainy season and this corresponded to higher SO_4^{2-}/Cl^- ratio. Even at the upper basin of the river, water showed rather higher SO_4^{2-}/Cl^- ratio especially at the lower part of the water column. This implies that sulfate discharge is significant even at the upper basin of the river. Risk of sulfate discharge clearly appeared even in the upper basin of the river without distinct acidification of the river water.

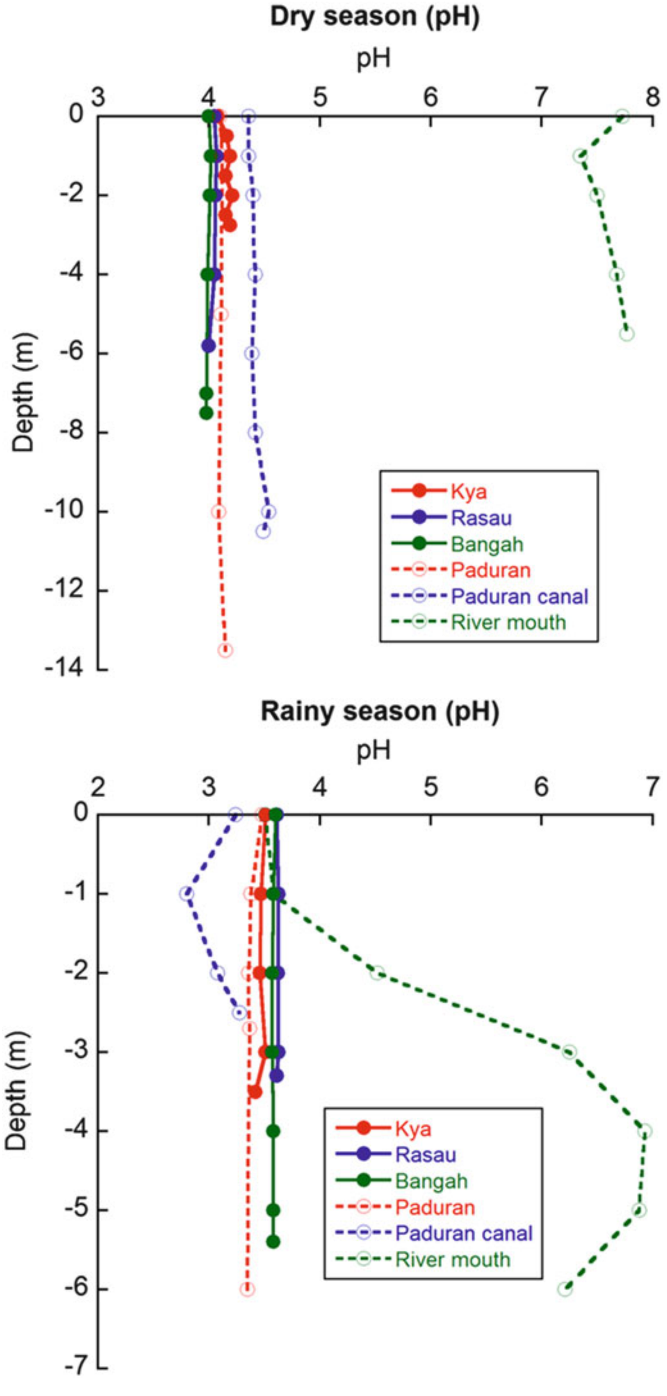


Fig. 19.4 Vertical profile of pH of the Sebangau River water in Central Kalimantan, Indonesia in the dry season (September 2004; *upper*) and in the rainy season (March 2007; *lower*). Kya is at the upper most basin of the river. Rasau, Bangah, Paduran and Paduran canal locate in this order from upper basin to the river mouth

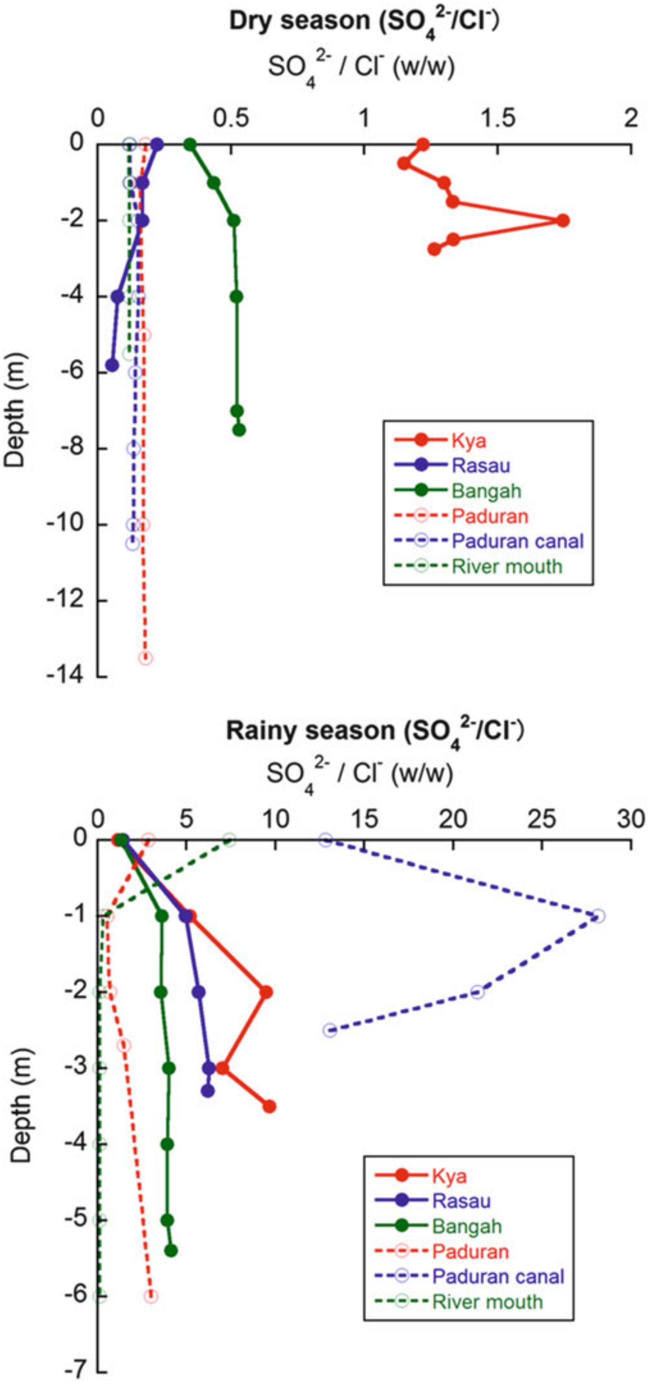


Fig. 19.5 Vertical profile of the ratio of sulfate and chloride ions (weight ratio) of the Sebangau River water in Central Kalimantan, Indonesia in the dry season (September 2004; *upper*) and in the rainy season (March 2007; *lower*). Kya is at the upper most basin of the river. Rasau, Bangah, Paduran and Paduran canal locate in this order from upper basin to the river mouth

19.6 Protection and Rehabilitation of Acid Sulfate Soils

Because of the extremely high acidity of acid sulfate soil, the primary production on the acid sulfate soil is strongly limited. And the impact of acid sulfate soil appeared not only in the soils themselves but in the surrounding limnological systems after the discharge of sulfuric acid from the acid sulfate soil. Although such environmental pollution by sulfuric acid discharge has appeared in large areas of the tropical peat swamps in Central Kalimantan, Indonesia, there have been no rehabilitation methods applied for the protection and rehabilitation of the acid sulfate soil or for vegetation recovery in the area. As a consequence, investigation of rehabilitation techniques is necessary for this tropical peat swamp area.

To the extent pyrite remains in a reduced condition under waterlogged soils or under thick peat cover, pyrite oxidation does not proceed extensively. Pyrite oxidation proceeds under oxic conditions. Therefore, the control of oxygen supply is an effective procedure to control pyrite oxidation in soil. Protection and acceleration of peat formation are effective methods to prevent sulfuric acid pollution. Agricultural land development by slash and burn, construction of drainage ditches, and the frequently related forest fires cause serious damage to tropical peat. Extensive destruction of peat as well as drying of peat increases the oxygen diffusion rate from the atmosphere to the pyrite-containing layer underneath the peat. Protection of the peat layer by protecting against forest fires and also by increasing the water table by re-filling up the drainage ditches would be effective procedures for rehabilitation of the acid sulfate soil.

Attempts to rehabilitate the acid sulfate soil and acidic lakes in lignite mining areas will provide us useful information concerning the development of rehabilitation techniques for tropical acid sulfate soils. One of the most successful techniques for the rehabilitation of vegetation on acid sulfate soils and in acidic lakes in lignite mining areas is to introduce some plant species highly tolerant of acidity. Some *Juncus* species such as *Juncus bulbosus* are known as an acid tolerant species and can colonize the highly acidic lignite mining lakes as a pioneer species (Chabbi 1999). Planting of *Pinus sylvestris* is also successful for the rehabilitation of vegetation in brown coal open mining areas (Hüttl and Weber 2001). Introduction of acid-tolerant species to the acid sulfate soil in tropical peat swamps and the acceleration of peat production could be effective methods for protection against sulfuric acid pollution in tropical peat swamps.

As for the improvement of runoff acid water discharged from acid sulfate soil, some attempts have been made by using constructed wetlands (Collins et al. 2004). Treatment of discharged water from acid sulfate soil before it enters the canal system is essential. Introducing non-polluted water to highly acidic lignite mining lakes (e.g. Senftenberg See in the Lusatian district, Germany) was successful in improving water quality and the consequent rehabilitation of vegetation (Werner et al. 2001). Although similar technologies do not directly apply to the rehabilitation of tropical peat swamp areas, control of water quality by controlling the water flow path should be effective in the tropical peat swamp. Study of a peat swamp in

Central Kalimantan clearly shows that the sulfuric acid was discharged from soil to river system via a constructed canal system (Figs. 19.2 and 19.3). This implies that the precipitated water penetrates into the peat layer and is discharged to the canal system via subsurface flow. Increase of soil surface water flow by filling in the canal system will limit the water discharges via the underground layer, and the sulfuric acid discharged to the river system will also be limited. Restoration of disturbed peatlands by increasing water table by blocking canals could be effective for water quality improvements as well as for rehabilitation of the local vegetation (Vasander et al. 2003).

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Chapter 20
Arrangement and Structure of Weirs on the Kalampangan Canal

Noriyoshi Ochi, Misao Okada, Hirochika Hayashi, Hiroshi Shimokura, and Mitsuhiko Kamiya

Abstract The main objectives of this study were to determine the suitable arrangement and structure of weirs on the Kalampangan Canal in the Mega Rice Project (MRP) area of Central Kalimantan based on the field investigation and laboratory test of materials. The purpose of the weir construction in this area is to keep the water level of canals high and to prevent the outflow of groundwater from peatlands. The field investigation was carried out to identify the types and reasons of the damages on the weirs which were already constructed on the canal. The undisturbed peat samples carefully taken by using the thin-wall sampler were used to determine the physical parameters of the peat. The sampling rates of peat columns were more than 90 %. The unconfined compressive strength of peat in this site was 3,2 kN/m^2. The weir should be strong mechanically and hydrologically during dry and wet seasons. The weir has a spillway of which the overflow width and depth are 10 m and 0.3 m respectively. The slope of the embankment is 2:1 with wooden supports. The weir structure is divided into two zones, a water blockade zone and an erosion protection zone. The clay soil is used for the water blockade zone and the sand bags are used for the erosion protection zone. The erosion protection zone can prevent the destruction by permeation of water. Clay and sandy soils can be procured locally.

Keywords Peatland • Weir layout • Weir structure • Peat sampling

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20.1 Introduction

The Kalampangan Canal is constructed on the peatland located in the northern Block C of the MRP area in Central Kalimantan. The free groundwater table of the area was comparatively high before the canal construction (Koizumi et al. 2013). After the canal construction, the canal drained the free groundwater in the peatland and lowered the ground water level near the canal. The groundwater level near the canal became remarkably low during dry season (Ishii et al. 2012). The drainage of free groundwater in peatlands had led to a significant decrease of the soil moisture of surface peat layer and caused wild fires in peatlands (Jaya et al. 2013; Takahashi and Limin 2012). Wild fires in the MRP area have become commonplace during the dry season and with various negative impacts on the natural environment (Hoscilo et al. 2011).

In order to maintain water levels high for reducing the occurrence of wild fires and mitigating the impact of wild fires, many plans to construct weirs on canals were devised and conducted in the MRP area. However, the most of weirs have been broken due to an increase of water pressure behind the weirs during rainy season within just a few years after construction. Therefore, the weir was designed considering seepage control and structural stability. An assessment of weirs along the Kalampangan canal was carried out considering their condition, location, on-site topography. On the basis of this assessment an improved design was formulated.

20.2 Basic Concepts for Weir Design

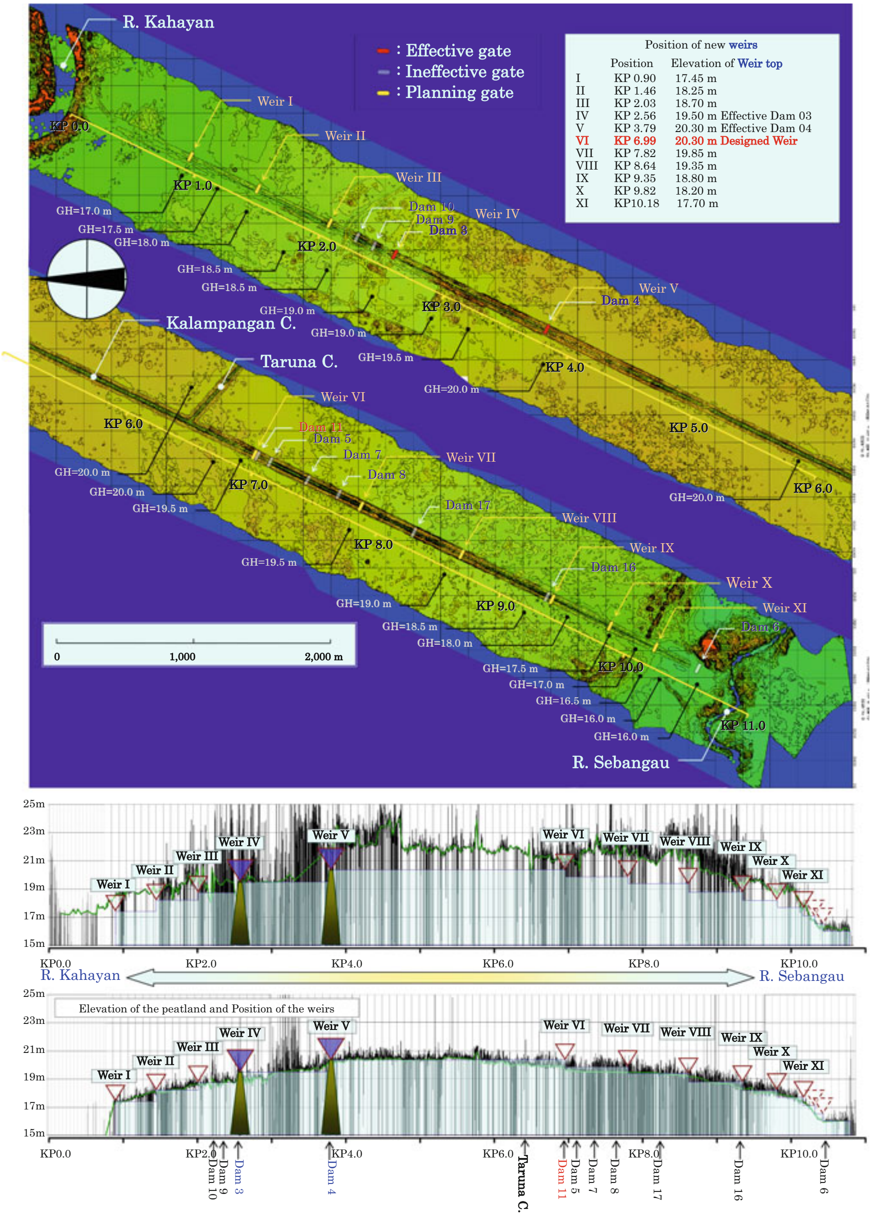
A field investigation was carried out to identify reasons why the weirs collapsed and lost the function of weirs in the MRP area. Through the field investigation, we got the following concepts for weir design in this area.

1. It should be considered the information of the boring exploration on site, the analyzed results of soil properties, and the observed volume of water discharge near the site in the structural design of the weir.
2. The structure of weir should be mechanically divided into two zones, a water blockade zone and an erosion protection zone, based on the assessment of a wide range of geological features.

On the basisof the above concepts, the ground plan, front elevation and cross-section of the weir were designed.

20.3 Arrangement of Weirs

Figure 20.1 shows plans for the weir arrangement in the Kalampangan canal. The layout and elevation of the weirs were determined using the airborne laser scanning data of the Kalampangan canal area (1.1 km in width and 12.5 km in



Position of new weirs

	Position	Elevation of Weir top
I	KP 0.90	17.45 m
II	KP 1.46	18.25 m
III	KP 2.03	18.70 m
IV	KP 2.56	19.50 m Effective Dam 03
V	KP 3.79	20.30 m Effective Dam 04
VI	KP 6.99	20.30 m Designed Weir
VII	KP 7.82	19.85 m
VIII	KP 8.64	19.35 m
IX	KP 9.35	18.80 m
X	KP 9.82	18.20 m
XI	KP10.18	17.70 m

Fig. 20.1 Weir arrangement along the Kalampangan canal

length) measured by Kalteng Consultants. The data were obtained from a helicopter flight path on 6 Aug. 2007 between the Kahayan and Sebangau rivers and along the Kalampangan canal. The maps and cross-sectional profile of this area were developed based on the data.

The objective of installing weirs in the drainage canal is to control the groundwater table in the dry season, to maintain the water content of the peatland, and to prevent wild fires on the peatland.

The additional concepts which should be considered for the weir design are as follows.

1. The peatland surface to be maintained wet.
2. The levees, which were created by depositing surplus soil on both sides of the drain, are maintained dry for the purpose of wild fire prevention activities.
3. The levels of the new weirs is set at the same level as the level of the peatland surface in order to maintain its wetness (The weir level means the elevation of the top of the weirs over which the flood water flows).
4. A sequence of weirs are installed with the elevation position of each weir not more than 0.8 m higher/lower than the next/previous for reasons of stability.
5. Weirs are not installed where the weir level is less than 17 m above sea level, since it is close to the low-water stage of rivers and the effect of installation here is limited.

20.4 Structural Design of Weir

20.4.1 Condition of Existing Weirs

Ten weirs were constructed with the aim of creating ponds for wild fire protection and maintaining canal water levels. The weirs which were constructed on the Kalampangan canal, were named as the proper names from Dam No. 1 to Dam No. 17 by local scientists. We use the proper name for the weirs which were constructed on the canal. However, the most of the weirs do not work anymore because the weirs have collapsed as a result of wild fires or flooding during wet season. The weir body and both sides of the embankment have collapsed by piping (Fig. 20.2) or over topping (Fig. 20.3). The weir material appears to be sandy soil or excavated soil (peat), and it is estimated that these soils do not have the appropriate water interception ability.

Dams No. 3 and No. 4 are still working. Dam No. 3 is structurally stable and it can still control seepage. Characteristically, the width (up-downstream direction) of a weir is long (about 8 m) and the creep ratio (length of seeping/difference of water head) is relatively large (about 8 m).

Fig. 20.2 Dam No. 5, dry season in 2009

Fig. 20.3 Dam No. 9, dry season in 2009

20.4.2 Function to Be Fulfilled

The function of weirs to be fulfilled is maintaining water levels of the canal in the dry season. For this is necessary to ensure a mechanically and hydrologically stabilized structure.

A mechanically stabilized structure are a weir body and foundations including embankment that does not slide and avoids subsidence due to the weight of the weir, even where peat soil forms the foundation. Hydrologically stabilized structures have to avoid piping of seepage flows through the foundation of the weir and not to have the apron washed away by overtopping water in the rainy season.

20.4.3 Soil Conditions of Foundation and Weir Surroundings

Since Dam No. 3 and Dam No. 4 are in working order, the location of the first weir construction is planned to be at the ex-Dam 11 position on the Sebangau river side from the Taruna canal junction.

Figure 20.4 shows the results of cross-section survey for the canal. The width of the canal at the water surface was approximately 16 m and the maximum water depth is approximately 0.85 m. The canal has channels to discharge water from surrounding ground on the outer sides of the weir embankments on both sides of the canal. In-situ tests were carried out from the crown of a weir embankment on the right bank. The ground consisted of a 2-m-thick layer of excavated sandy peat, the original 1-m-thick peat layer directly below it, and sand below that.

A thin-walled tube sampler (TS) with fixed piston in accordance with the Japanese Geotechnical Society's standard (Japanese Geotechnical Society 2004) is used to collect undisturbed samples from peat layers and standard penetration tests (SPT) were performed for the sand layer (Hayashi et al. 2013). In-situ permeability tests are also conducted.

In Kalimantan peatland, there is no report of the sampling of undisturbed specimens. It was possible to collect sample with the higher sampling rate than 90 % using the thin-walled tube sampler (sampling rate = the length of the collected sample/depth of drilling), and sampling of the sand was also possible by the standard penetration test. Results of the soil tests are shown Table 20.1. From these results, peatland was excavated to construct a canal in Kalampangan and the soil was piled on the banks on both sides of the canal. The estimated ground level was around

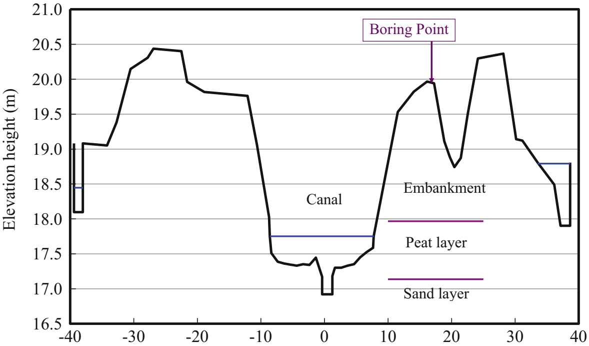


Fig. 20.4 Cross section at the site

Table 20.1 Result of soil tests

	Dam 11							Dam 3	
Material sampling	TS3	TS2	TS1	SPT1	SPT2	SPT3	Disturbed	Undisturbed	Undisturbed
Soil	Peat	Peat	Peat	Sand	Sand	Sand	Embankment	Embankment 1	Embankment 2
Depth (m)	2.5	2.6	2.7	3.2	3.6	4.2	Surface	Surface	Surface
Specific gravity	–	–	–	2.651	2.675	2.536	–	–	–
Water content (%)	673	634	463	19.1	18.9	21.6	99.7	113.5	136.4
Ignition loss	93.4	96.4	83.1	0.2	0.1	7.1	42.0	49.4	90.5
Wet density (Mg/m^3)	1.033	1.018	1.065	–	–	–	–	1.020	1.046
Dry density (Mg/m^3)	0.134	0.139	0.189	–	–	–	–	0.478	0.443
Coefficient of permeability (m/s)	–	5.20E-08	–	–	–	–	–	8.2E-05	4.7E-05
N value	–	–	–	15	17	15	–	–	–
Remarks	Under 0.5 m from water surface	Under 0.87 m from water surface	–	–	–	–	–	–	–
Coefficient of permeability in site (peat) (m/s)	2.7E-06	3.1E-08							

TS tube sampling
STP standard penetration test

EL. Nineteen meters before excavation, and several years have passed since the construction of the canal (ref. Fig. 20.4 I-I Section).

In the canal part of Dam No. 11, peat is distributed at around the elevation (EL) of 18 m above mean sea level (a.m.s.l) and sandy soil is distributed 1 m below that. It would appear that sandy soils have been excavated at the deepest point of the canal construction site when the existing weir was constructed. The permeability of the sand layer distributed in canal bed was estimated to be around from 2 to 3×10^{-5} m/s by the Creager's relationship between the 20 % grain size and permeability (Creager et al. 1944). The layer with this value of permeability is categorized as a permeable layer. Therefore the distribution and permeability of the sand layer in the canal bet should be considered in the design of the weirs.

In the embankment part (recorded with Dam 3 because of small sample site), it would appear that there is mainly peat piled up by the excavated soil and partially sandy soil based on visual observations of soil conditions and Ignition loss.

20.5 Design Conditions

20.5.1 Water Level Conditions

Figure 20.5 shows the water level conditions at the weir. The elevation upstream of the weir is EL. 19 m a.m.s.l, and water levels in the rainy season are assumed to be WL. 19.0 m a.m.s.l. The water level (WL) in the dry season is assumed to be 18.7 m a.m.s.l (overflow 0.3 m as will be described later). The water level differs between the up and downstream sides to be within 0.8 m based on the total disposition of the weirs. From the above, downstream water levels in the dry season are assumed to be WL. 17.9 m a.m.s.l.

20.5.1.1 Water Discharge Volume Conditions

To decide the appropriate flood discharge volume for safe discharge to the downstream, the designed volume was 0.26 m^3/s set at 0.13 m^3/s – two times higher (as a safety factor) than that observed in a nearby canal (Taruna canal) (Fig. 20.6).

Fig. 20.5 Water level conditions at the weir

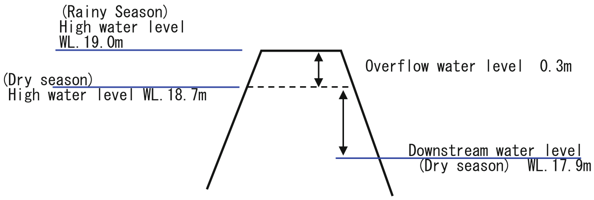
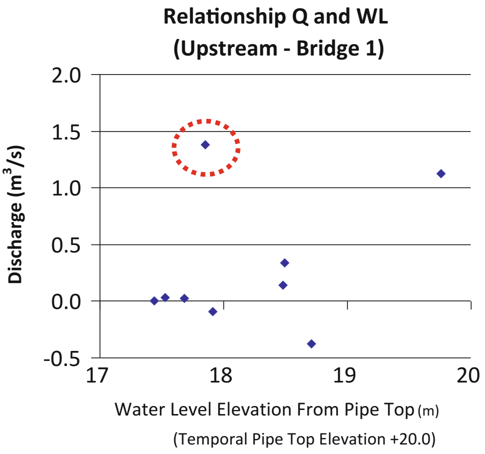


Fig. 20.6 Relationship water level and discharge (By Takashi Inoue)



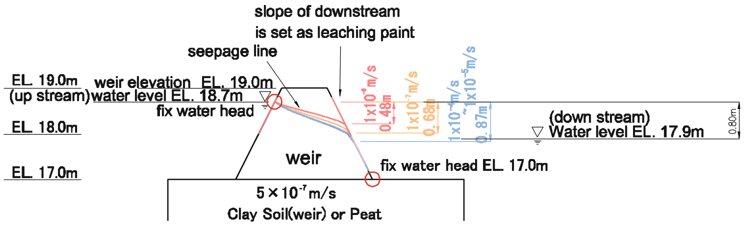


Fig. 20.7 Seepage line (relationship among material of weir and coefficient of permeability and seepage line) (dry season)

20.5.2 Weir Material

Materials to be used in the weir construction may be purchased (sandy/clay soil) or excavated (peat/sandy soil) on site. However peat soil is not an appropriate material, due to its high water content (400–600 %), difficulty of usage just after excavation for the embankment, poor resistance against water discharges due to its light weight with a wet density of 1.0 Mg/m^3.

Material for water blockading is recommended to have a lower than 1×10^{-7} m/s as permeability coefficient to be able to restrain the 0.8 m water level difference (Fig. 20.7). Sandy soil is not recommended, since the permeability coefficient is approx. 3×10^{-6} m/s.

Soil cement that is cement added to sandy soil (purchased soil) cannot stop the water (Table 20.2, Fig. 20.8). Soil cement that is purchased soil (1 m^3) with added cement (30 kg, 50 kg and 100 kg) had increased bearing capacity but it had no effect on permeability, remaining around 3×10^{-5} m/s. Clay soil has problems related to erosion at the time of overflow discharge.

Table 20.2 Coefficient of permeability and Support power strength of soil cement (employed material)

Employed material	Purchased sand + cement addition		
Sample number	No. 3	No. 4	No. 5
Quantity of cement addition	30 kg/m^3	50 kg/m^3	100 kg/m^3
Wet density (Mg/m^3)	1.647	1.699	1.794
Dry density (Mg/m^3)	1.581	1.638	1.669
Water content (%)	4.1	3.7	7.4
Coefficient of permeability (m/s)	3.6E-04	3.4E-04	3.2E-04
Bearing capacity (kN/m^2)	140	670	830

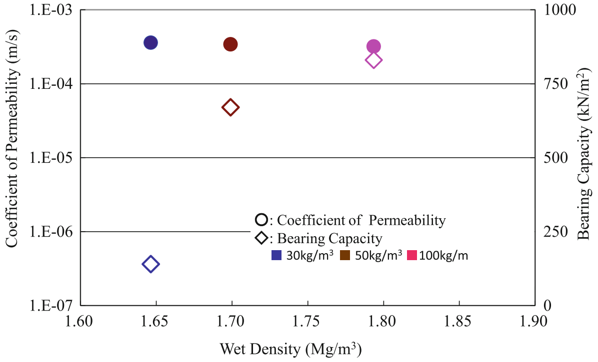


Fig. 20.8 Coefficient of permeability and bearing capacity of soil cement (employed material)

From the above, the weir structure is divided into two zones i. e. a water blockade zone and a protection zone to prevent the water blockade zone from erosion and destruction by permeation. Clay and sandy soils can be procured locally.

Even without these materials available near the site, excavation is not recommended as it may affect the underground water level. The particle size distribution curve and physical properties of sandy soil and clay soil (sample soils from the supposed borrow pit) is shown in Fig. 20.9 and Table 20.3.

20.5.3 Structure of the Weir

The structureof the weir is shown in Fig. 20.10. Sandy soils in the protection zone are to be packed into sandbags for protection from erosion and to maintain the slope of the embankment. The weir structure is to be symmetrical to the up and downstream canal since the stream course will change with water discharge volume.

To maintain a creep ratio of approx. 8 for the purpose of maintaining the water blockade and protection from destruction due to permeating water. For this purpose, a base seepage treatment is planned by a clay wall with a width of 0.5 m and piling.

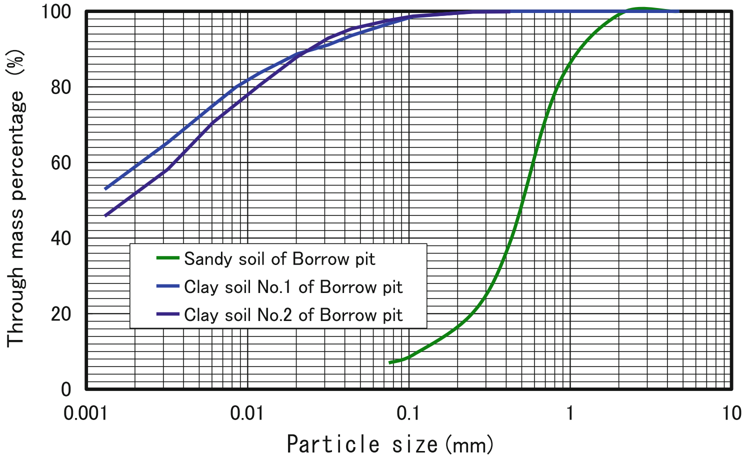


Fig. 20.9 Particle size distribution curve of sandy soil and clay soil (employed material)

Table 20.3 Physical properties of sandy soil and clay soil (used material)

Sampling point	Employed material		
Material sampling	Disturbed		
Soil	Clay-1	Clay-2	Sand
Depth (m)	Surface layer		
Specific gravity	2.65	2.62	2.64
Water content (%)	49.2	33.7	10.3
Ignition loss	–	–	1.5
Liquid limit (%)	63.5	64.9	–
Plastic limit (%)	31.6	32.0	–
Plasticity index Ip	31.9	32.9	–

To set up a spillway in the weir and apron on the up and downstream sides as a protection against piping and to protect against erosion due to over flow discharge.

The width of the overflow section and water depth of the overflow shall be calculated using the following overflow formula (Eq. 20.1).

$$Q_f = C_f B_f {H_f}^{3/2} \tag{20.1}$$

Where Q_f: amount of overflow ($\mathrm{m^3/s}$)

C_f: factor of overflow (1.5–1.8)
B_f: overflow width (m)
H_f: overflow depth (m)

To set up a spillway with an overflow width of 10 m and depth of 0.3 m for a safe discharge of the design water volume 0.26 $\mathrm{m^3/s}$. It was assumed that an ideal stable slope gradient for the embankment is more than 3:1.

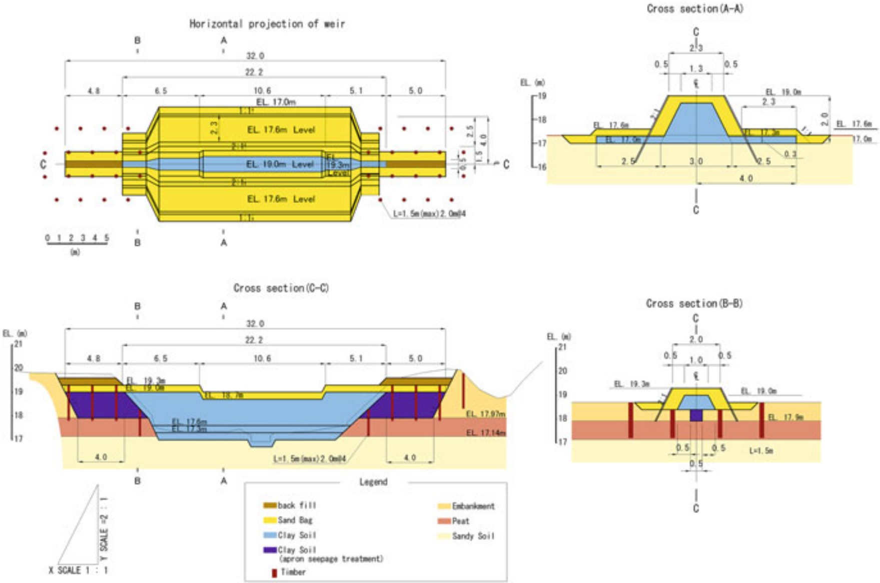


Fig. 20.10 Detail of the design of weir structure

However this would involve prohibitive costs. Therefore it was planned that the slope of the embankment was 2:1, with wooden supports.

20.5.4 The Issues to Be Resolved in Future

Through the field investigation, we found following issues to be resolved.

1. The weir alignment must be verified according to the elevation up and downstream of the weir and the underground water analysis combined with the weir construction, since it would be the affected by the in and out flow of underground water from the canal.
2. The sandy soil layer lies at the canal bed. Therefore, the more detail investigation on the geological characteristics of the sand layer will be necessary for the weir design. The spillway design was based on the water charge on the Taruna canal near the site of planned construction of the weir. In the future, water level charge observations and re-design of the overflow depth should be done prior to weir construction.
3. It is necessary to conduct quantity surveying and develop a plan for execution prior to the weir construction.
4. Monitoring of the structural conditions of the weir is necessary so that the weir may be maintained and repaired accordingly to continue to fulfill its

purpose. Meanwhile monitoring of the impact of the weirs should also be carried out including on the surrounding peatland ecosystem (e.g. in terms of forest succession resulting from re-wetting), water storage impact, maintenance of groundwater levels etc.

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Part V
Green House Gasses Emission from Peatland

Takashi Hirano and Muhammad Evri

Chapter 21
CO_2 Balance of Tropical Peat Ecosystems

Takashi Hirano, Siti Sundari, and Hiroyuki Yamada

Abstract We reanalyzed long-term field data of CO_2 flux, including net ecosystem CO_2 exchange (NEE), ecosystem respiration (RE), and soil CO_2 efflux (RS) to examine their seasonal and interannual variations for three conditions of disturbance (almost undrained peat swamp forest (PSF), drained PSF, and drained burnt ex-PSF) in a tropical peat area in Central Kalimantan, Indonesia. In addition, we simulated the CO_2 flux on a monthly basis using empirical equations shown by our previous studies under four scenarios of seasonal variations in groundwater levels (GWL). The GWL has a large interannual variation in October and November. The rainy season usually begins in October, but the onset is delayed until November in El Niño years, making the interannual variation in CO_2 fluxes the largest in these 2 months owing to the large GWL variations. On an annual basis, minimum monthly-mean GWL explained 82 % of interannual variations in NEE for the two PSFs. The linearity suggests that 10-cm drawdown of minimum monthly-mean GWL increases NEE or net ecosystem CO_2 emission by 48.5 gC m^{-2} $year^{-1}$ from PSF, independently of drainage degree. It can be said that minimum monthly-mean GWL is a practical measure to assess annual NEE of PSF.

Keywords CO_2 balance • Ecosystem respiration • Groundwater level • Net ecosystem CO_2 exchange • Soil respiration

21.1 Introduction

Tropical peat has accumulated a huge amount of soil organic carbon, up to 88.6 Pg over millennia, with coexisting peat swamp forest (PSF) (Page et al. 2011). However, tropical peatlands in Southeast Asia, which comprise 56 % of global

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tropical peatlands in area (Page et al. 2011), have been extensively logged, drained, and subjected to burning for the last two decades (Miettinen et al. 2012). Such human disturbances perturb the coexistence of tropical peat and PSF irreversibly and, as a result, make the massive peat carbon pool vulnerable (Hooijer et al. 2012; Hirano et al. 2012). Tropical peatland is recognized as a "hot spot" for vulnerable carbon pool in this century (Canadell et al. 2007), and it is urgent to assess the current carbon status of tropical peat ecosystems and quantify the effects of disturbances on the carbon balance to be able to make predictions of the role of tropical peatlands in the regional and global carbon balances. However, more knowledge based on field data is still essential for the predictions to be made with less uncertainties. We conducted field studies on ecosystem CO_2 exchanges (Hirano et al. 2007, 2012) and soil CO_2 efflux (Hirano et al. 2009, 2014; Sundari et al. 2012) in tropical peat ecosystems in Central Kalimantan, Indonesia, and showed practical relationships between the CO_2 flux and groundwater levels (GWL). We reanalyzed long-term field data measured at three ecosystems with different disturbance levels to examine seasonal and interannual variations in CO_2 flux. In addition, using such information and knowledge derived from the field data, we simulated CO_2 flux under the different GWL conditions to examine the effect of GWL on CO_2 flux on a monthly basis.

21.2 Field Study

Three study sites were established in a tropical peat area in Central Kalimantan, Indonesia. The sites are an almost undrained PSF (UF, Fig. 21.1a) (2.32°S, 113.90°E), a drained PSF (DF, Fig. 21.1b) (2.35°S, 114.14°E), and a drained burnt ex-PSF (DB, Fig. 21.1c) (2.34°S, 114.04°E), which are located on flat terrain within 15 km (Hirano et al. 2012). A large canal runs between the DF and DB sites (Fig. 21.1d) and has facilitated drainage. The DB site was burnt three times at least in El Niño years of 1997, 2002, and 2009. Vegetation mainly consisting of fern and sedge species had grown rapidly after the fires. At the UF, DF, and DB sites, net ecosystem CO_2 exchange (NEE) was measured continuously using the eddy covariance technique since 2004, 2001, and 2004, respectively. Conventionally, if an ecosystem functions as a CO_2 sink, the sign of the NEE becomes negative. Meteorological factors, such as precipitation, air temperature, humidity, and radiation, and underground environmental factors, such as GWL and soil temperature, were also monitored and averaged every 30 min. The half-hourly NEE was partitioned into gross primary production (GPP) and ecosystem respiration (RE) using an empirical method after quality control of the NEE data. Data gaps due to system malfunctions and removal by low quality were filled using the look-up table method (Hirano et al. 2007, 2012). In addition, soil respiration or soil CO_2 efflux (RS) was measured half-hourly from 2004 to 2006 at the three sites using an automated system with six chambers (Hirano et al. 2009, 2014; Sundari et al. 2012). The RS at the UF and DF sites was the total soil respiration including root respiration (Sundari et al. 2012), whereas the RS at the DB site was soil CO_2

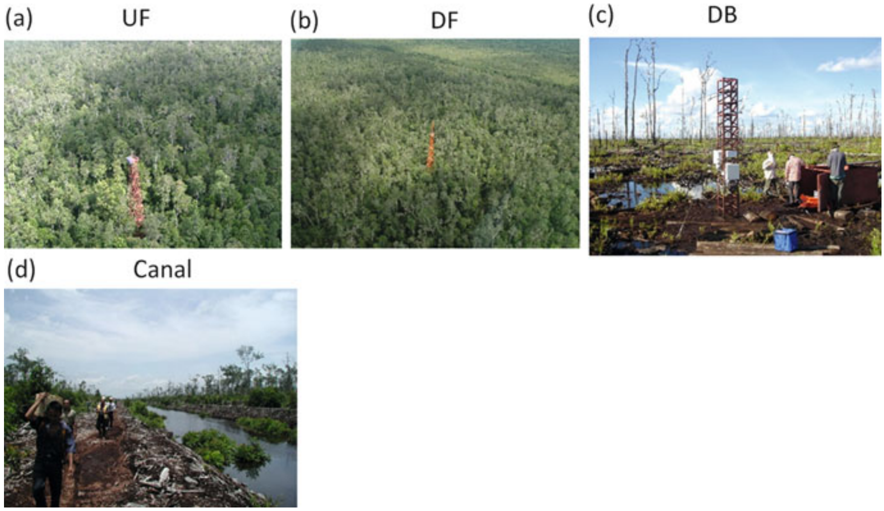


Fig. 21.1 Pictures of the towers at the UF ((**a**) July 2004), DF ((**b**) January 2007), and DB ((**c**) April 2004) sites and a canal ((**d**) March 2001) running between the DF and DB sites

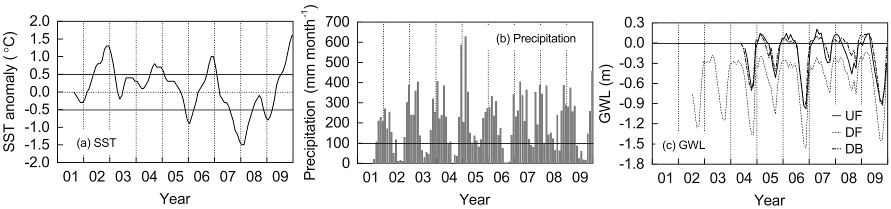


Fig. 21.2 Time series of monthly values of the 3-month running mean of sea surface temperature anomalies (SST) in the Niño 3.4 region (**a**), precipitation (**b**), and groundwater level (GWL) between 2001 and 2009 (Hirano et al. 2014). El Niño and La Niña events are characterized by five consecutive 3-month means with thresholds above +0.5 and below −0.5 °C, respectively (NOAA, http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.stml)

efflux only through oxidative peat decomposition (heterotrophic respiration), which excluded root respiration (Hirano et al. 2014). Annual sums of NEE, GPP, and RE were calculated for a period of 365 or 366 days starting on July 9 or July 10 (Hirano et al. 2012).

According to sea surface temperature (SST) anomaly in the Niño 3.4 region (Fig. 21.2a), El Niño and La Niña events occurred in the 2002–2003, 2004–2005, and 2006–2007 periods and the 2005–2006, 2007–2008, and 2008–2009 periods, respectively. Precipitation showed a clear seasonal variation with the rainy and dry seasons (Fig. 21.2b). The seasonality was strengthened by El Niño events with the prolonged dry season and weakened by La Niña events with the shortened or no dry season. Following the precipitation pattern, GWL varied seasonally (Fig. 21.2c). During the dry season, GWL continued to decrease and suddenly rose with the onset

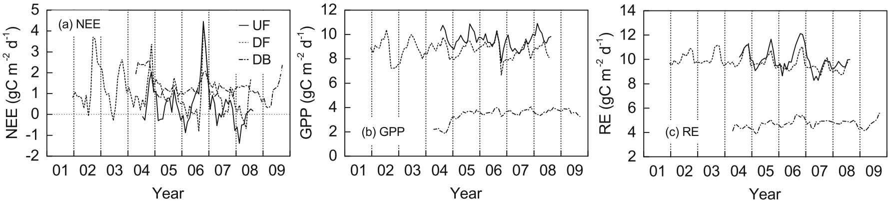


Fig. 21.3 Time series of monthly-mean daily values of net ecosystem CO_2 exchange (NEE) (**a**) (Hirano et al. 2012), gross primary production (GPP) (**b**) and ecosystem respiration (RE) (**c**) at the UF, DF, and DB sites between 2001 and 2009

of the rainy season. El Niño drought facilitated GWL lowering. In the rainy season, GWL rose aboveground in the UF site, whereas it remained belowground in the DF site because of drainage by a canal. However, GWL of the DB site was almost the same as that of the UF site in spite of drainage, because the DB site was subsided by about 0.5 m during peat fires in 1997 and 2002 (Hirano et al. 2014).

Monthly-mean daily NEE is shown in time sequence in Fig. 21.3 along with GPP and RE. The NEE increased regularly in September and October because of shading by smoke from field fires and the enhancement of oxidative peat decomposition due to low GWL (Hirano et al. 2012). In particular, during El Niño drought in 2002, 2004, and 2006, NEE showed sharp peaks, because solar radiation was attenuated by dense smoke emitted from large-scale peat fires. On the other hand, monthly mean NEE was negative (net CO_2 uptake) in 17 months (34 %) out of 50 months in the UF site and 8 months (10 %) out of 80 months in the DF site, whereas NEE never became negative in the DB site. In the UF site, NEE became negative almost in the rainy season from December to April when GWL rose aboveground. In the DF site, however, negative NEE occurred chiefly in the transition between the rainy and dry seasons with higher leaf area index (LAI) (Hirano et al. 2007). This time difference suggests that NEE became negative by different reasons: decreased RE and increased GPP, respectively, for the UF and DF site. The UF site had a larger standard deviation (0.91 gC m^{-2} day^{-1}) in RE than the DF site (0.63 gC m^{-2} day^{-1}) for the common period from July 2004 to July 2008, because RE decreased sharply when GWL rose aboveground in the UF site (Hirano et al. 2012). For the 4-year period, annual NEE was positive at all sites, except for at the UF site in an annual period of 2007–2008, in which a La Niña event occurred. Although no significant difference was found, mean annual NEE was largest at the DB, the most seriously disturbed site, followed by the DF site, a drained PSF, and the UF site, an almost undrained PSF (Fig. 21.4). Means of annual GPP and RE were significantly smaller at the DB site than the other PSF sites.

The RS was equivalent to soil respiration consisting of root (autotrophic) respiration and microbial (heterotrophic) respiration at the UF and DF sites, whereas it was only microbial respiration through oxidative peat decomposition at the DB site. Therefore, RS was much smaller at the DB site than at the UF and DF sites (Fig. 21.5). Because RS clearly decreased as GWL increased near the ground surface

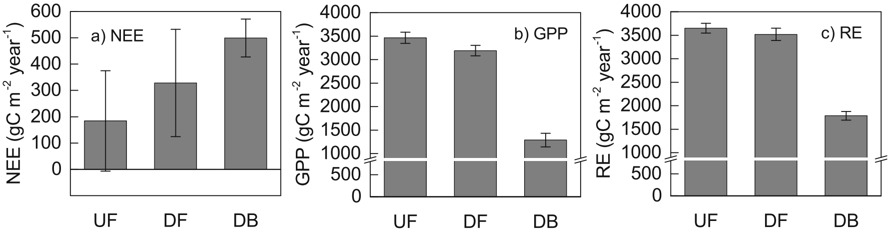
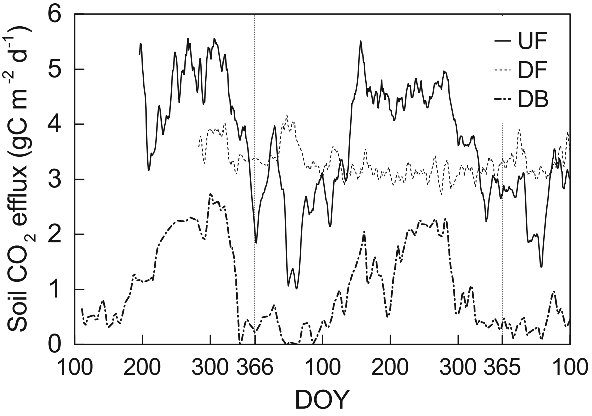


Fig. 21.4 Comparison of annual sums of net ecosystem CO_2 exchange (NEE) (**a**), gross primary production (GPP) (**b**) or ecosystem respiration (RE) among the UF, DFm and DB sites (Hirano et al. 2012). Annual sums were calculated for a period of 365 or 366 days from mid-July in a year to mid-July in the next year. *Vertical bars* denote ±1 standard deviations for 4 years

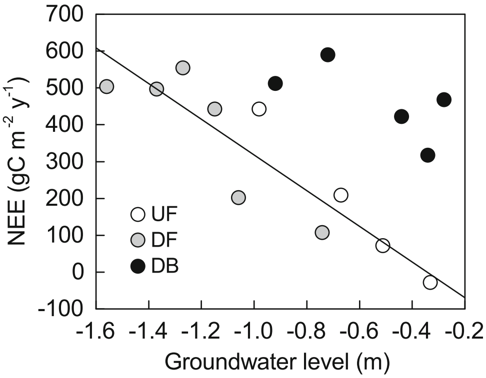
Fig. 21.5 Time series of daily soil CO_2 efflux at the UF, DF, and DB sites between April 2004 and April 2006 (Sundari et al. 2012; Hirano et al. 2014). The 5-day running means are shown



at UF (Sundari et al. 2012) and DB (Hirano et al. 2014), RS at UF and DB showed clear seasonality with its minimum in the rainy season (Fig. 21.5). On the other hand, RS was almost steady at the DF site throughout a year. Annual sums of RS for 2005 were 1,347, 1,225, and 348 gC m^{-2} $year^{-1}$, respectively, at the UF, DF, and DB sites; CO_2 emissions through oxidative peat decomposition at a burnt ex-forest was equivalent to about a quarter of soil respiration at the PSFs. The annual RS accounts for 37, 34, and 21 % of annual RE, respectively, at the UF, DF, and DB sites.

We found significant negative relationships between annual NEE and annually-mean GWL at the UF and DF sites (Hirano et al. 2012), whereas the linear relationships were different each other. If minimum monthly-mean GWL was used instead of annually-mean GWL, however, the relationships for the two PSFs were combined significantly into a single line ($y = -485 \times x - 167$; $r^2 = 0.82$, $p < 0.01$) (Fig. 21.6) with a root mean square error (RMSE) of 84 gC m^{-2} $year^{-1}$; no significant correlation was found for the DB site ($r^2 = 0.44$). A similar, but positive, single relationship was found between annual sums of evapotranspiration and minimum monthly-mean GWL for the PSFs (Hirano et al. 2015). The linearity suggests that 10-cm drawdown of minimum monthly-mean GWL increases NEE or

Fig. 21.6 Relationships between net ecosystem CO_2 exchange (NEE) and minimum monthly-mean groundwater level (GWL) on an annual basis. A line was fitted significantly ($p < 0.01$) to the data of the UF and DF sites



net ecosystem CO_2 emission by 48.5 gC m^{-2} $year^{-1}$ from PSF, independently of drainage degree. Also, NEE is expected to be zero at minimum GWL of −0.34 m. We can say that minimum monthly-mean GWL is more useful than annually-mean GWL to assess the CO_2 balance of PSF on an annual basis.

21.3 Simulation of CO_2 Flux

We calculated the CO_2 fluxes of NEE, RE, and RS on a monthly basis for each site using linear, quadratic, or logarithmic relationships with GWL shown in our previous papers (Hirano et al. 2012, 2015; Sundari et al. 2012), which were derived from the field data detailed above. The GWL data for the 4 years from August 2004 to July 2008 were used to calculate the monthly means and standard deviations (SD) for the 4 years. Using the means and SD for each month, we generated four scenarios for seasonal variations in GWL: Mean, Mean minus 2 SDs (−2SD, lowest), Mean minus 1 SD (−1SD, lower), and Mean plus 1 SD (+1SD, higher) (Fig. 21.6).

In the period of the 4 years, El Niño events occurred twice in 2004–2005 and 2006–2007, and two La Niña events occurred in 2005–2006 and 2007–2008 (Fig. 21.2a). Annual precipitation was 2457 ± 81 mm $year^{-1}$ (mean ± 1 SD) for the 4-year period, which is very similar to the 2,452 ± 110 mm $year^{-1}$ for the 7 years from 2002 to 2009 (Hirano et al. 2012). With a threshold of monthly precipitation at 100 mm, the dry season began in July and lasted for 3 months until September (Fig. 21.7a). Although interannual variation in precipitation was largest in February (Fig. 21.7a), that in GWL was largest in November (Fig. 21.7b–d); 1 SD in GWL was 0.47, 0.63, and 0.51 m for the UF, DF, and DB sites, respectively, in November. The large SD is attributed to the delayed onset of the rainy season because of the two El Niño events in the period. Thus, the mean GWL was lowest in October, whereas the GWL potentially decreases the most in November. The four scenarios provide GWL ranges with −1.35 to 0.20 m, −2.19 to −0.17 m, and −1.39 to 0.11 m for the UF, DF, and DB sites, respectively.

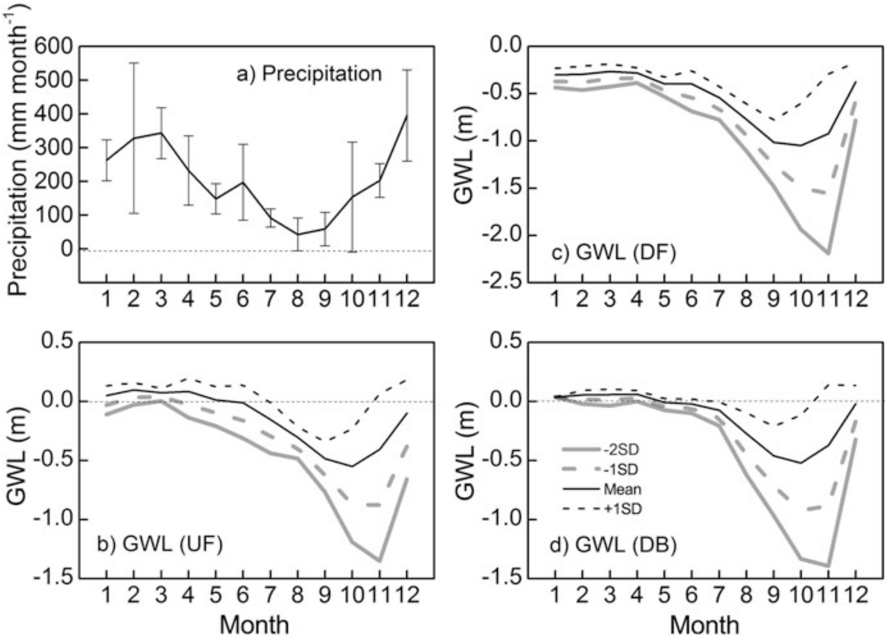


Fig. 21.7 Seasonal variations in monthly values of precipitation (**a**) and groundwater levels (GWL) at the UF (**b**), DF (**c**), and DB (**d**) sites. *Vertical bars* denote ±1 standard deviations for 4 years. Four scenarios of groundwater levels (GWL) are applied to each site

Figure 21.8 shows seasonal variations in CO_2 fluxes and the contribution of RS to RE (RS/RE). The monthly-mean NEE at the UF site was slightly negative from February through April under the Mean scenario and from December through June under the +1SD scenario (Fig. 21.8a). In contrast, the monthly NEE was always positive at the DF and DB sites even under the +1SD scenario (Fig. 21.8b, c). As a result, annual NEE was only negative (-61 gC m^{-2} $year^{-1}$), suggesting the UF site to be a CO_2 sink, under the +1SD scenario among the 12 combinations (= 3 sites × 4 scenarios). The NEE increased from the mid- to late dry season (September–November), typically in El Niño years, following the seasonal variations of the GWL (Fig. 21.7b–d). The differences in NEE between the Mean and −2SD scenarios became large in the period. In November, the differences reached 8.26, 8.45, and 2.60 gC m^{-2} day^{-1} for the UF, DF, and DB sites, respectively. This suggests that the annual NEE depends on the NEE in this period from September to November with large interannual GWL fluctuations.

The effect of GWL variations on RE was also larger in the period between September and November, similarly with that on NEE. At the UF and DB sites, however, even small GWL variations in the rainy season (Fig. 21.7b, d) affected RE considerably (Fig. 21.8d, f), because the GWL rising above the ground level decreases RE sharply (Hirano et al. 2012). In contrast, the effect of GWL variations was very limited in the rainy season at the DF site (Fig. 21.8e), where the GWL

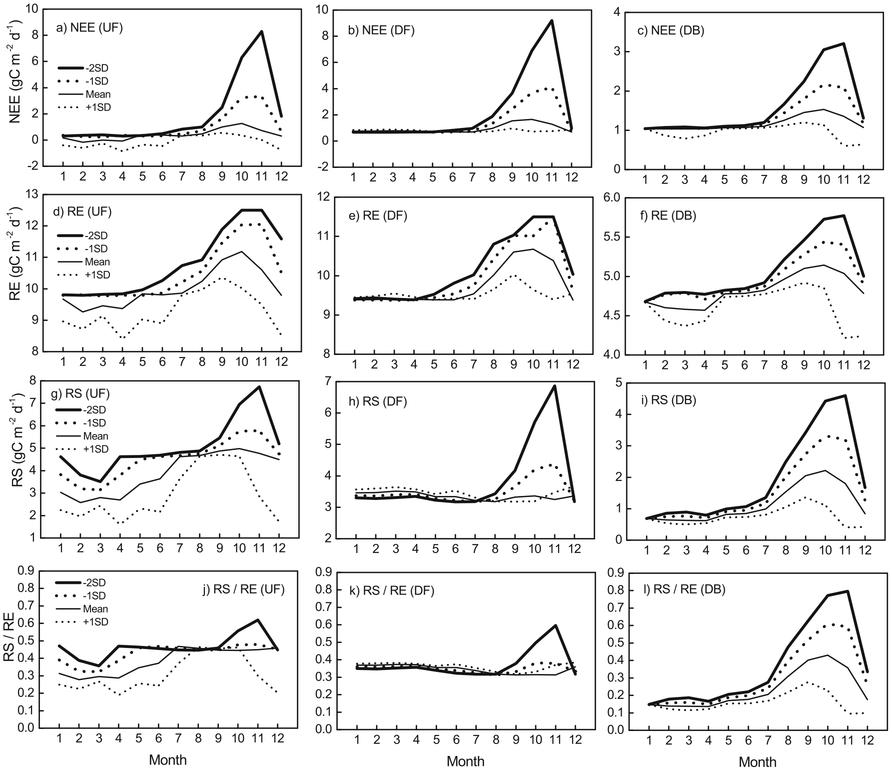


Fig. 21.8 Results of simulations under four scenarios of groundwater levels (GWL) for net ecosystem CO_2 exchange (NEE) (**a**, **b**, **c**), ecosystem respiration (RE) (**d**, **e**, **f**), soil respiration (RS) (**g**, **h**, **i**), and the contribution of RS to RE (RS/RE) (**j**, **k**, **l**) at the UF, DF, and DB sites

variation maintained GWL below the ground level. The RE differences in November between the Mean and −2SD scenarios were 1.90, 1.11, and 0.73 gC m^{-2} day^{-1} for the UF, DF, and DB sites, respectively; these account for only 13 % (DF) to 28 % (DB) of the differences in NEE. In the late dry season, typically in El Niño years, large-scale fires occur often in this area because of the low GWL, and dense smoke from the fires shades the ground. As a result, GPP decreases owing to the attenuation of solar radiation due to smoke shading and water stress due to low soil moisture, especially at the DB site (Hirano et al. 2012). The result was that the large increase in NEE due to low GWL in October and November probably resulted both from increases in RE and decreases in GPP.

The seasonal variation of RS was similar to that of RE at the UF site (Fig. 21.8g), whereas the RS variation was similar to that of NEE at the DF and DB sites (Fig. 21.8h, i). The effect of the GWL variation on RS was much larger than that on RE. The RS differences between the Mean and −2SD scenarios were 2.97, 3.61, and 2.80 gC m^{-2} day^{-1} for the UF, DF, and DB sites, respectively, in November.

Consequently, the contribution of RS to RE (RS/RE) increased in the September–November period and peaked in November under the −2SD scenario at 0.62, 0.60, and 0.80 for the UF, DF, and DB sites, respectively (Fig. 21.8j–l). Although root respiration was excluded from RS at the DB site (Hirano et al. 2014), the DB site had the largest RS/RE during the dry season under the – SD and −2SD scenarios. In the rainy season, however, the DB site had the lowest RS/RE (Fig. 21.8l). The UF site showed the largest seasonal variation in the RS contribution under the +1SD scenarios, ranging from 0.19 in April to 0.46 in October. At the DF site, except for the −2SD scenario, the RS contribution to RE showed low seasonality ranging between 0.31 and 0.38 (Fig. 21.8k).

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Chapter 22
Methane and Nitrous Oxide Emissions from Tropical Peat Soil

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Helena Lina Susilawati, and Kazuyuki Inubushi

Abstract Results of observations in Central Kalimantan, Indonesia clearly indicate that land use changes caused by drainage, fire, and agricultural practices change the methane (CH_4) and nitrous oxide (N_2O) emissions from tropical peatlands significantly. The CH_4 emissions were higher in burned area and croplands than in natural forests. The N_2O emissions were considerably higher in croplands than in natural forests, although there were no significant differences in N_2O emissions between burned areas and natural forests. In croplands, the N_2O flux was significantly correlated with the carbon dioxide (CO_2) flux. However, the CO_2 flux in croplands was not correlated with microbial biomass carbon (MBC), while this was significantly correlated in forests. These results indicate that agricultural land use of tropical peatlands varied the controlling factors of the greenhouse gas emissions through microbial activities. Peat fires were also a significant source of CH_4 and N_2O as well as CO_2. Linear correlations of the concentrations of CH_4, N_2O, and also carbon monoxide (CO) to CO_2 indicated that the molar ratios of CO, CH_4 and N_2O to CO_2 in the gas emissions through peat combustion are 0.382, 0.0261 and 0.000156, respectively.

Keywords CH_4 • Fire • Land use change • Microbial activity • N_2O

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22.1 Introduction

Tropical peatlands in Southeast Asia cover 24.8 million ha, which is only 6 % of the global peatland area, but they store 68.5 Pg of carbon (C), which is 11–14 % of the global peat C storage (Page et al. 2011). This shows that tropical peatlands are huge nitrogen (N) reservoirs. Therefore, if environmental conditions were changed by land use changes with drainage, fire, and agricultural practices, tropical peatlands may become a major source of not only CO_2 but also CH_4 and N_2O.

In recent decades, considerable areas of peatland in Southeast Asia have been reclaimed to support agroforestry and rice paddy development. The deforestation and development of peatlands involved are usually accompanied by drainage changes, releasing much C through aerobic peat decomposition. In addition, the water table level may drastically decrease in El Niño and Southern Oscillation (ENSO) years, increasing the incidence of large scale peat fires in Southeast Asia. The average annual C releases by peat fires during 2000–2006 from Indonesia, Malaysia and Papua New Guinea was estimated to be 0.128 ± 0.051 PgC year^{-1} (van der Werf et al. 2008), comparable to the emissions from fossil fuel combustion in these countries.

The range of CH_4 emissions from tropical peatlands has been reported to be one fifth of that in temperate and boreal peatlands (Couwenberg et al. 2010). The low CH_4 emission is attributed to the poor quality of the woody tropical peat, which contains higher levels of hardly decomposable components such as lignin. Also, the oxygen supply through the roots of vascular plants in wetlands contributes to oxidize CH_4 produced in the peat (Adji et al. 2014). This is a reason why the CH_4 emissions in burned areas with little vegetation are higher than in forests (Jauhiainen et al. 2008).

The N_2O emissions from agricultural tropical peatlands have been reported to be very variable compared with those from agricultural boreal peatlands. The estimated values range from −1.1 to 858 kg N ha^{-1} year^{-1} in tropical peatlands (Terry et al. 1981; Inubushi et al. 2003; Hadi et al. 2005; Takakai et al. 2006; Melling et al. 2007; Toma et al. 2011), while the range is from 0.1 to 37 kg N ha^{-1} year^{-1} in boreal peatlands (Maljanen et al. 2003; Regina et al. 2004; Klemedtsson et al. 2005). Although a very high N fertilizer application rate (>500 kg N ha^{-1} year^{-1}) may trigger the very high N_2O emissions, similar levels of N_2O emissions were also reported for fields without N fertilizer application (Toma et al. 2011). This suggests that the source of the N_2O emissions is mineral N released with the peat decomposition, and that N_2O producing bacteria and fungi without N_2O reductase may potentially contribute to the high N_2O emissions at the fields (Hashidoko et al. 2008; Yanai et al. 2007).

In this chapter, we detail the characteristics of CH_4 and N_2O emissions associated with land use changes and during the peat burning in Indonesian tropical peatlands.

22.2 Methane Emissions from Tropical Peatlands

Methane (CH_4) emissions from tropical peatlands are relatively small compared with the CH_4 emissions from boreal Sphagnum bogs (20–150 kg C ha^{-1} $year^{-1}$, Martikainen et al. 1995; Nykänen et al. 1998). Melling et al. (2005) reported CH_4 emissions of 0.18 kg C ha^{-1} $year^{-1}$ from natural peat swamp forests established in tropical peatlands in Sarawak, Malaysia. In central Kalimantan, Indonesia, ecosystems in natural forests (DNF), regenerated forests after burning (DRF), and burned forests (DBF), which were affected by drainage, function as both CH_4 sink and source (CH_4 emission: −1.7–2.5 kg C ha^{-1} $year^{-1}$, Table 22.1). Annual variations in CH_4 emissions in tropical regions can be influenced by the variation in precipitation and water table levels, but not temperature due to the uniformity of air temperatures throughout the year. Jauhiainen et al. (2008) reported that CH_4 emissions from natural forests affected by drainage near Palangka Raya city in central Kalimantan decreased from −1.6 to 2.8 kg C ha^{-1} $year^{-1}$ after the water table level was raised by constructing dams in drainage canals. The CH_4 emissions from burned forests increased from 1.5 to 2.1 kg C ha^{-1} $year^{-1}$. These conflicting results due to changes in water table levels were discussed from the point of view of soil compaction. In drained natural forests, soil aerobic conditions and CH_4 absorption were maintained in the surface peat layer due to its porous structure. However, in drained burned forests, there may be higher soil water contents in the surface layer and the CH_4 emissions have increased due to a more compacted surface peat layer after burning. In agricultural peatlands (A–C, GL) near Palangka Raya, the interannual variations of CH_4 emissions were relatively small compared with those in DNF, DRF, and DBF, although the CH_4 emissions in agricultural peatlands were higher than those in DNF, DRF, and DBF (Table 22.1). The periodic plowing taking place in agricultural fields may cause rapid drainage after rainfall events and so retain the soil aerobic conditions, agricultural peat soil can be a CH_4 source because of CH_4 oxidation inhibition caused by frequent applications of

Table 22.1 Annual CH_4 emissions from tropical peatlands in central Kalimantan, Indonesia

	Land use type						
	DNF	DRF	DBF	A	B	C	GL
Year[a]	(kg C ha^{-1} $year^{-1}$)						
2002–2003	−0.21	−1.7	0.36	0.59	1.0	2.7	0.56
2003–2004	0.34	2.5	−0.19	0.72	2.5	93	0.25
2004–2005				1.4	1.1	0.59	0.89
2005–2006				1.3	1.8	1.4	0.9
2006–2007				1.8	1.3	2.4	2.67
Average	0.065	0.37	0.08	1.2	1.7	24	1.2
CV (%)	606	800	483	43	35	168	80

[a] From April to March. Calculation method for annual CH_4 emissions was shown by Toma et al. (2011), *DNF* Natural forest affected by drainage, *DRF* Regenerated forest affected by drainage after burning, *DBG* Burned forest affected by drainage, *A–C* Cropland, *GL* Grassland

fertilizer N and application of easily decomposable organic matter in plant residue at wetter conditions (Le Mer and Roger 2001).

22.3 Nitrous Oxide Emissions from Tropical Peatlands

Nitrous oxide (N_2O) emissions from tropical peatlands varied depending by land-use type. The N_2O emissions from DNF, DRF, DBF, and agricultural fields (A–C, GL) near Palangka Raya are shown in Table 22.2. In DNF, DRF, DBR, and GL where N fertilizer was not applied, there was a 1.6–9.8 times increase in N_2O emissions in 2003–2004 over those in 2002–2003 which shows the highest annual variation in N_2O emissions. Increasing precipitation was one of the reasons for the higher N_2O emission in 2003–2004, because annual precipitation in 2003–2004 (2,339 mm) was 17 % higher than in 2002–2003 (1,994 mm). Tropical regions have clear seasonal patterns of rainfall in the dry and rainy seasons, although the air temperature is stable throughout the year (Fig. 22.1a, Hirano et al. 2007). The N_2O flux clearly increased in the rainy season in agricultural land near Palangka Raya (Fig. 22.1b, Takakai et al. 2006; Toma et al. 2011). The amount of N fertilizer application is also an important factor for controlling N_2O emissions in agricultural areas. Multi-cultivation management (e.g. corn (*Zea mays*) and eggplant (*Solanum melongena*)) was often practiced in tropical agricultural fields. Fertilizer N amounting to 644–1,638 kg N ha^{-1} $year^{-1}$ was annually applied to agricultural areas of A–C throughout the year (three to four times per cultivation), and 11–698 kg N ha^{-1} $year^{-1}$ of N_2O was emitted from 2002 to 2007 as shown in Table 22.2. The estimated emission factor for N_2O, the percentage of emitted N_2O-N from applied fertilizer N, was 0–3.6 % (Toma et al. 2011). Therefore, a 10 % increase of N fertilizer application potentially increases the N_2O emission by up to 5.6 kg N ha^{-1} $year^{-1}$, when fertilizer N increases to 10 % of the maximum application

Table 22.2 Annual N_2O emissions from tropical peatlands in central Kalimantan, Indonesia

	Landuse type						
	DNF	DRF	DBF	A	B	C	GL
Year[a]	(kg N ha^{-1} $year^{-1}$)						
2002–2003	0.62	0.40	0.97	131	21	83	7.1
2003–2004	4.4	4.0	1.5	259	52	151	23
2004–2005				416	52	36	31
2005–2006				627	13	74	66
2006–2007				698	11	163	32
Average	2.5	2.1	1.2	306	68	101	32
CV (%)	106	115	32	38	123	53	68

[a] From April to March, the Calculation method for the annual CH_4 emission was shown by Toma et al. (2011), DNF: Natural forest affected by drainage, *DRF* Regenerated forest affected by drainage after burning, *DBF* Burned forest affected by drainage, *A–C* Cropland, *GL* Grassland

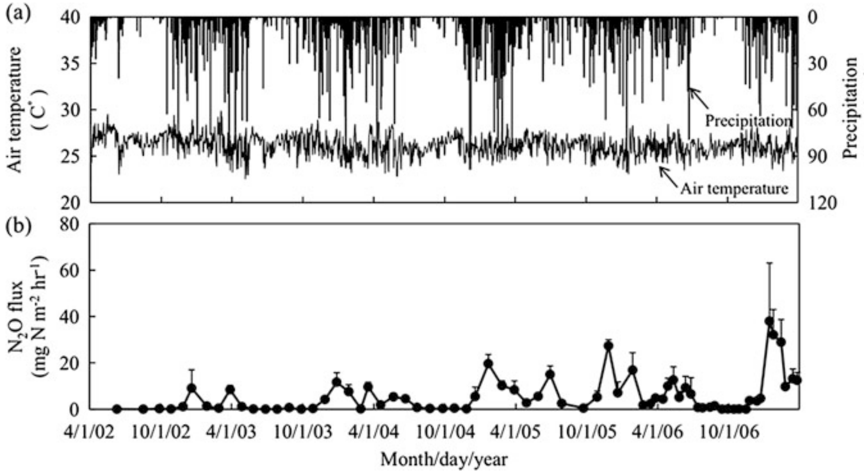

Fig. 22.1 Seasonal variation of air temperature, precipitation from Hirano et al. (2007) (**a**) and N_2O flux (**b**) from agricultural tropical peatland (Modified from Takakai et al. 2006; Toma et al. 2011) in central Kalimantan, Indonesia. *Error bars* represent standard deviations

of N (163.8 kg N ha^{-1} year^{-1}) and the N_2O emission factor is 3.6 %. The N_2O emission arising from soil organic matter decomposition is also an important process contributing to N_2O emissions from agricultural land in tropical peatland. Toma et al. (2011) reported that N_2O emissions induced by peat decomposition was measured to be 6.6–853 kg N ha^{-1} year^{-1} in agricultural land in A–C from 2005 to 2007. Because N_2O emissions by peat decomposition in agricultural land are influenced by agricultural practices such as multiple cultivation and the fertilizer N application, it is difficult to explain the annual variation by the meteorological characteristics. As N_2O emissions by peat decomposition significantly contribute to the N_2O emissions from agricultural land, it is also difficult to explain the annual variation in N_2O emissions from agricultural land in tropical peatland. The mechanisms of these variations are still unclear, so, future study of the N_2O emissions by peat decomposition is necessary to be able to consider mitigation of N_2O emissions from agricultural land in tropical peatlands.

22.4 Microbial Biomass and Fluxes of Carbon Dioxide and Nitrous Oxide in Tropical Peatland

Both the amount and activity of microorganisms in peatland are important factors to understand the process of peat decomposition. This is because the respiration of microorganisms and nitrogen dynamics in soil such as nitrification and denitrification are the main microbial processes for carbon dioxide and nitrous oxide emissions from the soil, processes both of which are subject to land-use changes and forest management practices (Arai et al. 2014a, b). However, little investigation has been carried out on the relationships between N_2O emissions and the populations of related soil microorganisms (Jumadi et al. 2008) and the amount of the microbial biomass in tropical peatlands (Inubushi et al. 2005; Sjögersten et al. 2011). To evaluate relationships among microbial biomass C (MBC) and N (MBN), and fluxes of CO_2 and N_2O from peatlands, the fumigation-extraction method (Inubushi et al. 1991; Joergensen 1996; Arai et al. 2014a) and the closed chamber method (Furukawa et al. 2005; Hadi et al. 2005; Arai et al. 2014a, b) were employed to in situ measurements and the soil samples were collected at sites almost in the same area as described in Sect. 4.2.1 from July 2009 to March 2011. The MBC and K_2SO_4-soluble organic carbon (SOC) contents were higher in DNF than in undrained natural forests (UNF) (Fig. 22.2a, b), indicating that drainage may have enhanced microbial activity to increase the microbial biomass. Because SOC did not show any relationship with CO_2 fluxes but was related with MBC and MBN (Fig. 22.2b), it suggests that the SOC in tropical peat soils may have enhanced assimilation rather than dissimilation. Although SOC did not show a significant relationship with CO_2 fluxes in our investigation, there are several incubation experiments with the substrates induced respiration method, suggesting that an increase of substrate concentration may enhance the ratio of respiration to carbon assimilation (Sawada et al. 2008). The MBC showed a positive linear relationship with the CO_2 fluxes in forest soils but not in crop lands (Fig. 22.2a). With respect to crop land soils, the CO_2 fluxes were higher than those in forest soils despite the lower microbial biomass there, probably because of the effect of fertilization on the increases in CO_2 fluxes were larger than the effects of the vegetation changes. The CO_2 fluxes in croplands were significantly correlated

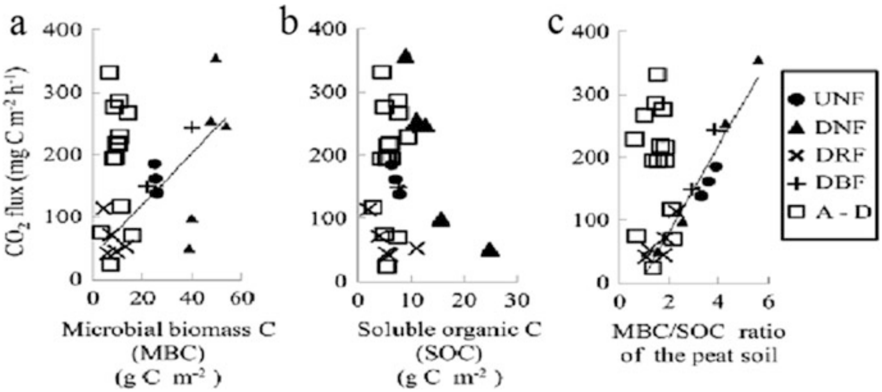

Fig. 22.2 Correlations between microbial biomass carbon (**a**), K_2SO_4-soluble organic carbon (**b**) contents in the depth of 0–10 cm, and MBC/SOC ratio (**c**) of the peat soil and CO_2 flux from the peat soils. *Solid lines* of significant ($p < 0.01$, $n = 17$) regressions are given in forests. *UNF* Undrained natural forest, *DNF* Natural forest affected by drainage, *DRF* Regenerated forest affected by drainage, *DBF* Burned forest affected by drainage, (**a**–**d**) Croplands

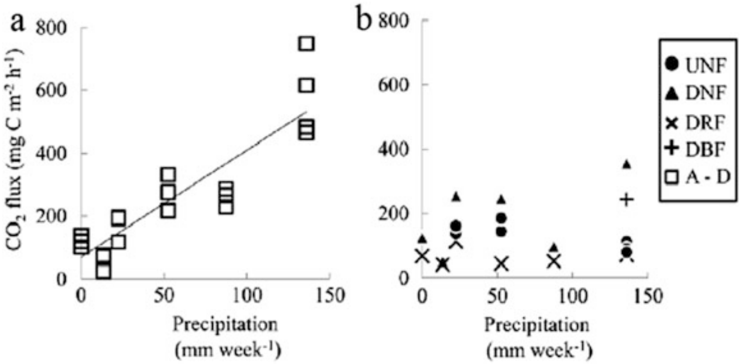

Fig. 22.3 Correlations between precipitation and CO_2 flux in (**a–d**) (**a**) and forest soils (**b**). *Solid lines* of significant ($p < 0.01$, $n = 21$) regressions are given in (**a–d**). *UNF* Undrained natural forest, *DNF* Natural forest affected by drainage, *DRF* Regenerated forest affected by drainage, *DBF* Burned forest affected by drainage, (**a–d**) Croplands

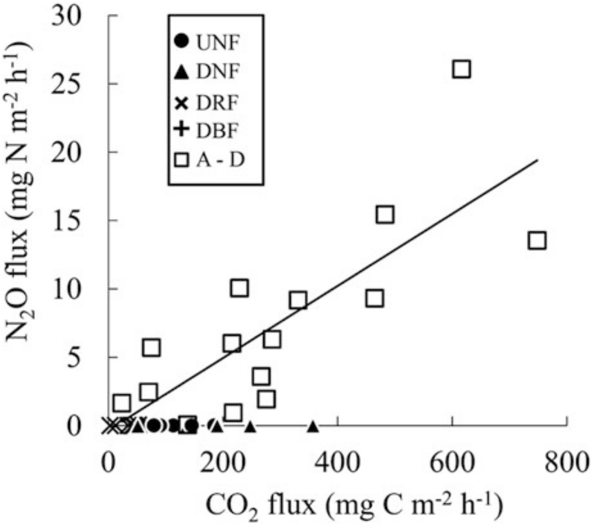

Fig. 22.4 Correlations between CO_2 fluxes and N_2O fluxes from the peatlands. *Solid lines* of significant ($p < 0.01$, $n = 21$) regressions are given in Croplands. *UNF* Undrained natural forest, *DNF* Natural forest affected by drainage, *DRF* Regenerated forest affected by drainage, *DBF* Burned forest affected by drainage; (**a–d**) Croplands

with precipitation during a week before gas sampling (Fig. 22.3a) and N_2O fluxes (Fig. 22.4), but not in the forest soils. Soluble organic carbon (SOC) showed a positive linear relationship with microbial biomass C and N and a negative linear relationship with the NO_3^- concentration (data not shown) both statistically significant. The CO_2 fluxes in forest soils were also significantly correlated with the MBC/SOC ratio (Fig. 22.2c), but not in cropland. Further, the microbial biomass N showed a significant negative relationship with most probable numbers (MPN) of ammonium oxidizers (Arai et al. 2014a). Ammonium oxidizers are generally autotrophs growing without any C source in soils (Alexander 1977). Vanitchung et al. (2011) reported that denitrification was found to be the main N_2O production pathway in all tropical forest soils except in moist evergreen forests among the examined five types of forests in Thailand. These results indicate that SOC enhanced heterotrophic N assimilation of N competitors for nitrifiers (Arai et al. 2014a). With respect to the effect of N competition in N_2O emissions, several reports also suggest that N competition may inhibit N_2O emissions (Khalil and Inubushi 2007; Wang et al. 2011). Although few reports have attempted to clarify the relationships among SOC, MBN, and N_2O fluxes, MBC and soil organic carbon has been studied to estimate N_2O emissions with the Denitrification-Decomposition (DNDC) model considering N competition (Cai et al. 2003). These results indicate that different mechanisms of tropical peat decomposition are operating in the forests and in the croplands.

22.5 Emission of CH_4 and N_2O from Biomass Burning

The combustion of biomass, which consists of wildfire and artificial biomass burning, is an important source of atmospheric CH_4 and N_2O. In case of forest fires occurring in a peatland, the above-ground biomass burning which emits extremely strong heat and light (flaming phase) lasts for relatively short periods, and the following combustion period of the fallen tree trunks and/or peat soil which more gently release heat with much smoke (smoldering phase) is longer. The production of CH_4 and N_2O is usually promoted under low temperature combustion and limited oxygen supply during the smoldering phase, relative to the higher temperature combustion with sufficient oxygen supply during the flaming phase. Consequently, the contribution of emissions of CH_4 and N_2O from tropical peatland fires to global warming would be more important than the emissions from combustion of other types of ecosystems; however, studies on fire-generated CH_4 and N_2O from tropical peatland are still few.

According to the summary of the Fourth IPCC Assessment Report published in 2007, global CH_4 emissions from anthropogenic biomass burning from the late twentieth century to the early twenty-first century were estimated as 11–66 TgC year^{-1} (Denman et al. 2007). This emission accounts for 7–14 % of the total emissions and 5–25 % of the anthropogenic emissions worldwide. Several previous studies suggested a considerable contribution of CH_4 emissions from biomass burning to the rapid increase in global atmospheric CH_4 in 1998 (Dlugokencky et al. 2001; van der Werf et al. 2004). The IPCC report also presented the evaluated global N_2O emission from the burning of biomass and biofuels in the 1990s as 0.2–1.0 TgN year^{-1} (Denman et al. 2007). This emission accounts for 1.1–5.6 % of the total emissions and 3–15 % of the anthropogenic emissions worldwide.

Previous studies have reported that N_2O is likely to be generated under the condition in which nitric oxide (NO) and sulfur dioxide (SO_2) coexist (e.g. Muzio and Kramlich 1988; Linak et al. 1990; Preto et al. 2004). In general, NO is the single most abundant species among detectable fire-generated N compounds (usually N_2 is most abundant but it's hard to detect), whereas most of gaseous form S from the combustion of plants is SO_2 (Andreae 1991). Cofer III et al. (1990) observed that N_2O concentrations in grab-samples which were obtained from a smoke plume considerably increased during storage. According to Preto et al. (2004), a detectable N_2O increase was observed within an hour after the sample collection at 25 °C in proportion with the initial concentrations of NO and SO_2. These results suggest that additional N_2O is generated during the transport from the ground-level emission source into the atmosphere in a smoke plume. Overall, to consider all chemical reactions related to N_2O at the burning condition is more important than the N_2O generation by the combustion processes alone.

Carbon monoxide (CO) generally presents the second largest gas volume produced by biomass burning. The global background level of CO was 89 ppb in 2009, higher in the Northern Hemisphere than in the Southern Hemisphere (WMO 2011). Although CO itself is not a greenhouse gas, the emission of CO indirectly affects global warming. The presence of CO may increase the lifetime of CH_4, because both gases are oxidized by photochemical reactions with OH radicals in the atmosphere (WMO 2011). In addition, CO is a precursor of tropospheric ozone (O_3), which is the third most important anthropogenic greenhouse gas (Denman et al. 2007) and a major source of OH radicals. Because biomass burning is one of the major sources of atmospheric CO, its emission from peatland fires indirectly affects the global climate. Several studies have tried to evaluate this effect as “indirect global warming potential” (e.g. Fuglestvedt et al. 1996; Johnson and Derwent 1996; Daniel and Solomon 1998). On the basis of the results reported there, the indirect 100-year GWP for CO is likely to be 1.0–3.0.

To investigate the emission characteristics of individual gases which are generated and emitted from biomass burning, the emission ratio (ER) has been widely used. The emission ratio of gas Y to gas X ($ER_{Y/X}$) is defined as the quotient of excess mixing ratios ($\Delta Y/\Delta X$), which is the ratio of the excess amount of gas Y above the background to that of gas X above the background (Christian et al. 2007). On the basis of the “CO_2-normalized” emission ratios ($ER_{Y/CO2}$), emissions of fire-generated gases are evaluated quantitatively relative to that of CO_2. For example, the ER of CO to CO_2 ($ER_{CO/CO2}$) is widely used as a reliable indicator of the relative amounts of the flaming and smoldering combustion (Radojevic 2003; Yokelson et al. 2007).

Figure 22.5 shows the relationships between the concentrations of CO_2 and other gases in smoke samples obtained at the ground level during a severe peatland fire from late September to early October in 2009 (Hamada et al. 2013). Maximum concentrations of CO_2 and CO reached nearly 2,500 and 1,000 ppmv, respectively. Those of CH_4 and N_2O were less than 100 and 1 ppmv, respectively. Concentrations of CO, CH_4, and N_2O generally increased with that of CO_2. On the basis of these relationships, the value of $ER_{Y/CO2}$ is given by the slope of a linear regression line (Helas et al. 1995; Yokelson et al. 1999).

The $ER_{CO/CO2}$, $ER_{CH4/CO2}$ and $ER_{N2O/CO2}$, which were estimated as the slope of the linear regression for the whole range of observed CO_2 values, were 0.382, 0.0261, and 0.000156, respectively (Fig. 22.5). All correlations were high ($R^2 = 0.773$–0.968) and statistically significant ($P < 0.001$). In the case of N_2O, additional analysis of the regression was carried out by dividing the CO_2 range into two parts. When CO_2 <1,500 ppmv, the correlation was not significant ($P > 0.05$).

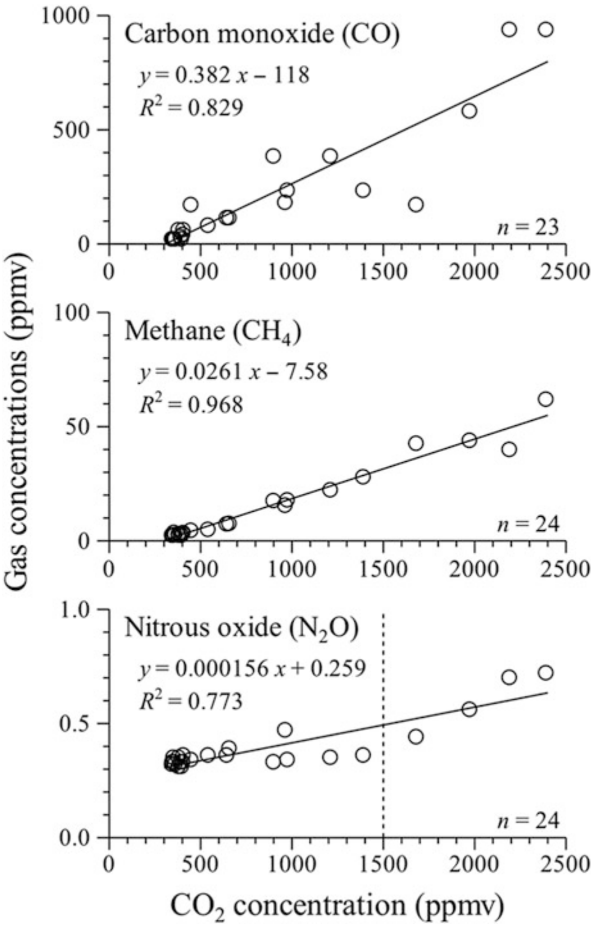

Fig. 22.5 Concentrations of CO, CH_4, and N_2O vs. that of CO_2 in the sample obtained from ground-level measurement during a tropical peatland fire (Modified from Hamada et al. 2013)

When CO_2 >1,500 ppmv, the correlation was higher ($R^2 = 0.954$) but less significant ($P < 0.05$) relative to the regression for the whole CO_2 range, because only four samples were obtained in this CO_2 range. Such a difference in the correlation of CO_2 and N_2O by dividing the CO_2 ranges may be attributed to the additional generation of N_2O during storage, as mentioned above.

Based on the $ER_{Y/CO2}$ for the whole range of observed CO_2 values, the molar ratio of all gas emissions can be simply given as CO_2:CO:CH_4:N_2O = 1.00:0.382: 0.0261:0.000156 although the value of $ER_{N2O/CO2}$ may be questioned. In Central Kalimantan, Page et al. (2002) estimated the amount of peat carbon loss by wildfires in 1997 as 120–150 TgC from the entire Mega Rice Project area (nearly 1 million ha). If it is assumed that all the carbon loss is converted to CO_2, CO, or CH_4, the emissions of CH_4 and N_2O from the 1997 fire are estimated as 2.2–2.8 TgC and 0.031–0.039 TgN, respectively. These values represent about 6.5 % and 5.8 % of the total global emissions from biomass burning for CH_4 (11–66 TgC) and N_2O (0.2–1.0 TgN), respectively.

On the GWP basis, the ER is given as CO_2:CH_4:N_2O = 1.00:0.237:0.0465. This evaluation of the GWP emissions (1.00 + 0.237 + 0.0465 = 1.28) was equivalent to 91.2 % of a simpler evaluation, in which only the total amount of gaseous carbon emissions (CO_2, CO, and CH_4) was considered and all the carbon emissions were in the form of CO_2 (i.e., 1.00 + 0.382 + 0.0261 = 1.41). The difference between the ER-based evaluation and the simple evaluation results in uncertainties in the effect of biomass burning on global warming. Overall, evaluations of peat carbon losses alone are not sufficient; it is necessary to include an evaluation of the $ER_{Y/CO2}$ of major fire-generated gases.

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Chapter 23
Carbon Stock Estimate

Sawahiko Shimada, Hidenori Takahashi, and Mitsuru Osaki

Abstract Tropical peatlands have changed their role from carbon sinks to carbon sources mainly by recent anthropogenic disturbances. It is an urgent issue to evaluate the importance of tropical peatlands as carbon stocks and to preserve the ecosystems including their carbon dynamics. Spatial distribution of carbon mass at a regional level needs to be delineated in order to utilize it in the simulation of carbon release impact of peat fires or in preservation planning strategy from a carbon dynamic perspective. In this chapter, a simple method to predict peat thickness was introduced. This pridiction method focuses on the differences in phenological characteristics due to the differences in hydroperiod and thickness of peat layer. Since the hydroperiod is a seasonal characteristic of peatlands in Southeast Asia, the phenology of the peat swamp forest was hypothesized to be a predictor of underlying peat thickness. Monthly NOAA-AVHRR data (Sep. 1992–Aug. 1993) were used to trace the fluctuation of vegetation activities among three seasonal periods. The peat swamp forests of Kalimantan was discovered to be classified into eight major phenology types and the classified map was found out be a good indicator to estimate the accumulated peat volume in peat swamp forests. According to our further estimation analysis, the carbon mass below the peat swamp forests (2.04 Mha) and the non-forest area (0.36 Mha) of Central Kalimantan peatlands were estimated to be 1.69 and 0.55 Gt C Mha^{-1}, respectively. Extrapolating these values, we estimate that ca. 27 Gt C is stored within Indonesian peat (16.90 Mha) and 29.9–67.6 Gt C within Southeast Asian peat (19.7–41.5 Mha).

Keywords Carbon density • Carbon stock • Peat thickness • Phenology type classification • Volumetric C density

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23.1 The Carbon Cycle of Tropical Peatlands

Tropical peatlands play a very important role in the global carbon (C) cycle, which is involved through the fluxes of two important greenhouse gases, i.e., carbon dioxide (CO_2) and methane (CH_4). Although the global warming potential of CH_4-C is estimated to be ca. 3.7 times larger than that of CO_2-C (Gorham 1991), most of the C flux in this amount is attributed to CO_2-C flux because the annual CO_2-C emission from peatland soil surface is ca. 1,000 times greater than CH_4-C emission (cf. Inubushi et al. 2003).

Since the C input rates have been greater than the output rates (i.e., C flux flows inward toward the ecosystems), tropical peatlands have acted as C sinks and store enormous C stocks. According to C^{14} dating study results, long term C sequestration in tropical peatlands in Borneo and Sumatra varies from 0.313 t C ha^{-1} $year^{-1}$ to 6.0 t C ha^{-1} $year^{-1}$ (Anderson 1964; Sieffermann et al. 1988; Neuzil 1997; Dommain et al. 2011). The annual net CO_2 absorption (i.e., downward flux) of the pristine and secondary peat swamp forests (PSF) in Thailand was estimated to be 5.32 and 5.22 t C ha^{-1} $year^{-1}$, respectively (Suzuki et al. 1999).

However, anthropogenic disturbances such as deforestation, drainage, cultivation, and oil palm plantation increased the C emission rate from tropical peatlands because of an enhanced peat oxidation rate and also a large amount of gaseous carbon emitted from peat fires that occurred in 1997, 2000, 2002, 2006, and 2009 (Fuller and Fulk 2001; Page et al. 2002; Hooijer et al. 2006, 2010; Koh et al. 2009). Deforestation of PSFs changes peatland ecosystems into C sources which gives a flux of ca. 9.9–15.4 t C ha^{-1} $year^{-1}$ from the bare peat surface (cf. Inubushi et al. 2003; Melling et al. 2005). Drainage disturbed PSF in Central Kalimantan was discovered to be a C releasing environment, i.e., C flux of 3.1–6.0 t C ha^{-1} $year^{-1}$ (Hirano et al. 2007). Moreover, peatland fires in the last decade transformed tropical peatlands into very serious C sources. The amount of C emissions from peat combustion which occurred during the 1997 El Niño event has been reported to be ca. 280–330 t C ha^{-1} over the Sumatra and Kalimantan regions (Page et al. 2002). Recurring peat fires during every El Niño dry season cause substantial amounts of C emissions from tropical peatland ecosystems. It is, therefore, an urgent issue to evaluate the importance of tropical peatlands as C stocks and to preserve the ecosystems including their C dynamics.

23.2 Carbon Density Characteristics of Tropical Peats

The volumetric C density (CD_V; dry C density per unit volume) of the tropical peats has been assumed to be constant in the estimations of C accumulation rates or C mass stocks (e.g., Immirzi et al. 1992; Sorensen 1993; Page et al. 2002). However, those estimated values may change a great deal according to the variability in CD_V value. In some temperate-subarctic regions, variability in bulk density (BD) and C content between different peatland types (Botch et al. 1995) or at various depths (Howard et al. 1995) have been reported and applied to the calculation of C pool estimates.

Combined data on BD and C content are needed to determine the value of $\mathrm{CD_V}$ in order to estimate spatial C mass distribution. The $\mathrm{CD_V}$ can be calculated using the following equation.

$$CD_V = BD \times CC \tag{23.1}$$

where *BD* and *CC* are dry bulk density and carbon content (dry weight percentage), respectively.

From the study of Central Kalimantan peat (Shimada et al. 2001), it has been determined that there are no vertical $\mathrm{CD_V}$ trends for tropical peat, unlike most peats in temperate regions (cf. Driessen and Rochimah 1976; Howard et al. 1995; Robinson and Moore 1999). Vertical variability in $\mathrm{CD_V}$ is mainly caused by the presence of sandy and clayey, or woody peat layers. Input of sand or clay significantly increases the peat $\mathrm{CD_V}$ as a consequence of increasing BD. These sandy or clayey peats often occur near the bottom of the peat layers if the peatland type is ombrogenous (i.e., not affected by river floods). The presence of undecomposed woody fragments within peat layers usually decreases peat $\mathrm{CD_V}$. These woody peat layers randomly exist throughout the peat thickness except near the surface. The appearance of these layers which influence peat $\mathrm{CD_V}$ value is not detectable. However, the frequency of their appearance is discovered to be dependent on the peatland type. A woody peat layer is common for ombrogenous young peatlands (cf. Sieffermann et al. 1988), but less common for old peatlands and riverine peatlands which might have been affected by the river floods, while sandy/clayey peat layers which appear vertically are common only for riverine peatlands.

Table 23.1 shows the differences in the mean values of $\mathrm{CD_V}$ of peatland types (modified from Shimada et al. 2001). Mean value of $\mathrm{CD_V}$ for young ombrogenous peats (48.7–54.4 kg $\mathrm{m^{-3}}$) was found to be significantly ($P < 0.01$) smaller than riverine peats (71.0 kg $\mathrm{m^{-3}}$) or old peats (70.9 kg $\mathrm{m^{-3}}$). The relatively greater value of old ombrogenous peat $\mathrm{CD_V}$ is explained by carbon consolidation from the longer decomposition period (Shimada et al. 2001). Since the old peats are thought to be twice as old as the young peats, the effect of longer anaerobic decomposition might be the plausible factor accounting for the physical and biogeochemical consolidation of the peat carbon.

23.3 An Estimation Equation for Peat Carbon Stocks

Total world C stocks contained in soil including peat is estimated to be between 1,395 and 1,515 Gt (1 Gt = 10^{15} g) at present (Post et al. 1982; Schlesinger 1984), although 60 Gt of soil C was assumed to have been released into the atmosphere

Table 23.1 Volumetric carbon density characteristics among different peatland types

Peatland type	N	N_{wood}	CD_V (kg m^{-3})
			Mean ± SD
Riverine	70	2	71.0 ± 16.1^a
Old ombrogenous	56	13	70.9 ± 17.3^a
Young ombrogenous	12	38	54.4 ± 12.0^b
Young ombrogenous (Neuzil 1997)	29	–	48.7 ± 6.3^b

Modified from Shimada et al. (2001)
N Number of peat samples
N_{wood} Number of woody peat samples
CD_V Volumetric carbon density
$a > b$ values followed by the same letter are not significantly different at the $P < 0.05$ significance level (Sheffé's test)

since the 'preindustrial' era (IPCC 1990). Peats contain about one-third of the mass (329–528 Gt C; Immirzi et al. 1992) of the total stock of soil C in the world. Tropical peat C stock was estimated to be 70 Gt (Immirzi et al. 1992) – 88.6 Gt (Page et al. 2011). Immirzi et al. (1992) broadly estimated the tropical peat C stock by assuming tropical peatland area to be 41.5 Mha and C density per unit area (CD_A) to be 1.69 Gt Mha^{-1}. Whilst, Page et al. (2011) reviewed the available inventories at country/regional levels and recalculated the best estimate by assuming the area to be 44.1 Mha and volumetric C density (CD_V) to be 50.4 kg m^{-3}, and revising each country's best peat thickness estimates (e.g., Indonesian peat to be 5.5 m deep).

Page et al. (2011) estimated the best C stock for 24.78 Mha of Indonesian peat at 57.367 Gt (maximum estimate at 58.33 Gt) using the above estimate parameters. Sorensen (1993) estimated the C stock for 27.0 Mha of Indonesian peat at 15.93–19.29 Gt by assuming a CD_V of 60.9 kg m^{-3} and peat volume of between 261.5 and 316.7 km^3. However, the spatial distribution on a regional scale of C mass is not fully understood. Spatial distribution of carbon mass at a regional level (CD_A) needs to be delineated in order to utilize it in the simulation of C release impact of peat fires or in preservation planning strategy from a C dynamic perspective.

Since CD_V variability was assumed to be dependent only on peatland type for tropical peats, the estimation equation of peat C stock can be simply derived from multiplying peat volume by peat CD_V. In order to be able to map the spatial distribution of regional C mass, area is divided into grid cells (Fig. 23.1) and total C mass is set to be derived by summing every C mass value within a cell (i.e., CD_A). Thus, the estimation equation of total C mass can be expressed by the following equation,

$$TC = \sum_{i=1}^{n} A_i CD_{Vi} \sum_{j=1}^{m} d_{ij} \tag{23.2}$$

where *TC* is the total mass of carbon stocks, *A* is peatland area, *d* is peat thickness, CD_V is volumetric carbon density of peat, *n* is the number of patches of peatland

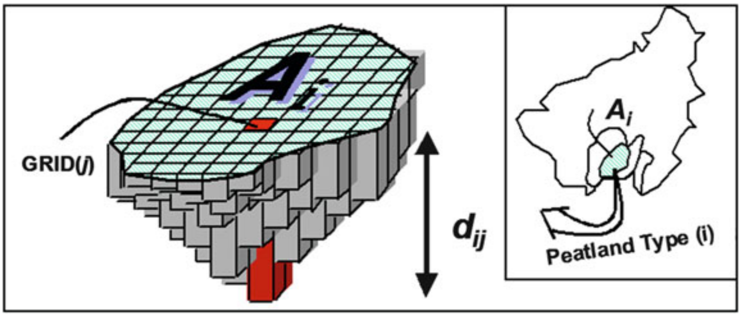

Fig. 23.1 Schematic image of carbon stock estimation model, where *A* peatland area, *d* peat thickness, *i* number of peatland type patches, *j* number of grid cells (After Shimada 2001)

type, *m* is number of grid cell or the class of the surrogate predictor for peat thickness estimation. It is obvious from the Eq. 23.2 that detailed distribution maps of peatland type and of peat thickness at regional levels are needed for accurate C stock estimation.

23.4 Areal Extent of the Tropical Peatlands

Estimates of the areal extent of tropical peatland varied considerably owing to a lack of data. Armentano and Menges (1986) suggested that tropical peatlands covered more than 44 Mha. Compiling the reports of Driessen (1978) and Maltby and Immirzi (1993), estimates for the tropical peatland area of Southeast Asia including Papua New Guinea are between 19.7 and 33.3 Mha (Table 23.2). Recently, review work with a revised best estimate value of 24.78 Mha was provided by Page et al. (2011). Using a GIS approach with GIS data (ESRI 1993), we calculated the tropical peatland area of Southeast Asia at 33.5 Mha (Fig. 23.2a, Table 23.2). With the same approach but assigning the Histosols area of Southeast Asia (FAO 1994), we obtained an area of 24.3 Mha (Table 23.2). The scales of the maps derived by ESRI (1993) and FAO (1994) are 1:1,000,000 and 1:5,000,000, respectively. More detailed maps are needed for accurate peatland area estimation for all of Southeast Asia. Such maps have been developed for all of Indonesia at 1:250,000 scale by RePPProT (1985–1989) and Wetlands International (2003–2006), who estimated the area of Indonesian peatland respectively at 16.9 Mha and 20.6 Mha by calculating from these maps (see Chap. 32).

In order to reflect CD_V variability for C stock estimation, a peatland type distribution map derivation is needed. Currently such map is only available in Indonesia (Fig. 23.2b; RePPProT 1985–1989; Shimada et al. 2001) at present. Using these peatland type maps, it is possible to evaluate the C resource precisely and presuppose a more detailed distribution of C within tropical peats.

Table 23.2 Estimates of tropical peatland area in Southeast Asia

Peatland area (Mha)	ESRI (1993)[a]	FAO (1994)[b]	Maltby and and Immirzi (1993)[c]		Page et al. (2011)[d]
			Lower	Higher	
Indonesia	27.3	21.3	17.0	27.0	20.7
Malaysia	3.28	2.70	2.25	2.73	2.59
Brunei	0.03	0.16	0.09	1.65	0.091
Philippines	0.26	–	0.10	0.24	0.065
Thailand	0.26	0.05	0.07	0.20	0.064
Vietnam	1.24	0.17	0.18	1.50	0.053
Myanmar (Burma)	0.82	–	–	–	0.123
Cambodia	0.30	–	–	–	–
Laos	0.01	–	–	–	–
Papua New Guinea	3.56	0.52	0.50	2.89	1.10
Total Southeast Asia	33.54	24.34	19.70	33.32	24.78

Sources: Driessen (1978), ESRI (1993), FAO (1994), Maltby and Immirzi (1993), Driessen (1978), and Page et al. (2011)

[a] Calculated from Digital Chart of the World (ESRI 1993)

[b] Calculated the area of Histosols from Digitized Soil Map of the World (FAO 1994)

[c] Modified from Maltby and Immirzi (1993) and Driessen (1978)

[d] Best estimates from Page et al. (2011)

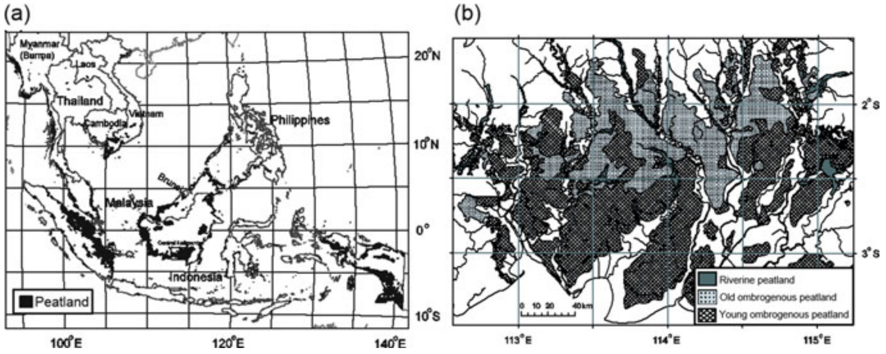

Fig. 23.2 Distribution maps of (**a**) peatland area in Southeast Asia (ESRI 1993), and of (**b**) peatland type in Central Kalimantan

23.5 Prediction of Peat Thickness

The variation of peat thickness value, which reach sometimes up to 10–20 m deep in tropical regions (Bruenig 1990; Page et al. 2002), affects the calculation of C stock estimation in a linear fashion (cf. Eq. 23.2). Hence it is utmost important to estimate peat thickness distribution for deriving an accurate estimate of C mass within tropical peatlands. RePPProT (1985–1989) and Wetlands International (2003–2006) published the maps of peat thickness within their attribute tables for Indonesia (Figs. 23.3 and 23.4). Jaenicke et al. (2008) also derived a peat thickness

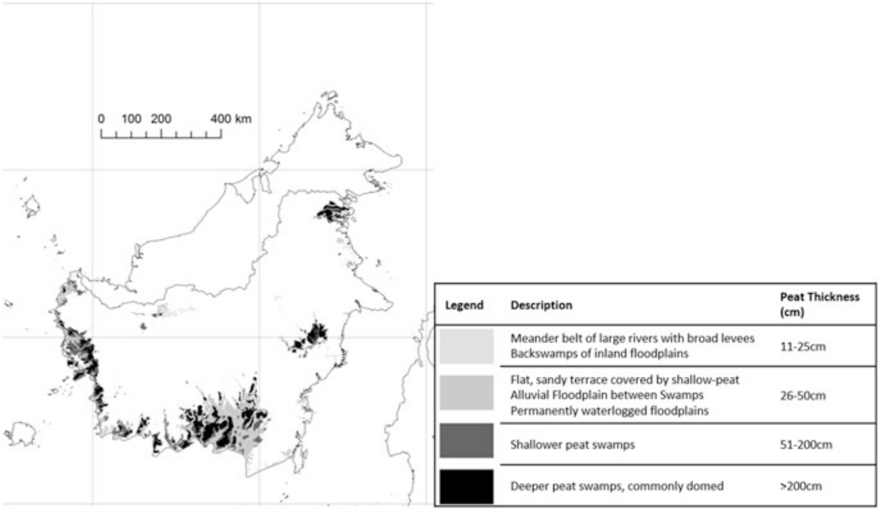

Fig. 23.3 Distribution map of peatland distribution with peat thickness category (RePPProT 1985–1989)

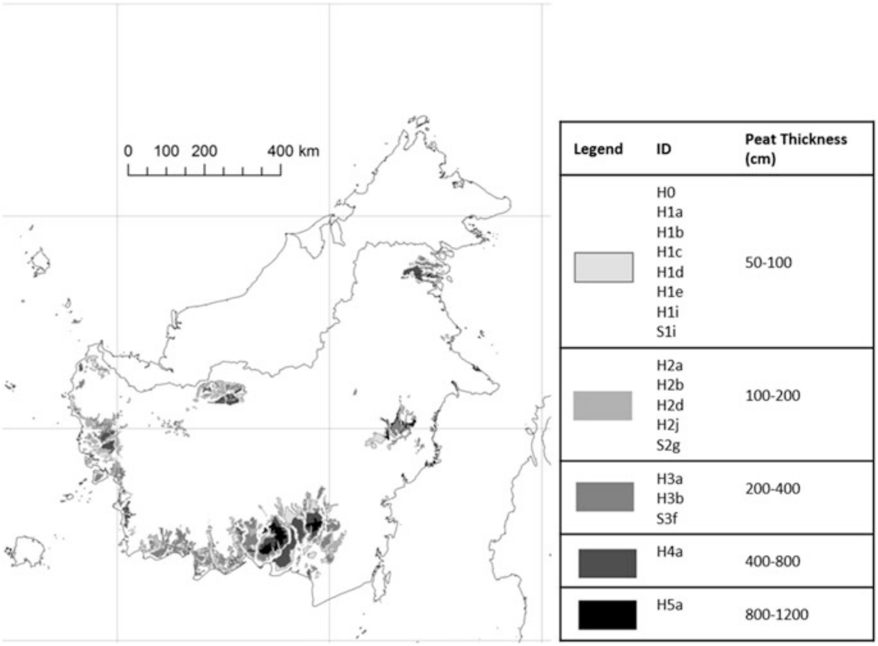

Fig. 23.4 Distribution map of peatland distribution with peat thickness category (Wetlands International 2003–2006)

distribution map for Central Kalimantan. However, those peat thickness data weren't derived from methods that can be extrapolated and applied to other regions since the estimates were derived only by interpolation methods with empirical observations. Shimada (2003) and Shimada et al. (2004) reported that peat thickness can be predictable by the forest phenology type above the peat layer. This pridiction method focuses on the differences in phenological characteristics due to the differences in hydroperiod and thickness of peat layer. Since the hydroperiod is a seasonal characteristic of peatlands in Southeast Asia, the phenology of the peat swamp forest (PSF) was hypothesized to be a predictor of underlying peat thickness (see also Chap. 32). One-year period of the vegetation index (e.g., NDVI) calculated from multi-temporal (1992–1993) monthly NOAA Advanced Very High Radiometers (AVHRR) data are used to trace the fluctuation of vegetation activities among three seasonal periods (i.e., WET1: Sep. 1992–Jan 1993, WET2: Feb.–June 1993, DRY: July–Aug. 1993). The PSFs of Kalimantan was discovered to be classified into eight major phenology types (viz. PHIL, W1, W2, W2D-A, W2D-Z, W1D, PHOB-Z, PHOB-V) (Table 23.3). The classified map of phenology types (Fig. 23.5a) had been found out to be a good indicator to estimate the accumulated peat volume in peat swamp forests.

The root mean square error (RMSE) for the peat thickness estimation map, derived by assigning each associated mean peat thickness value (cf. Table 23.3, Fig. 23.5a) in Central Kalimantan, is calculated at 2.49 m. Considering the distribution map of CD_V (Fig. 23.2b), with weighting on the areal extent, mean CD_V and CD_A for each phenology type were calculated here (Table 23.3).

In order to reduce the observed RMSE, here we considered topographic features that were hypothesized might also influence peat thickness, specifically, slope, convexity index (CVI), and distance to river (D_r). These were computed from the GIS data layers (derived from maps of BAKOSURTANAL 1997). The CVI was defined by the following equation.

$$CVI = h_{Mean} - \frac{h_{Max} + h_{Min}}{2} \tag{23.3}$$

where h_{Mean}, h_{Max}, and h_{Min} are mean, maximum, and minimum, elevation value, respectively, within a 2-km radius circle from the focal point. The absolute value of CVI represents the degree of convexity ($CVI > 0$) and concavity ($CVI < 0$). Each of the three topographic factors was divided into three categories as follows: slope of <0.03°, 0.03–0.05°, and >0.05°, CVI of <0, 0–0.35, and >0.35, and D_r of <2 km, 2–5 km, and >5 km. Peat thickness over a PSF area in Central Kalimantan was predicted from both phenology and topographic factors (items) using quantification theory type I (Hayashi 1959). The prediction model was defined by the following equation.

$$d = X_s + X_r + X_c + X_p + 1.31 \tag{23.4}$$

Table 23.3 Phenological pattern, mean peat thickness, percentage of areal extent, mean volumetric carbon density (CD_V), and carbon density at unit area (CD_A) among eight peat swamp forest types in Central Kalimantan

Phenology type	Phenological pattern[a]					Mean peat thickness (m)	Percentage of areal extent (%)	Mean CD_V ($kg\ m^{-3}$)	CD_A ($Gt\ Mha^{-1}$)
	WET1 → WET2 → DRY								
PHIL	1	(+) (−)	1	(−)	0	0.75	0.5	63.7	0.48
W1	1	(−)	0	(+) (−)	0	–	0.8	63.0	–
W1D	1	(−)	0	(+)	1	$1.56^{b, c}$	9.1	59.7	0.93
W2	0	(+)	1	(−)	0	$4.70^{a, b}$	6.4	64.2	3.02
W2D-A	0	(+)	1	(−)	1	4.59^{a}	13.6	62.5	2.87
W2D-Z	0	(+)	1	(+)	1	2.64^{b}	47.2	60.8	1.60
PHOB-Z	0	(+)	0	(+)	1	1.35^{c}	13.3	59.2	0.80
PHOB-V	0	(−)	0	(+)	1	0.84^{c}	9.1	58.6	0.49

WET2: period of latter half rainy season (Feb.–Jun. 1993)
DRY: dry season and the second half (July–August 1993)
0: NDVI at a seasonal period is smaller than 1 year mean NDVI
1: NDVI at a seasonal period is greater than 1 year mean NDVI
(+): the gradient between seasonal period is positive
(−): the gradient between seasonal period is negative
a > b > c: values followed by the same letter are not significantly different at the $P < 0.05$ significance level (Sheffé's test)
[a] WET1: period of former half rainy season (Sep. 1992–Jan. 1993)

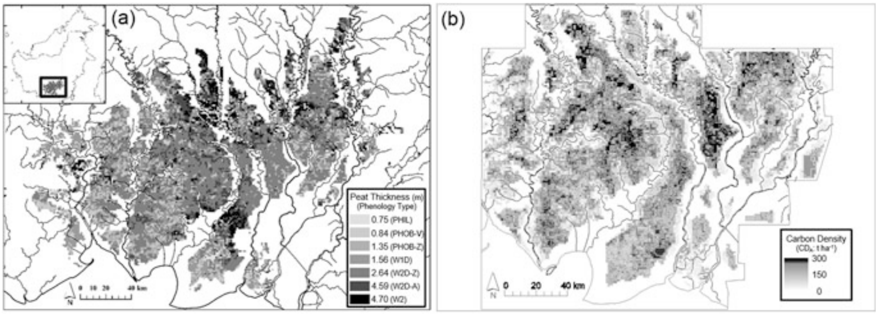

Fig. 23.5 Distribution maps of (**a**) forest phenology type with each corresponded mean peat thickness value, and of (**b**) estimated carbon density per unit area of peatlands in Central Kalimantan. The peat thickness estimation model was conducted only within the enclosed polygon area where the topographic data was available

where d is peat thickness (m), X_s, X_r, X_c, and X_p are category scores for slope, distance to river, CVI, and phenology, respectively. The category scores are shown in Table 23.4. The category score of the W1 phenology type was defined as 0, since there was no ground-truth data. However the coefficient of determination was 0.38; the accuracy of predicted peat thickness was improved (RMSE = 2.32 m) by using this model. Individually, the RMSE of W2, W2D-A, and W2D-Z phenology type were reduced to 2.04 m, 2.80 m, and 2.57 m, respectively. Yet, we found it difficult to explain the variability of peat thickness, especially for deep peat layers, only by topographic and forest type factors on a local level.

23.6 Estimates of Peat Carbon Stocks in Southeast Asia

Accumulated C mass within the peat can be computed (Fig. 23.5b) integrating estimated peat CD_V (Fig. 23.2b) and peat volume distribution derived by summating the multiplied estimated peat thickness (Eq. 23.4) by specific area (see Eq. 23.2). Multiplying the CD_V values by the peat volume distribution, the C mass below the PSF (2.04 Mha) and the non-forest area (0.36 Mha) of Central Kalimantan peatlands were estimated to be 1.69 and 0.55 Gt C Mha^{-1}, respectively. Extrapolating these values to the whole of Indonesian peatland area (16.90 Mha; RePPProT 1990) and assuming that the C density distribution of Indonesian peats is similar to that observed in the Central Kalimantan site (see Fig. 23.5b), we estimate that ca. 27 Gt C is stored within Indonesian peat. Expanding these assumptions to the 19.7–41.5 Mha Southeast Asian peatlands (cf. Table 23.2, Immirzi et al. 1992), it is estimated that as much as 29.9–67.6 Gt C may be stored within Southeast Asian peat.

The tropical peat C mass values per unit area (CD_A) estimated here are comparable to previous estimates (Immirzi et al. 1992; Sorensen 1993; Page et al. 2002; 2011). However, an important demonstration of this estimation model

Table 23.4 Category scores and statistics of each factor for peat thickness estimation model in Central Kalimantan

Item	Category	Category score	Number of ground-truth	Score range	Correlation coefficient	Partial correlation coefficient
Slope	<0.03°	0.01	326	0.23	0.05	0.06
	0.03–0.05°	−0.11	351			
	>0.05°	0.12	297			
Distance to river	<2 km	−0.34	423	1.49	0.43	0.31
	2–5 km	−0.25	350			
	>5 km	1.2	201			
Convexity index	<0	−0.10	362	0.17	0.10	0.04
	0–0.35	0.05	363			
	>0.35	0.07	249			
Phenology type	PHIL	−1.1	2	3.93	0.55	3.93
	W1D	0.08	35			
	W2D-Z	1.11	190			
	W2D-A	2.82	48			
	W2	2.54	14			
	PHOB-Z	−0.14	63			
	PHOB-V	−0.47	42			
Non-forest area[a]		−0.68	580			

[a] Non-forest area indicates peatland area with no forest cover and was included as a category in the item of phenology type for the estimation model

(Eqs. 23.2 and 23.4) is the integration of surface observations, remote sensing and GIS technologies to predict distribution maps at regional scales of peat volume and accumulated peat C mass (cf. Fig. 23.5b). Such maps offer promise to aid in the planning of limiting disastrous C emissions from tropical peatlands. For example, had such maps been previously available, decision makers may have avoided or redirected construction of the canal trench in the Central Kalimantan peatlands, in which the resulting lowering of peatland groundwater levels increased aerobic decay and burning and thus brought on extensive C emissions.

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Chapter 24
Evaluation of Disturbed Peatland/Forest CO_2 Emissions by Atmospheric Concentration Measurements

Gen Inoue and Masahiro Kawasaki

Abstract Due to its portability in the field measurement of hot fires, a fiber Fabry-Perot interferometer was used to measure CO_2 emissions from locations over a wide area and unpredictable local sources in forest/peatland fires near Parangka Raya, Indonesia, during the dry season of 2011. For nocturnal CO_2 emission measurement from peatlands, a cost-effective methodology is proposed, with which data processing is easier than the conventional eddy covariant and chamber methods. With the tempearture-inversion trap method the CO_2 flux from the peatlands in Parangka Raya was measured in 2013.

Keywords MRV • Fiber optics • Latent flux • Inversion layer • Trapping

24.1 Introduction

Wildfires and land-use changes are important sources of greenhouse gases. The loss of forest carbon stock by fire can be recovered in a relatively short time, several tens of years, in general. However, since the carbon in peatlands has accumulated during some centuries, the peat carbon loss is as important as fossil fuel consumption, or worse than fossil fuel use as it does not produce any usable energy. Action taken to suppress peat carbon loss, which is caused by either peatland fire or microbial conversion to carbon dioxide in an aerobic environment, should be easier than the suppression of fossil fuel use. In order to evaluate the amount of carbon reduction achieved by peatland conservation, the methodology to draw the business as a usual base line, and the amount of emission reduction, MRV (Measurement, Reporting and Verification) by this activity should be developed.

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The amount of emission must be measured at first, and compared with a model to describe the emission rate by parameters that are related to natural variability and human activity. The natural variables which control fire probability and aerobic respiration are those related to water cycle parameters; rain fall, ground water level, surface soil moisture and land-cover (Hooijer et al. 2010; Sundari et al. 2012). The human activities are land-use changes, construction of drainage systems, and wild fires started by land-clearing fires.

The CO_2 flux from a flat and homogeneous land area can be measured by a micrometeorological method called the eddy covariant method which measures vertical flux, from the ground to the atmosphere, by a covariance measurement of vertical wind velocity and CO_2 concentration. This continuous operation method is accurate, but is limited to homogeneous emission, and hence, not applicable to inhomogeneous emission from a point source such as a fire. The other reliable method for soil respiration called the chamber method measures the concentration increase in a box covering the land surface, and is very local.

In this report, we propose the horizontal flux method to measure CO_2 flux from fire, and also the nocturnal temperature-inversion layer trap method to measure soil flux including smouldering underground fire.

24.2 Measurement of Horizontal CO_2 Flux from Forest/Peat Land Fire: The Lateral Flux Method

Horizontal CO_2 flux in a plume can be calculated by multiplying wind velocity and concentration at a point and integrating over the cross section of the plume as schematically explained in Fig. 24.1. The CO_2 emissions from an area of interest can be measured from the difference in the fluxes passing through a screen downwind

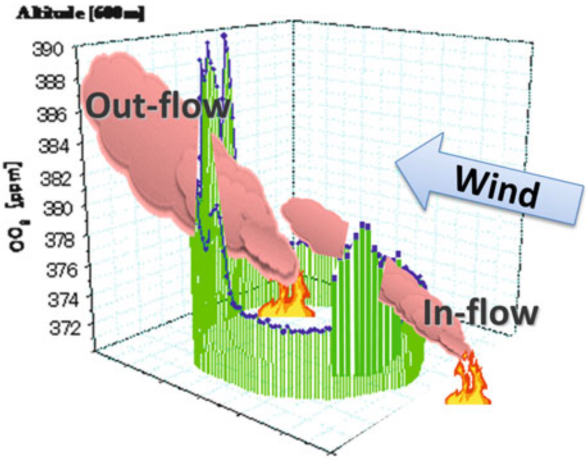

Fig. 24.1 The latent flux method for estimating total CO_2 emitted from a targeting area. *Vertical bars* indicate xCO_2 mixing ratios measured by an observation network that surrounds the targeting area where forest/peatland fires occur. By factoring the difference in CO_2 mixing ratios at out- and in-flow points, along with fluxes of air mass, the total amount of CO_2 emitted in the area can be determined

and upwind. This simplification is appropriate even if a number of observation points are practically impossible to place on the entire screen during the fire period.

We describe a compact instrument for measuring atmospheric CO_2 columns, utilizing commercially available fiber optics and a fiber Fabry-Perot interferometric spectrometer called FES-C (Fiber Etalon Sun-photometer for Carbon dioxide, Meisei Electric Co.) (Kobayashi et al. 2010) Wilson et al. reported a CO_2 column spectrometer, in which they used a glass optics and a solid glass Fabry-Perot interferometer (Wilson et al. 2007). In our FES-C instrument, sunlight is collimated through an optical filter by a fiber collimator installed on a small sun tracker, and then, it is split into two optical components; one component is the CO_2 spectrometer and the other is a light detector for correcting the spectrum intensity due to solar intensity fluctuation. The CO_2 rotational lines centred at 1,572 nm are analysed with the fiber interferometer that has a temperature coefficient toward the transmittance wavelength. This allows the solar light wavelength passing through the interferometer the ability to be on- and off-aligned with the CO_2 rotational lines by controlling the temperature. The I_0 and I values in the Beer-Lambert law equation are deduced by modulating the temperature in 40 s/cycle, which allow measurement of $x\mathrm{CO}_2$ with the precision of less than 1 ppm under clear sky conditions. The practical usefulness at a surface monitoring site was examined in parallel with a high resolution Fourier transform spectrometer situated at the Moshiri Observation Site of Nagoya University as well as in-situ measurements by an air-born spectrometer and a balloon-born CO_2 sonde.

Due to its portability in field observation, the FES-C instrument was used to measure CO_2 emission from locations over a wide area and less predictable local sources such as forest/peatland fires. As shown in Fig. 24.1, the local flux of CO_2 can be obtained if a CO_2 observation network is constructed to surround the target emission area, and air flux data are obtained. This method is called the lateral method. A campaign using the FES-C instruments in central Kalimantan, Indonesia was carried out as a part of MRV activities for carbon emission reduction. In this campaign, two sets of the FES-C instruments were deployed parallel to the predominant wind direction at Banjar Baru (in-coming flow point) and Palangka Raya (out-going flow point) in Kalimantan. CO_2 column data were automatically obtained for a 2-month period, some of which is shown in Fig. 24.2. Between 24 and 26th of August in 2011, large fires were detected by the Moderate- Resolution Imaging Spectroradiometer (MODIS) satellite, and we found differences in the $x\mathrm{CO}_2$ data between our two observation points. The difference in CO_2 emissions between the observation points can be evaluated after factoring in the $x\mathrm{CO}_2$ difference due to wind flux.

During the dry season of El Ninõ years, large-scale forest/peatland fires have a high occurrence rate in Kalimantan. It has been estimated that $(0.42–2.8) \times 10^8$ tons of CO_2 per year was emitted from wild fires over the Kalimantan archipelago between 2002 and 2011 (Page et al. 2002). The wide range of this estimate reflects the uncertainty of estimation methods. Using the present data in $x\mathrm{CO}_2$ with a combination of typical wind speed and number of hot spots counted by MODIS satellite images, we can estimate the emission is 29×10^8 tCO_2/y in 2011. Although this value looks too large, it is reasonable in view of the limited conditions, that

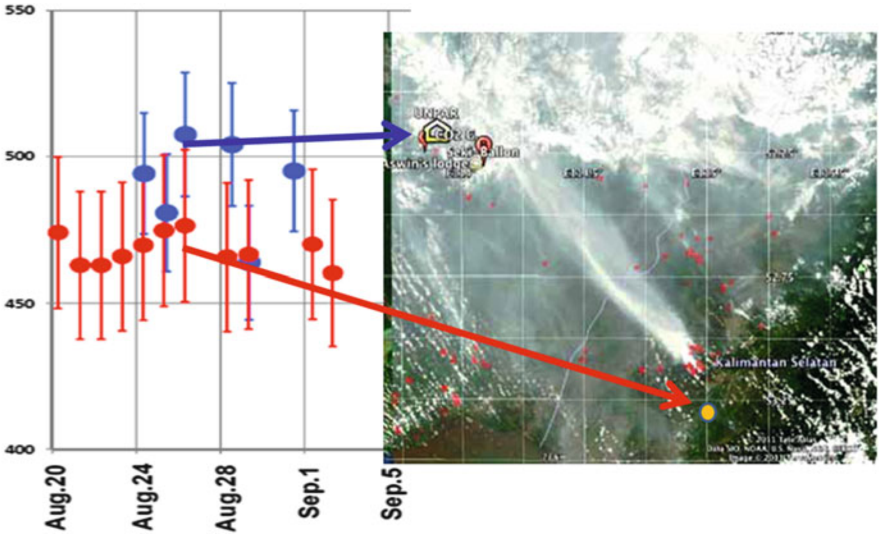

Fig. 24.2 *Vertical axis*: Variation of day-averaged CO_2 mixing ratios (ppm) measured at Parangka Raya (*blue*) and Banjar Baru (*red*), which are situated 95 km apart at 1.12°S; 113.54°E and 3.26°S; 114.50°E, respectively, in Kalimantan, Indonesia, when forest/peatland fires occurred between 20 August and 5 September 2011. The MODIS satellite image (NASA, USA) on the map (Google Maps) shows huge white smoke caused by fires on Aug. 25, 2011. *Red dots* on the image denote hot spots

is, the emission data were taken only by a pair of the FES-C instruments for one dry season. We are now reviewing and continuing to implement CO_2 emission MRV activities, and working to establish an operating structure that allows effective monitoring, especially in situations and regions where there has not yet been sufficient data collection to quantitatively assess CO_2 emissions.

24.3 Measurement of Nocturnal CO_2 Emission: The Temperature-Inversion Layer Trap Method

After trees are harvested or burned during the human action of peatland to agricultural land conversion, a large area of forest is lost. The microbial conversion from peatland soil to CO_2 is enhanced under the aerobic conditions that come about after drainage system construction. The amount of CO_2 emissions from the cold fires of dried peatland is similar in magnitude to that from the hot fires of forest/peatland (Hooijer et al. 2010; Sundari et al. 2012). Here we propose a cost-effective methodology for nocturnal CO_2 emission measurement, the data processing of which is easier than the conventional methods.

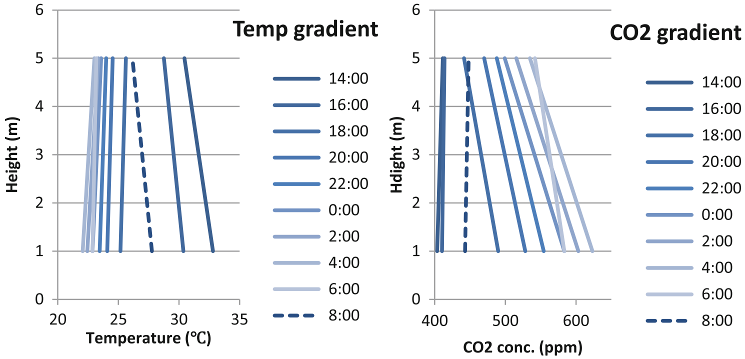

Fig. 24.3 Average temperatures and CO_2 concentrations in calm days between February and March, 2013 at Palangka Raya, Indonesia *(left)* Temperatures at 1 and 5 m height in the daytime and at nighttime. *Solid lines* represent temperature gradients at various time (*right*) Corresponding CO_2 concentrations at 1 and 5 m height

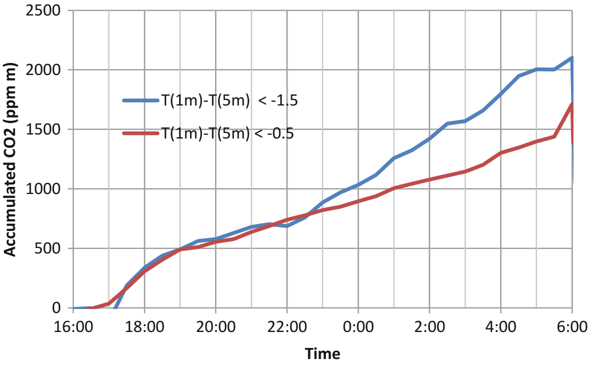

Fig. 24.4 Accumulation of CO_2 in the temperature-inversion layer vs. time in calm days. The trapped CO_2 concentration increases at the nights when the temperature gap between 1 and 5 m height is less than −0.5° (*red*) or −1.5° (*blue*)

In the daytime, CO_2 emitted from soil to air is quickly mixed with background air by heat convection. However, in the night time CO_2 remains near the surface under the temperature inversion layer. Figure 24.3a shows that temperature in the daytime at the lower position ($h = 1$ m) is higher than at the higher position ($h = 5$ m). However, at nighttime from 17:30 to 5:30, the temperature-inversion layer appeared, and disappeared at 8:00 as shown by the broken line. Figure 24.3b shows the corresponding changes in the CO_2 concentrations. The concentration at $h = 1$ m is a little lower in the daytime because of photosynthesis of surface vegetation, mainly fern, while the surface concentrations at $h = 5$ m increase at nighttime. The integrated value of the concentrations from surface to inversion top is the amount of CO_2 trapped in the temperature-inversion layer. As a simple approximation, the areas of the triangle area are calculated in Fig. 24.3b, which is composed of (1) the vertical line at the daytime concentration of 415 ppm, (2) the line connecting the concentrations at 1 and 5 m height, and (3) the horizontal line at 0 m height. Figure 24.4 shows the increase of the thus calculated amounts of CO_2 trapped at

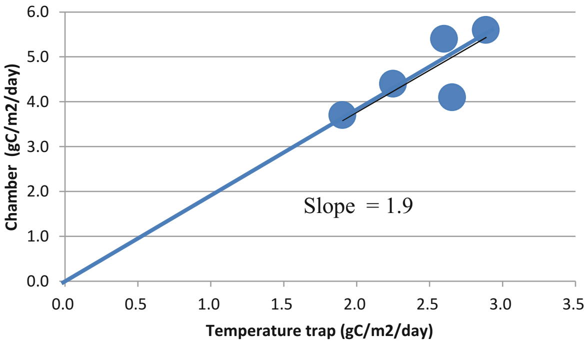

Fig. 24.5 Comparison between the same-time results of the chamber and temperature-inversion trap methods. The amounts of CO_2 trapped in the inversion layer measurements (*horizontal axis*), and those from chamber measurements after sunset (*vetical axis*) are on a line with a slope of 1.9. The *solid circles* are monthly averaged fluxes in March–August, 2013. Accumulation of CO2 taken from chamber method and inversion trap method from *sunset to sunrise* are 0.23∼1.43 gC/m^2 and 1.06 gC/m^2, respectively (Note that these values are fluxes for a half day)

nighttime when the temperature gap between 1 and 5 m height is less than −0.5° (red) or −1.5° (blue). The result of −0.5° is smaller than that of −1.5° because the temperature-inversion is weaker, and hence, the accumulated CO_2 is partially transported upward by wind, thus, CO_2 is accumulated under the inversion layer that works as an accumulation box. The slope of these lines as a function of time corresponds to the flux in ppm/m^2/day or gC/m^2/day.

We have also measured CO_2 flux with the conventional chamber method in the same observation site with the use of two chambers at a hammock and a hollow place, respectively. The flux from the hamock place was seven times larger than that from the hollow place in this season. Suppose that the total area of hamock in the entire observation field is equal to that of hollow, an average emission rate is estimated to be 57 % of the hamock data. Figure 24.5 shows a comparison between the same-time results from the chamber method at the hamock place at nighttime (vertical axis) and the nocturnal temperature-inversion trap method (horizontal axis). The flux depends on the underground water level, and the circles in the time-series figure are the data in different waterlevel periods between March and August when weather conditions changed. Figure 24.5 shows a good correlation between the results of those two different methods, as suggested by the solid line with a slope of 1.9. These results suggest that the emission rate obtained by the nocturnal accumulation method is 47 % of the flux from the rate of the hamock place, which is in good agreement with the averaged emission rate described above.

Nighttime respiration consists of microbial conversion of peat soil to CO_2 and the respiration of live surface vegetation. The photosynthesis uptake of CO_2 is added to the nocturnal flux in daytime. Since the main surface vegetation is grass, the respiration may be estimated from the typical photosyntheis process described in an anual budget report. The ratio between vegetation respiration and peat carbon loss is a subject of future study.

The most reliable method of evaluating CO_2 flux from soil and vegetation is the eddy covariance method. The disadvantage of this method is that the initial cost is high because it requires a tall tower, a sonic anemometer, fast response CO_2 sensors, a large-size data logger and a power supply system. In addition, only trained scientists can evaluate the quality of the raw data. Local CO_2 flux measurement by the chamber method is suitable for learning the relationship between flux and cotrolling factors, e.g. vegetation, temperature, soil water content, underground water level, nutrients and so on. A model to evaluate emission can be developed using long-term data in a different environment. The chamber method requires less initial cost if it is a manual measurement, but it is not realistic to operate in a long term at many locations.

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Part VI
Wild Fire in Peatland

Toshihisa Honma and Adi Jaya

Chapter 25
Peat Fire Occurrence

Hiroshi Hayasaka, Hidenori Takahashi, Suwido H. Limin, Nina Yulianti, and Aswin Usup

Abstract In this chapter, various peat combustion properties, temporal and spatial peat fire occurrence in Kalimantan, and the peat fire index (PFI) for the early warning of peat fire were discussed. Firstly, tropical peat was sampled from Mega Rice Project (MRP) area in Central Kalimantan and analyzed in the laboratory. The flash point, ignition temperature and calorific value of tropical peat were measured by using a thermogravimetry and differential thermal analysis (TG-DTA) and a bomb calorimeter. The ignition probability of tropical peat was estimated by using literature values. In fields of the study area, peat ignition test, surface temperature measurement of actual burning peat and peat fire propagation measurement were carried out to identify actual peat fire conditions. Secondly, recent seasonal and special fire occurrence trends in Kalimantan were discussed using analysis results of MODIS hotspots data (fires) and precipitation data (the 10 years data, from 2002 to 2011). The two provinces of Central and West Kalimantan have the different severe fire periods. The fire season in West Kalimantan started in early August and lasted until early September. On the other hand, the fire season in Central Kalimantan started in middle August and continued until early November. Finally, peat fire index (PFI) derived from monthly and daily rainfall data was proposed to estimate peat fire conditions. The PFI has a linear relationship to the annual lowest groundwater level in peatland with the coefficient of determination $R^2 = 0.84$, and to the total number of hotspots observed by MODIS during the dry season from June to November in Central Kalimantan with $R^2 = 0.74$. The PFI was found to be useful for the early warning of peat fire in tropical peatlands. The depth of combustible peat layer increased linearly with lowering of groundwater level in tropical peatlands.

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Keywords Peat fire • Dry season • El Niño • MODIS hotspot • Groundwater level • Ignition

25.1 Introduction

Tropical peatlands are important natural resource and have considerable effects on regional and global environments. Wetlands, including peatlands, provide a wide range of products and services that are important for direct and indirect human uses, the welfare of wildlife, and the maintenance of environmental quality (Maltby and Immirzi 1993). Tropical peatlands are one of the largest near-surface reserves of terrestrial organic carbon, and their stability therefore has important implication for climate change (Kayama et al. 2000; Page et al. 2002). They also play a significant role in supporting biodiversity, with a unique combination of habitats and endemic and endangered species. In both these regards, tropical peatlands, most of which are located in the Southeast Asian coastal lowlands, are particularly important (Page et al. 2012). However, the stability of tropical peatlands has been threatened since the early 1980s by human activities, such as converting forest to farmland, constructing transmigration settlements, excessive draining, and logging.

Page et al. (2002) estimated that between 0.81 and 2.57 Gt of carbon were released to the atmosphere in 1997 as a result of burning and vegetation in Indonesia. Putra et al. (2008) suggested that the land area of the Mega Rice Project, MRP, (14,571 km^2) in Central Kalimantan occupies only 0.77 % of whole land area of Indonesia (1,890,754 km^2), but CO_2 emission from fires in the MRP area are estimated to be responsible for 12.4 % (0.32 Gt) and 11.6 % (0.22 Gt) of Indonesian CO_2 emission in 1997 and 2006, respectively. Another more suggestion by them was the effect of the anomalies of the sea surface temperature, SST, in the equatorial area of the Pacific Ocean on the peat/forest fire in Central Kalimantan.

The El Nino event in 1997/1998 was the largest one since 1946 and the drought in Kalimantan was also estimated to be the most serious one in twentieth century (Takahashi et al. 2001). The transportations in Southeast Asia were seriously damaged by the low visibility with dense haze emitted peat/forest fires. The most tragic accident occurred on the flight arriving to Medan in Sumatra on 26 September, 1997. The aircraft collided into a mountain near the airport according to too low visibility for flight and 234 people on board were killed. In several cities, including Jambi, Pontiank and Banjarmasin, visibility at times declined to 20 m (Potter 1997). The peat/forest fires have large impacts on tropical forest ecosystems not only by being burned but also by reducing solar radiation and photosynthetic photon flux density (PFD) with dense haze caused by fires (Tang et al. 1996; Takahashi et al. 1999).

To make clear the characteristics of peat fire in tropical peatland of Central Kalimantan, the laboratory and field experiments were carried out (Takahashi et al. 2003; Usup et al. 2004). The seasonal and regional characteristics of peat fire occurrence in Kalimantan were also analyzed by using MODIS. The Peat Fire Index, PFI, was proposed and the effectiveness of the index was confirmed. The results of the experiments and analysis are shown in this paper.

25.2 Peat Fire Conditions

25.2.1 Study Area

To understand details of the combustion properties of tropical peat is very important for firefighting and also for fire forecasts. Due to lack of data on tropical peat, field studies and laboratory analyses were carried out. As shown in Fig. 25.1, the field study plots were located in a secondary peatland forest along the Trans Kalimantan Highway between Palangkaraya and Pulang Pisau and in a secondary peatland forest near the University of Palangkaraya Climatology Station, in Central Kalimantan-Indonesia. The peatland is a mixed farmland and wasteland in the fluvial plain of the Kahayan and Sebangau Rivers.

Nine field study plots along the highway shown in Fig. 25.1 were selected for field observations of wildfires in peatland during the dry seasons in 2002 and 2004. The university plot was used for various purposes such as peat ignition tests. The wildfires in each plot arose independently. The distances between plots ranged from about 1 to 30 km. The depths of the peat layer at the nine plots were about 1–3 m (RePPProT 1990). The principal types of vegetation in the study plots were cinnamon ferns (*Osmunda cinnamomea*, pakis), vegetable ferns (*Stenochlaena palustris*, kalakai), and bracken ferns (*Pteridium*, Gleditsch, hawuk) with heights

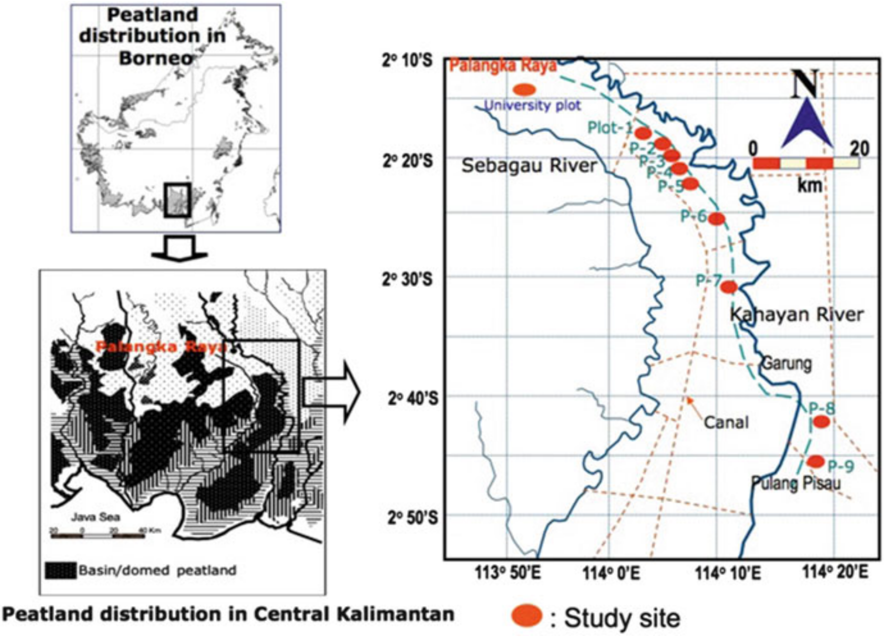

Fig. 25.1 Geographical map of the study area and location of the field study plots along the Trans Kalimantan Highway, between Palangkaraya and Pulang Pisau

ranging from 1 to 3 m. The poor tree vegetation in the study plots was caused by commercial logging, road clear-cutting, conversion of forests to farmlands, and settlements since the 1980s, as well as by frequent fires. Because of the poor tree vegetation, the study sites were subject to intense solar heat and strong winds.

25.2.2 Fundamental Combustion Properties of Tropical Peat

Ignition Temperatures Peat samples were taken from peat layers at depths of 0–20 cm, 20–40 cm, and 40–60 cm in a secondary peat swamp forest near the University of Palangkaraya Climatology Station. Each peat sample was separated into fine and coarse peat components using a 2-mm-mesh sieve. Ignition temperatures were determined in the laboratory using a Thermo-gravimetry Differential Thermal Analysis, TG-DTA Seiko A 6300. The heating rate used was 10 °C min^{-1} from ambient temperature to 500 °C. The samples used in this analysis were only 0.20–0.35 g each, because the heating rate of a sample cannot be kept constant if the mass of the sample is too large.

Figure 25.2 shows the pyrolysis processes of peat samples obtained from a depth of 40 to 60 cm from the secondary peat swamp forest as measured by the TG-DTA in the laboratory. Pyrolysis is defined as the chemical breakdown of solid fuel under the influence of heat and usually in an oxygen-deficient environment (Miyanishi 2000). In this section, approximate flash and ignition point temperatures were defined as

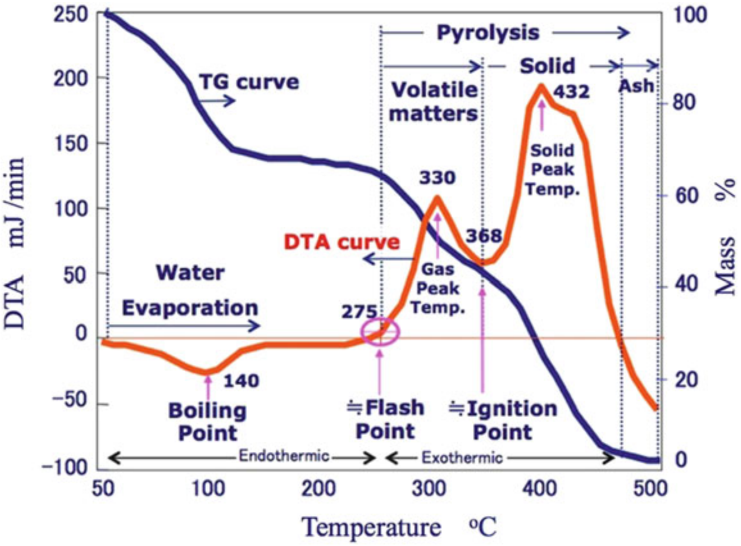

Fig. 25.2 TG-DTA curves of the peat sampled at 40–60 cm in depth from the secondary peat swamp forest of Central Kalimantan

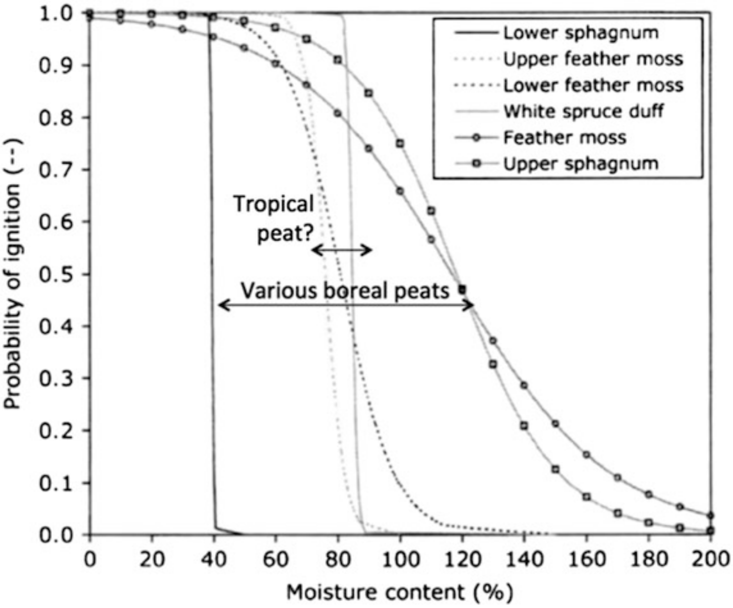

Fig. 25.3 Ignition probability as a function of moisture content (Babrauskas 2003)

the point of transition from endothermic to exothermic processes (Frandsen 1997) for the flash point (≈275 °C) and rapid transition point both in TG and DTA for ignition point (≈368 °C), respectively. Other ignition temperatures of various peat samples varied from 256 to 277 °C (Usup et al. 2004).

Ignition Probability and Other Peat Properties The ignition probability of tropical peat is one of the important combustion properties of peat, however it was not possible to locate a suitable report on tropical peat ignition. The ignition handbook (Babrauskas 2003) gives basic knowledge of peat ignition, and a very important property of peat among various parameters is ignition probability. Figure 25.3 from the above handbook clearly shows that ignition probability varies with moisture content, and shows ignition probabilities of a few organic soil types (peat materials) as possibly very high at around 100 % gravimetric moisture contents. This implies there is a so-called threshold value in ignition of peat, and this ignition property could explain the severe peat fire occurrence in dry seasons.

Calorific value is an important combustion property of peat. Calorific values of various peat samples in pristine and secondary peat forests, and agriculture (bare) land peat measured by a bomb calorimeter (model C7000) varied from 18.34 to 23.89 kJ/g (Usup et al. 2004). These values were very similar to the values of 10–20 kJ/g for the lowest rank of coal, Lignite.

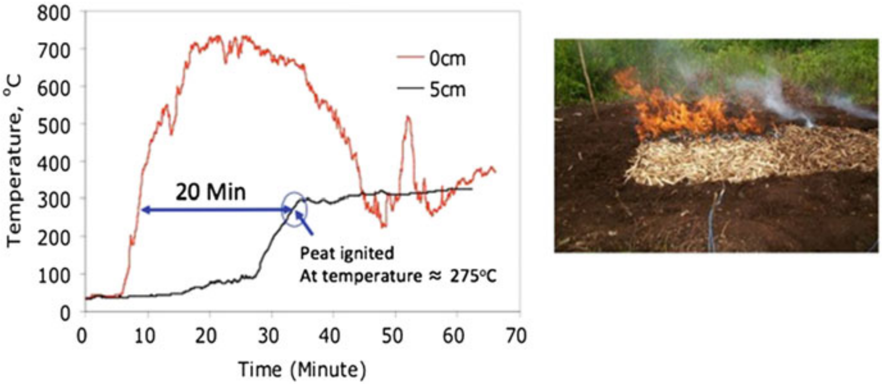

Fig. 25.4 Temperatures of peat at 5 cm depth and at the surface during a peat ignition test

25.2.3 Field Tests and Results of Observations

Peat Ignition Tests in the Field at the University Plot Chromel-alumel thermocouples 0.5 mm in diameter with a stainless steel sheath and a six-channel data logger (KADEC-US, KONA System Co. Ltd, Japan) were used to measure fire temperatures in the field above and below the ground surface. Thermocouple sensors were set at peat depths of 0 (surface) and 5 cm near igniter made by small wood chips.

Peat ignition tests were carried out in the field at the University plot. Considerable amounts of wood chips were prepared to ignite the peat in the field. The reason for using wood chips as an igniter came from preliminary experimental results in the field, where actual peat in the field was very hard to ignite. Experimental results are shown in Fig. 25.4. From this figure, peat ignition started at around 20 min after the fire experiment started and the peat temperature measured at 5 cm from the surface was at around 300 °C. This temperature almost coincided with the 275 °C of the flash point temperature of peat in Fig. 25.2. We must note that the peat temperature at 5 cm depth stayed at around 300 °C even after the wood chip fire became weak. In other words, once peat was ignited, peat fire could last long under the ground.

Surface Temperature Measurements in Actual Peat Fire in the Field Measurements using a thermal video system (Avio Neo Thermal TVS 600) were carried out in Plot 8 on 15 September 2004. The surface temperature distribution captured by the thermal video is shown in Fig. 25.5. Infrared sensors installed on the thermal video could measure only solid (peat) temperatures and could not measure the temperature of smoke and volatile matter from the peat. As we set average emissivity on the thermal video to 0.9, the expression of "apparent" temperature is used here. From the apparent temperature distribution of the actual peat surface (fire front in a peat fire hole), most of the peat surface temperatures were around 400 °C

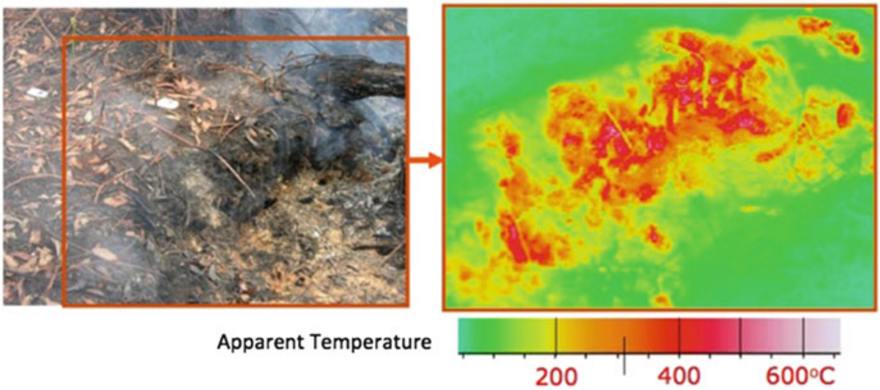

Fig. 25.5 Apparent surface temperature distribution measured at an actual fire in plot 8

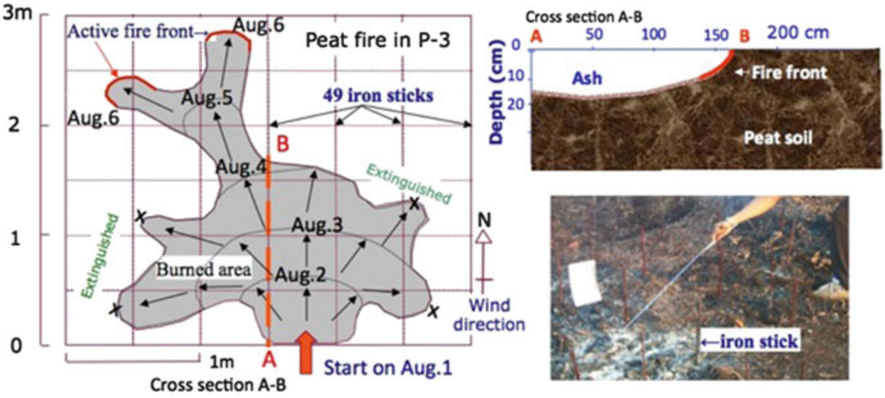

Fig. 25.6 Horizontal and vertical propagation of a peat fire measured at plot 3 on August 10, 2002

(red in the temperature scale in Fig. 25.5). This temperature level corresponds to the pyrolysis temperature of peat solid in Fig. 25.2.

Peat Fire Propagation Peat fire spreading rates in peat soil were measured in three quadrates (each 3 m by 3 m) in study plots 3, 5, and 7. The quadrates were set up leeward to the fire front against the prevailing wind of these areas. Iron rods of 75 cm long and 6 mm in diameter were placed at 50 cm intervals in each quadrate for the fire observations. A typical fire front measurement is shown in Fig. 25.6. Since the fire movement depends on both wind direction and peat properties, the fire fronts form complex shapes. The distance between an initial point and several points on the fire front were measured at 1-day intervals. In this paper, the mean value of several measured distances is defined as the speed of peat fire spreading. The distance of the fire front movement was measured using an iron ruler and observed once a day during the fire season in 2002.

Table 25.1 Speed of fire spread in tropical peatlands, with standard deviation (SD) and Number of samples (*N*)

Peat fire type	Min. (cm h^{-1})	Avg. (cm h^{-1})	Max. (cm h^{-1})	SD (cm h^{-1})	*N*
Surface peat fire (0∼20 cm)	1.73	3.83	6.49	1.41	20
Deep peat fire (20∼50 cm)	0.50	1.29	2.50	0.64	20

Measurements at overhanging areas were carefully done using an iron stick and ruler. Surface peat fires move quickly in zigzag directions of several fire fronts searching for favorable conditions to burn into the deeper peat layers. The width of the fire front is about 10–50 cm (Fig. 25.6). Surface peat fires ignite deep peat fires and serve as kindling charcoal for subsequent fires.

Table 25.1 shows the spreading rates of fire fronts measured at depths of 0–20 cm and 20–50 cm at study plots 3, 5, and 7. The average speed of the surface peat fire (at a depth of 0–20 cm) was 3.83 cm h^{-1}, or about 92 cm day^{-1}. The maximum speed of a surface peat fire was 6.49 cm h^{-1}, or 155 cm day^{-1}, and the minimum was 1.73 cm h^{-1}, or 42 cm day^{-1}. The average speed of fire spreading in deep peat (at a depth of 20–50 cm) was 1.29 cm h^{-1}, or about 29 cm day^{-1}. The maximum speed of deep peat fires was 2.50 cm h^{-1}, or 60 cm day^{-1} and the minimum was 0.50 cm h^{-1}, or 12 cm day^{-1}. The speed of spreading of deep peat fires was half to one third that of the surface peat fires.

The above measured speeds of fire spreading in tropical peatland are not greatly different from those reported for different types of peat and in different regions. In a Russian peat fire, the speed of fire in stockpiled peat was reported to be 0.5–10 cm h^{-1} (Cristjakov et al. 1983). The speed of fire in Australian peat was reported to be 4.2 cm h^{-1}, and that in Canadian peat, is 3–12 cm h^{-1} (Wein 1983). Unfortunately, these reported speeds do not include depth measurements. The speed of fire spread has been shown to have a linear relationship with wind speed (Fernandes 2001), but the relationships between the speed of fire spreading in a tropical peatland and soil moisture and wind speed are still not clear.

25.3 Recent Peat Fires in Kalimantan

25.3.1 Fire-Prone Areas and Peatland

Analysis of the most recent 10-year period (2002–2011) of MODIS hotspots data (fires) and precipitation in Palangkaraya and Pontianak was carried out to identify seasonal and spatial fire occurrence in Kalimantan by applying an every 10-day analysis. This new 10-day analysis approach clearly showed seasonal fire occurrence and explained fire occurrence by using precipitation patterns of each place.

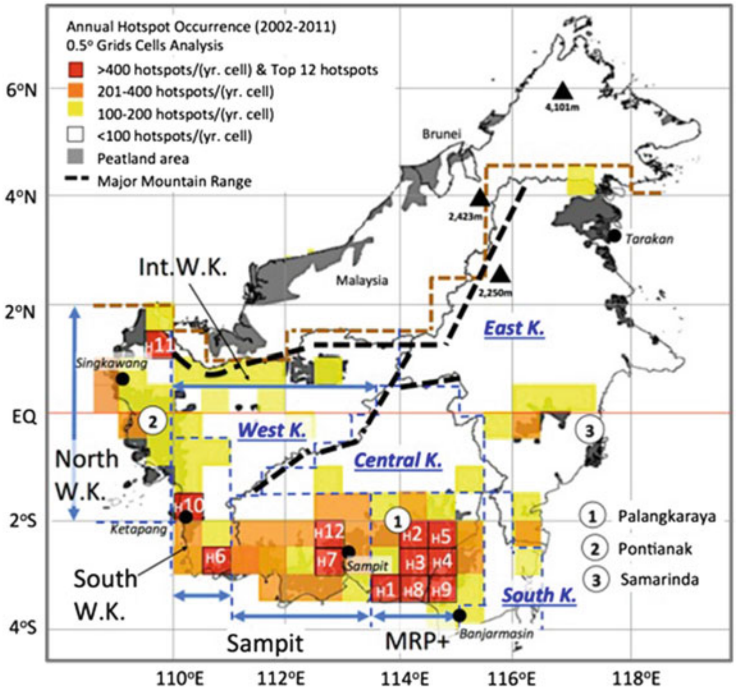

Fig. 25.7 Fire-prone areas, peatland, and local regions in Kalimantan

Four province borders in Kalimantan and one country border with Malaysia, defined by the side of a 0.5° grid cell are shown by dotted lines in Fig. 25.7 for convenience. The total number of cells in the four provinces was 225, comprising 64 for West, 66 for Central, 82 for East, and 16 for South Kalimantan. To identify fire prone areas and to discuss fire activity in Kalimantan in detail, we defined five local regions inside three provinces, excluding East Kalimantan. They were "MRP+" (17 cells including 6 cells from South Kalimantan, the "+" stands for additional "6 cells") in Central and South Kalimantan, "Sampit" (29 cells) in Central Kalimantan, "North West Kalimantan" (a subset of West Kalimantan, North W.K. for short here after) (24 cells), "South West Kalimantan" (South W.K.) (12 cells), and "Interior West Kalimantan" (Interior W.K.) (26 cells), as shown in Fig. 25.7.

Fire-prone areas (>100 hotspots/(year cell) = 0.033 hotspots/(year km^2)) in the recent 10-year period are highlighted by colors in Fig. 25.7. Many are located in the above-mentioned five local regions or coastal peatland areas. Among them, 12 cells showed a very high hotspot density (>400 hotspots/(year cell)). They were named H1, H2, H3, etc. in descending order of hotspot density.

The seven highest hotspot density cells of H1, H2, H3, H4, H5, H8, and H9, were located in the MRP+ area and covered most of the MRP area. Another two cells (H7 and H12) were in the Sampit area (north and east side of Sampit). The rest of the

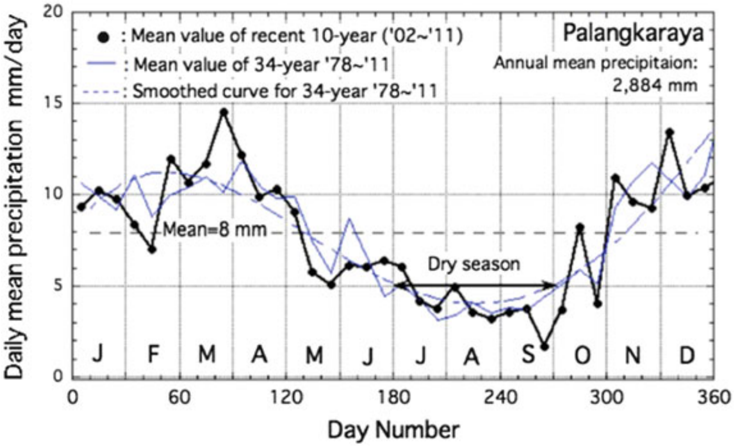

Fig. 25.8 Daily mean precipitation patterns in Palangkaraya, Central Kalimantan

cells (H6, H10 and H11) were in West Kalimantan, with H6 and H10 in South W.K. and H11 in North W.K. From these distributions, we are able to conclude that most fires in Kalimantan are peatland fires because the top ten highest hotspot density cells (H1∼H10) are located in the south coastal peatland areas.

25.3.2 Dry Season in Palangkaraya and Pontianak

In total, 36 accumulated precipitation data points for each year, one for every 10-day interval, were made to identify dry seasons in this paper. Each precipitation data point was placed at its representative point such as 5, 15, 25, . . . (values stand for day number (DN) for short, here after)) as shown in Figs. 25.8 and 25.9.

In Fig. 25.8, the daily mean precipitations of two different periods are plotted with thick and thin solid lines. The thick line with a solid round mark shows the seasonal change of the daily mean precipitation in the recent years from 2002 to 2011. Daily mean precipitation for the recent 10-year interval from 2002 to 2011 was 7.88 mm/day. The thin line shows the seasonal variation of daily mean precipitation for the 34-year period from 1978 to 2011. The 34-year daily mean precipitation is 7.98 mm/day. The dotted curve in Fig. 25.8 is a simple smoothed curve for the daily mean precipitation from the 34-year data, and was used to define the dry season.

In this paper, a daily mean precipitation of 5 mm/day was provisionally used as a threshold value to define the dry season in Palangkaraya. With this threshold value, the dry season period in Palangkaraya was defined as the 3-months from early

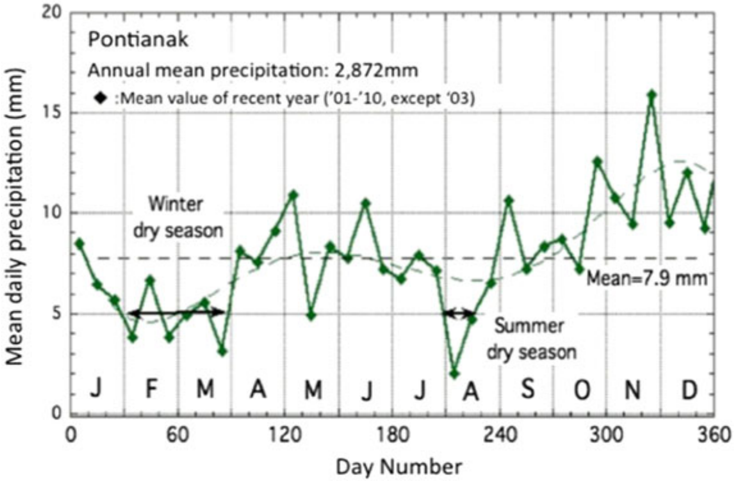

Fig. 25.9 Daily mean precipitation patterns in Pontianak, West Kalimantan

July to late September, as shown in Fig. 25.8. This period coincided with the period with the lowest groundwater level (Putra and Hayasaka 2011). However, there was about a one and a half month time lag between the lowest value of precipitation at DN = 230 and the lowest groundwater level at DN = 275. The recent fire activity tended to show a fire peak at around DN = 275 (Putra and Hayasaka 2011). The very low daily mean precipitation (1.52 mm/day) in late September was the lowest daily mean precipitation of the last 34-years.

In Fig. 25.9, the daily mean precipitation in Pontianak from 2001 to 2010 (except 2003 due to data missing) are shown with a thick line with solid diamond shaped symbols. The dotted thin line is a simple smoothed curve for daily mean precipitation. Daily mean precipitation in Pontianak was 7.85 mm/day. This value is almost the same amount as that in Palangkaraya, but Pontianak showed a different precipitation pattern from the pattern of Palangkaraya (Fig. 25.9). Pontianak had two dry periods (using the same definition as in Palangkaraya, daily mean <5 mm/day); one was from early February to late March, and the other was from early August to mid August. This precipitation pattern or a two dry season pattern is also a typical precipitation pattern in Indonesia, found in northern Sumatra (Aldrian and Susanto 2003). In Pontianak, the winter dry season is relatively longer but wet for two periods in mid February (7 mm/day) and mid March (6 mm/day). Due to this higher precipitation tendency, fires were not so active in the winter dry season. The summer dry season period in Pontianak was only 2/3 month and was shorter than the 3 months in Palangkaraya. However, Pontianak also had a very dry period (1/3 month with 2 mm/day) in early August.

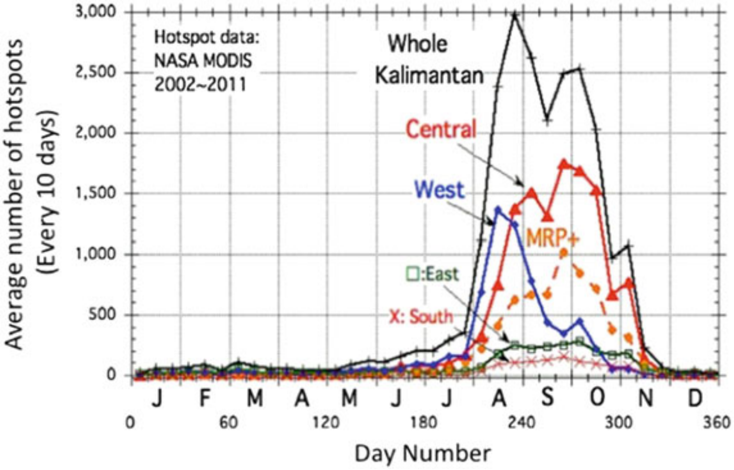

Fig. 25.10 Average annual fire occurrences in Kalimantan

25.3.3 Recent Seasonal (Every 10-Day Period) Fire Occurrence

A previous study by Yulianti et al. (2012) has shown that fires in Kalimantan were most common in August, September, and October. About 85.5 % of the annual hotspots were observed during these 3 months. To understand the seasonal fire occurrence tendency in detail for various areas in Kalimantan, the same method of analysis using 10-day periods as in the previous section on the "Dry season" was also applied here.

From Fig. 25.10, the fire season in each of the four provinces in Kalimantan can also be identified more clearly. We can say that a severe fire season (severe fire: >1,000 hotspots/(year 10-day)) in the whole of Kalimantan starts in early August and lasts until early November. The fire peak in late August for the whole of Kalimantan occurs because of the contribution of fires in West and Central Kalimantan.

The two provinces of Central and West Kalimantan show different severe fire periods. The fire season in West Kalimantan started in early August and lasted until early September (>500 hotspots/(year 10-day)). There was a fire peak in mid to late August (about 1,360 hotspots/(year 10-day)). The fire season in West Kalimantan almost coincided with the dry season in August in Pontianak (see Fig. 25.9). Relatively, high fire occurrence (220–450 hotspots/(year 10-day)) from mid September to mid October mainly occurred in the south region of West Kalimantan.

Fires were most severe in Central Kalimantan. The fire season in Central Kalimantan starts in mid August and lasts until early November. A severe fire plateau (>1,300 hotspots/(year 10-day)) formed in late August and lasted until mid

October. The fire season did not coincide with the dry season from July to September in Palangkaraya (see Fig. 25.8). The fire season starts from July, 1-month later than the onset of the dry season. The reason for the 1-month time lag could be explained by the groundwater level, as previously explained by our research group Putra and Hayasaka (2011).

25.3.4 Fire Propagation from West to South Kalimantan

In Fig. 25.11, three typical fire occurrence distributions in El Niño years are shown. Pre-dry and early dry season fires in late July are plotted with dots in Fig. 25.11a. From Fig. 25.11a, it is clear that most fires are located on coastal peatland areas in West Kalimantan (W.K), the inland peatland area in Interior W.K., and in the MRP+ (Mega Rice Project Area with surrounding areas).

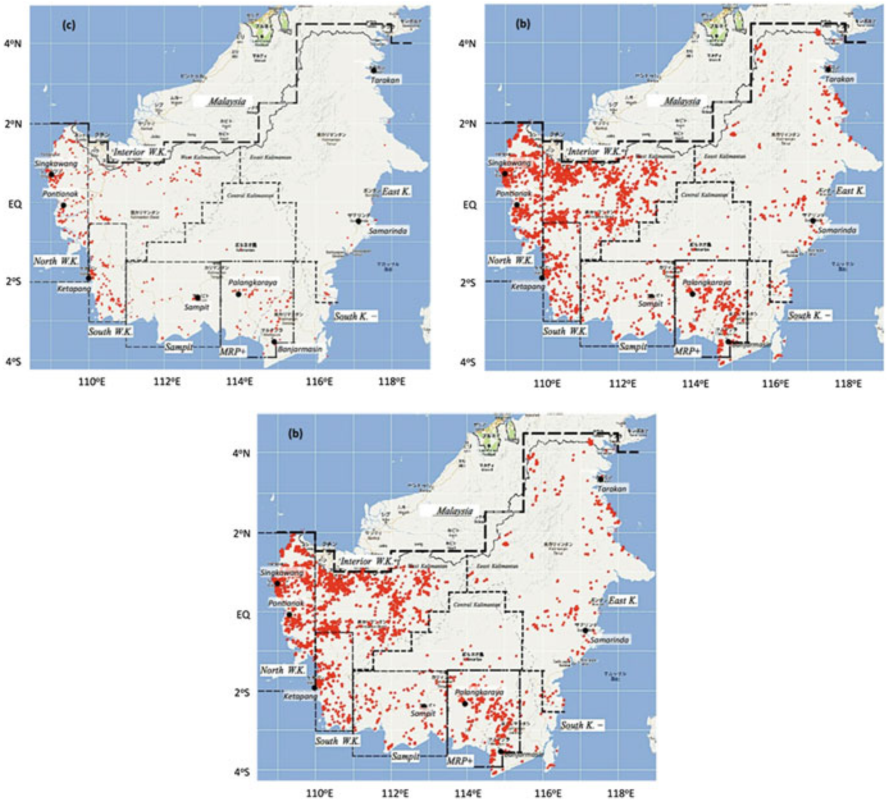

Fig. 25.11 Three typical fire occurrence distributions in Kalimantan. (**a**) Typical pre-dry season (caution) fire distribution in late July (2009), (**b**) Typical West Kalimantan fire distribution in early August (2009), (**c**) Typical severe fire distribution in mid October (2006)

The dry season fires for West Kalimantan (including North, Interior, and South W.K.) occurred early in August (DN = 210–219) in 2009. The total number of hotspots in early August was 3,094 and they were distributed like in Fig. 25.11b. In Fig. 25.11b, there is a high density of fires on coastal and interior peatlands, and in mountain areas (deforestation fires) along the border to Malaysia. Fires in MRP+ already became active from early August.

In 2006, seasonal fire peaks appeared in mid October during the long drought from early July. The Sampit area suffered from the severest fires (total number of hotspots exceeded more than 17,000) in the most recent 10-years (2002∼2011). The total number of hotspots in mid October was 4,178 (418 hotspots/day) and the distribution is shown in Fig. 25.11c. From Fig. 25.11c, it is clear that most fires were distributed along the coastal peatland in southern Kalimantan. These severe fires on peatland in Central Kalimantan during the end of the dry season could become very active due to the very low level of groundwater (Putra and Hayasaka 2011). In 2006, drought conditions lasted for more than 4 months from mid July to early November. Under these long-lasting dry conditions, peat fires could continue by smoldering under the ground or in the peat layer, with the result that peat fires cannot be suppressed (Usup et al. 2004). The 2006 fires were a good example because they showed that peat fires could remain active until heavy rain comes or even until November. From the above mentioned seasonal and special fire occurrences found in Kalimantan, a new smart fire forecast and fire-fighting way will be proposed.

25.4 Water in Peat and Peat Fires in Tropical Peatland

25.4.1 Methods

Data Used for Calculation of Peat Fire Index (PFI) Monthly total rainfall data for the 18 years from 1993 to 2010 at Palangka Raya Meteorological Observatory, Indonesian Agency for Meteorology, Climatology and Geophysics, was used to calculate a monthly peat fire index. The groundwater level in a forest was measured at the site, named Plot-1b, in the marginal peat swamp forest in the Sebangau Natural Laboratory, Central Kalimantan, Indonesia (Takahashi, Yonetani 1997; Takahashi et al. 1998).

Basic Equation for PFI A one-dimensional water balance equation was used to calculate the peat fire index (PFI). The components of water balance in the peat are rainfall and evapotranspiration. In this equation, the seepage from the hydrologic system was neglected, because this index has to cover the many different types of land use in peatland.

$$I_i = -(I_{i-1} + P_i - aM_i) \quad (i = 1, 2, .., 6)$$

$$\mathrm{PFI} = \max_{1 \le i \le 6} I_i$$

Where I_i: Monthly index of peat fire (mm)
P_i: Monthly amount of precipitation (mm month^{-1})
M_i: Number of days in a month
a: Empirical constant (3.5 mm day^{-1} in Central Kalimantan)
Suffix i from 1 to 6: from June to November
$I_0 = 0$ (mm)
PFI: Peat fire index in a year

3.5 mm day^{-1} was a proportional constant to evapotranspiration in Central Kalimantan.

25.4.2 Annual Lowest Ground Water Level and PFI

The daily mean ground water levels from September, 1993 to December, 2007 are shown with the daily rainfall in Fig. 25.12. The lowest groundwater levels in every year are marked with red circles in the figure.

The peat fire index for each year was calculated and is shown in Fig. 25.13. In the years with low groundwater levels, the peat fire indices become high. And the two sets of figures show a linear relation with a 0.84 coefficient of determination.

Number of Hotspots and Peat Fire Index The number of hotspots in the Central Kalimantan area (1.4–3.2° S, 113–115° E) was counted from the data set of MODIS (Terra and Aqua) satellite information supplied by the Fire Information for Resource Management System. The total number of hotspots in the area from June

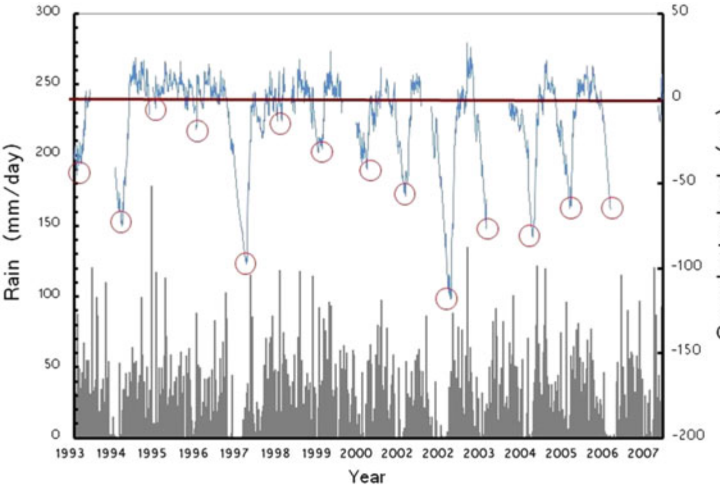

Fig. 25.12 Daily mean groundwater level from September 1993 to December 2007 at Plot-1b in the Sebangau Natural Laboratly and daily amount of rainfall at at Palangka Raya Meteorological Observatory

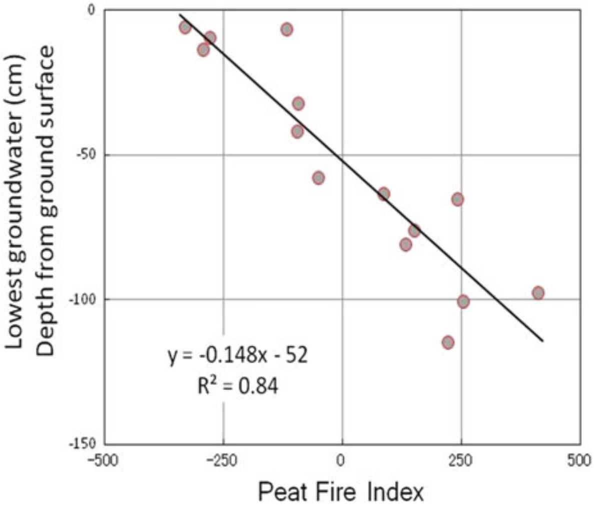

Fig. 25.13 Linear regression of the peat fire index and the annual lowest groundwater level in the forest

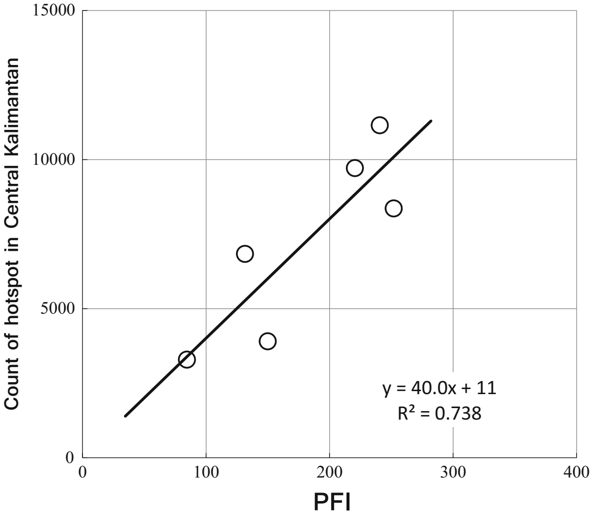

Fig. 25.14 Relationship between the number of hotspots during dry season and the peat fire index in Central Kalimantan area from June to November for 6 years from 2001 to 2009

to November was counted for 8 years from 2002 to 2009, and shown in Fig. 25.14 excepting the data in 2007 and 2008, because the PFI of those 2 years were minus values with large amounts of rainfall. The PFI has a linear relationship to the hotspot count in Central Kalimantan with a 0.738 coefficient of determination.

Groundwater Level and Combustible Depth of Peat Layer Jaya et al. (2012) showed the drying processes of peat layers by using the one dimensional tank model, in which the peat layer from the surface to 1 m depth was divided into 20 layers

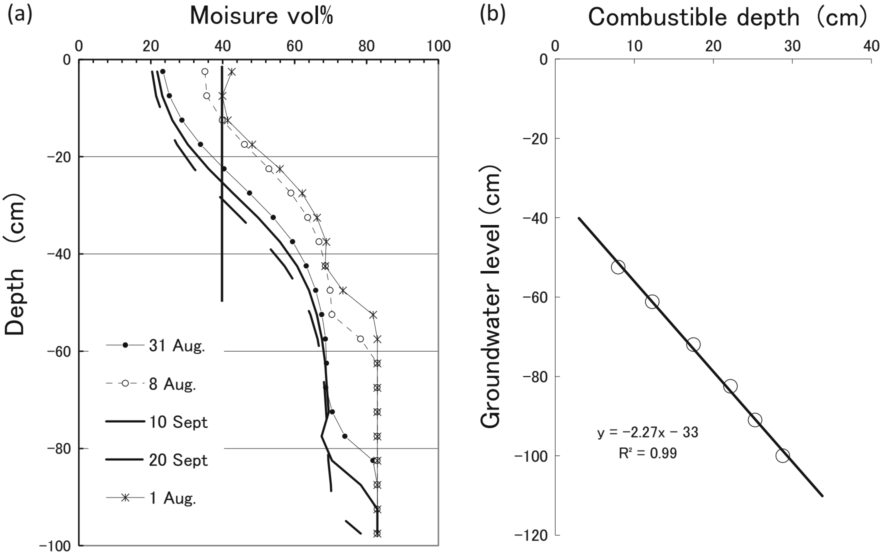

Fig. 25.15 Estimated moisture profile in peat layer (**a**), partly re-drawn from Jaya et al. (2012), and the relationship between the combustible depth of peat layer and groundwater level (**b**)

with the thicknesses of 5 cm per layer. Using the model, they showed the changing vertical profiles of peat moisture during the dry season in 2002 (Fig. 25.15a). Usup et al. (2004) noted that surface peat in the field was easy to ignite when the peat is dried to around 100 % gravimetric water content, which corresponded to 10 % in volumetric water content. After the surface peat was ignited, the deeper layers of peat also burned. But when the peat layer was wet enough, the layer could not burned. The threshold moisture of peat layer for burning varied with the fire intensity. The 40 % in volmetric water content was used as the threshold peat moisture for burning in this paper. The depth of the peat layer, where the moisture was dryer than 40 % in volumetric content, was defined as the combustible depth of peat.

The relationship between the ignitable depth of the peat layer derived from Fig. 25.15a and the groundwater level is shown in Fig. 25.15b. The depth of the combustible peatlayer increases linearly with lower groundwater levels.

It is concluded that, the peat fire index, PFI, proposed in this paper has a linear relationship with the lowest groundwater level in the peatland, and the total number of hotspot observed by MODIS during dry season from June to November. The depth of the combustible peat layer increased linearly by being lowered the groundwater level. From the results, the depth of the combustible peat layer can be estimated by using the PFI. The total amount of peat loss by fire is calculated by the total burned area and the burned peat depth. Therefore PFI has a possibility to be used for one of the early warning index in tropical peatlands, and for estimation of carbon loss by peat fire.

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Chapter 26
Detection and Prediction Systems of Peat-Forest Fires in Central Kalimantan

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Abstract Fire detection systems and fire prediction systems were developed in peatland of Central Kalimantan, Indonesia. Through the fire detection systems, the fire occurrence information with more than 1 km^2 coverage is obtained by 4 pilot villages at an average of 13–16 h. As a result, in order to send messages to stakeholders more smoothly, we needed to estimate traffic congestion time of the short message system (SMS) of real traffic in Indonesia. Next, in order to confirm all record of ten hotspot data (July 2009) and two current firing hotspot data (September 2012) detected by the improved algorithm, we introduced the unmanned aerial vehicle (UAV) into the systems, so that all hotspot data were confirmed to be burnt or burning area by UAV photographs and also the wireless sensor network (WSN) was confirmed to be useful to fire detection and prediction through the artificial field-fire experiment. Thirdly, fire spread prediction time in the fire prediction systems is about 4 h for 2 km area from the pilot villages when applying simplified fire-extension model. When we consider the interval of satellite image acquisition, predicted fire spread coverage error becomes within 50 % if the velocity of hotspot center is less than 2 m/min. In order to improve the simplified fire-extension model, we have to examine and establish the velocity of the movement of hotspot center determined by wind velocity, soil moisture and vegetation, and verify the precision of the simplified fire-extension model through the time-series hotspot data analysis and on-site inspection. As a result, we will be able to estimate the time-series CO_2 emission due to fires based on the time-series hotspot data. Finally, the systems developed in the project was validated thorough the fire practical operation in the peat land, so that it was found that we have to discuss and coordinate about fire communication systems with local government authorities for their realization. In

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addition, it is necessary to review the possibility of making accumulated data open for researchers and practitioners to share observation data among researchers and practitioners even if the project is finished.

Keywords Hotspot satellite data • Unmanned aerial vehicle • Fire detection and prediction • Wireless sensor network

26.1 Introduction

El Nino often caused serious damages by peat-forest fires to transportation, daily life and human health in Indonesia. For this reason, it is necessary to develop the effective fire detection and fire prediction systems of peat-forest fires (Honma et al. 2014).

In order to achieve the project, there are three numerical indicators in targets of Fire Detection and Fire Prediction Group Activities. Namely, (1) In the fire event with more than 1 km^2 coverage, four pilot villages can obtain fire information within 16 h, and moreover they can obtain information on fire spread prediction within 8 h. (2) Fire detection accuracy can reach the level of more than 80 %. (3) Rate between predicted fire spread coverage and real fire coverage can reach the level of more than 50 %.

26.2 Fire Detection Systems

Communication network of fire detection and alarm systems consists of several processes such as step 1 (satellite hotspot detection and hotspot data analysis), step 2 (fire information production and delivery) and step 3 (UAV (unmanned aerial vehicle) verification and fire suppression). As shown in Fig. 26.1, these processes are systematically integrated and stakeholders can obtain the fire information at an average of 13–16 h from hotspot detection by satellite. Namely, average satellite detection time is 6–8 h, hotspot data analysis time is 4 h, fire information data production time is 1 h and SMS (wireless sensor network) data transmission time is 2–3 h.

26.2.1 Step 1: Hotspot Algorithms and Water Regime Model

We have compared the revised algorism proposed by the project with other existing algorisms and improved the precision of the revised algorism. The revised MODIS

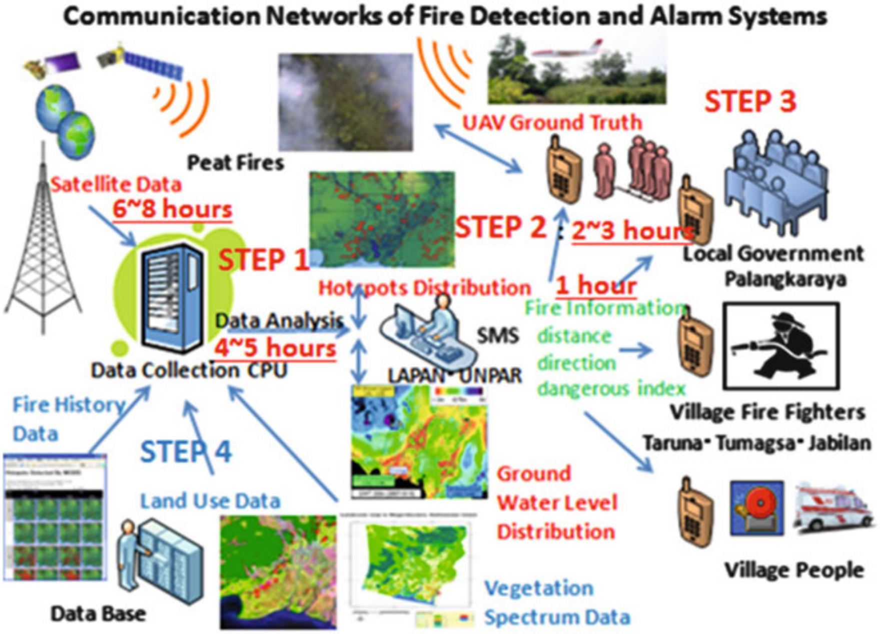

Fig. 26.1 Fire communication networks

(1 km^2 mesh) fire hotspot detection data was transferred to the server purchased and set up in LAPAN in Indonesia and has been accumulated every day since 20 May 2011 as step 4 (fire history data, land use data and vegetation spectrum data) as shown in Fig. 26.1.

A model was established to estimate the spatial distribution of soil moisture based on satellite data, and the validity of the model was verified by comparing the measurement data of ground water level with simulation data of the model. By integrating the data from fixed point observation into the satellite data, the spatial distribution of soil moisture was presented with high precision for the first time in the world. The validity of the established water fluctuation/soil moisture estimation model was examined though the accumulation of data and fixed point measurement.

In addition, the level of the PFI (peat fire index) was defined by the correlation of the ground water level with the number of fire occurrence and the fire dangerous index (referred to as FDI) based on PFI was developed in Fig. 26.2.

26.2.2 Step 2: Transfer of Fire Information

The software for the short message system (SMS) was selected and four pilot villages (Tarunajaya, Tumbang Nusa, Pilang and Djabiren) were selected for the

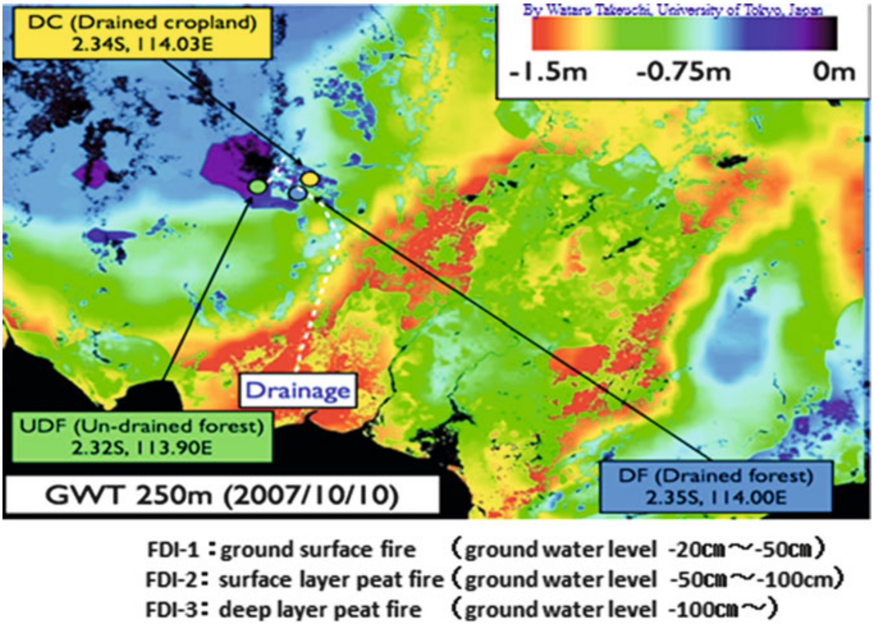

Fig. 26.2 Two dimensional profile of fire dangerous index (FDI)

installation of fire communication system. We procured the SMS system including both hardware and software in Indonesia and installed in Pekayon office, LAPAN. The fire information transmission system based on SMS was established, and introduced to the pilot villages. In addition, we developed the system that integrates useful forest fire information, for example, date of fire detection, the distance and the direction to occurred hotspots inside the distance 2 km from the center of villages as shown in Fig. 26.3, the fire dangerous index (FDI) determined by step 1 (the soil moisture), and step 4 (types of peat fires, land use data and vegetation data). The recipients of the fire communication system (SMS) are set to be village heads and leaders of fire-fighter teams.

In addition, Fig. 26.3 shows (a) the connected time-series data and (b) disconnected hotspot data within area of radius 2 km from the center of village. Then, only fire information of solid-line hotspot data inside the 2 km-radius area is informed to the stakeholders and fire information of dashed-line hotspot data outside the 2 km-radius area is not informed to stakeholders.

26.2.3 Step 3: UAV Validation and WSN Operation

In order to validate the satellite detection accuracy of hotspots data, three types of the electrically-powered UAV (unmanned aerial vehicle) were developed during the

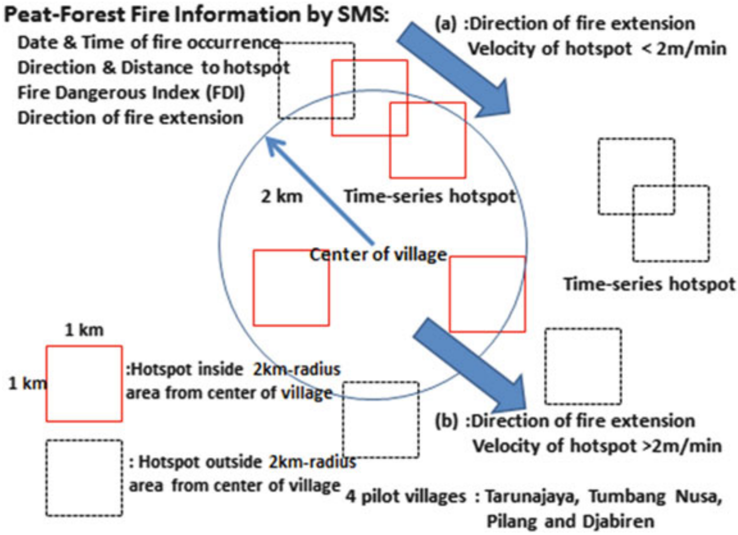

Fig. 26.3 Hotspots inside the distance 2 km from the center of a village

project. Aerial photography was taken by the UAV equipped with optical camera and infrared camera. At this time, the hotspots map detected in July, 2009 was utilized because there were no fires occurred in study site during dry seasons in 2010–2011. All 10 hotspots in the 2009 map shown in Fig. 26.4 were confirmed to be burnt area by UAV aerial photography in 2011 and 2012.

In addition, two hotspots detected by satellite in 3rd September, 2012 were first confirmed to be real on-going fires by UAV aerial photography taken in 6th September, 2012. In a word, the improved hotspot detection algorithm could find the fire at 100 % accuracy though the sample cases are limited. In addition, by UAV observation, it was confirmed that 15∼20 % areas were burning inside the hotspot (1 × 1 km) as shown in Fig. 26.5.

Experiments of temperature increase by artificial fire were conducted, in which the temperature was measured by WSN (wireless sensor network) at 500 m away in distance from the base station. Time-series temperature data and UAV aerial photography are shown in Fig. 26.6 and then the applicability of WSN to fire detection and prediction was confirmed. In addition, hotspot data detected by satellite is combined with UAV and WSN data, so that MRV (measurement, report and verification) systems will be established for fire detection, prediction and validation. For this reason, the new technical specification of the 500 wireless sensors that cover the area of 10 × 10 km was elaborated.

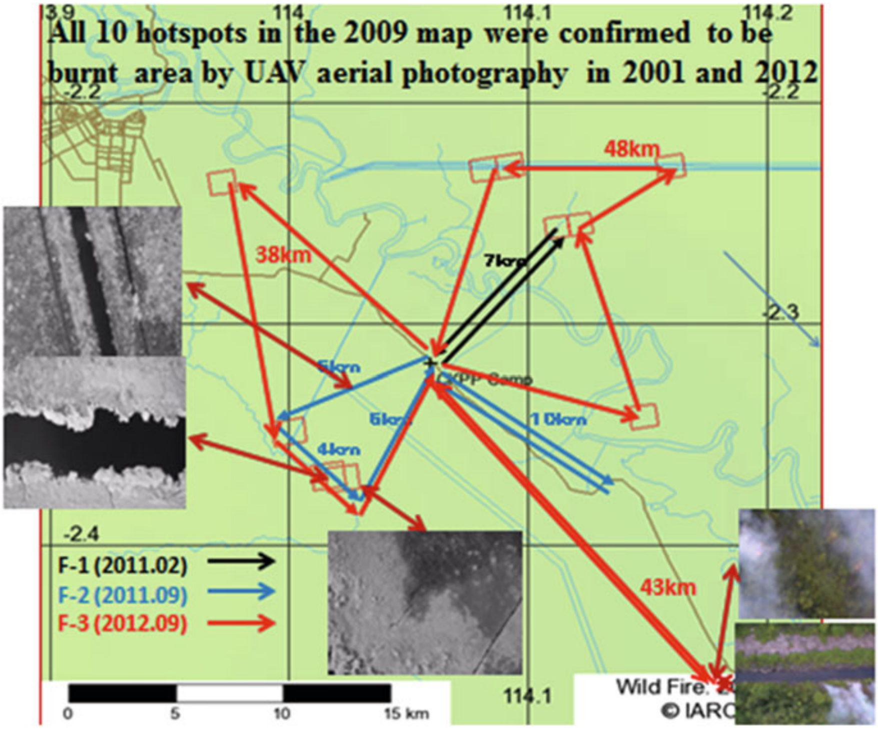

Fig. 26.4 UAV flight routs for validation of hotspots satellite data

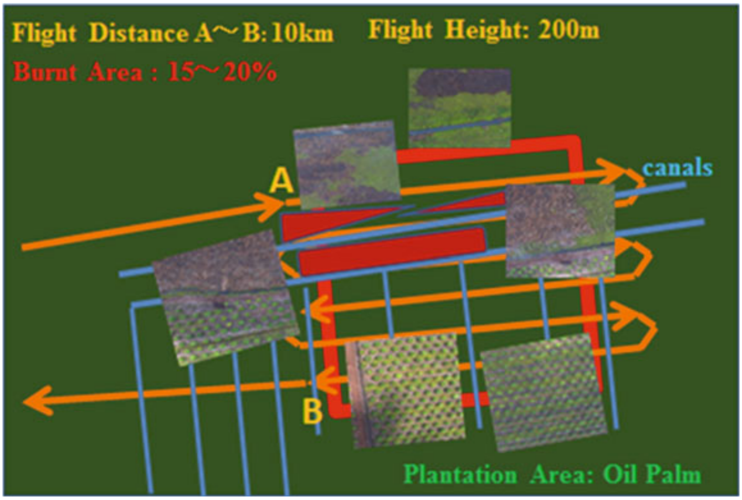

Fig. 26.5 UAV flight rout inside a pixel for validation of hotspot satellite data

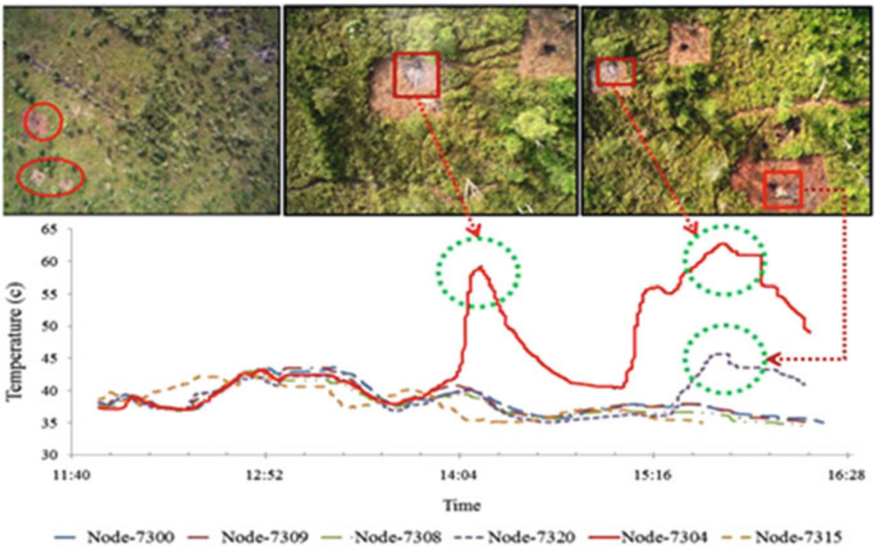

Fig. 26.6 Comparison of UAV with WSN data

26.3 Fire Prediction Models

26.3.1 Large-Scale Simulation Model for Fire Area (100 × 100 km)

A simulation model on forest fire spread in the large area (about 100 × 100 km), taking into consideration the vegetation data, was developed and its validity was examined from viewpoint of both omission and commission errors in Fig. 26.7. Here, if the blue rectangle denotes the burnt area A_F and the red rectangle denotes the simulation area A_S, then fire spread simulation yields areas a_F, a_C and a_O corresponding to fire area, commission area and omission area, respectively. In addition, A_F and A_S are defined by $A_F = a_F + a_O$ and $A_S = a_F + a_C$, and the omission error E_O and the commission error E_C are defined as $E_O = a_O/(a_F + a_O)$ and $E_C = a_C/(a_F + a_C)$, respectively. The parameter k represents the time evolution of the simulation using the relation $A_S = k\ A_F$ and then starting point of simulation is given by $k = 0.0$, i.e., $A_S = 0.0$, $E_O = 1.0$ and $E_C = 0.0$.

Figure 26.7 shows that in the range of parameter $0.0 < k < 1.0$, the relation of omission and commission errors becomes $E_C < E_O < 0.5$ and then in the range $1.0 < k < 2.0$, we have the relation $E_O < E_C < 0.5$. As a result, the simulation result without considering the vegetation is shown as the fire spread prediction result 1 with $E_O = 0.048$, $E_C = 0.5$ and when considering the vegetation, the simulation result is shown

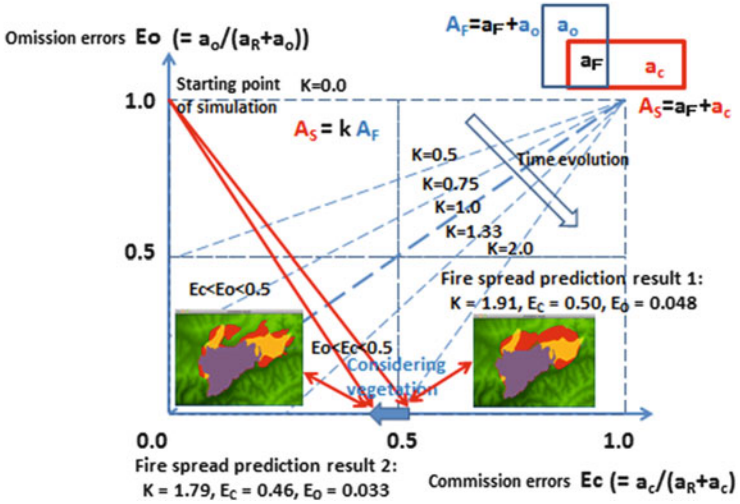

Fig. 26.7 Simulation results of fire spread considering both omission and commission errors in the large area (100 × 100 km)

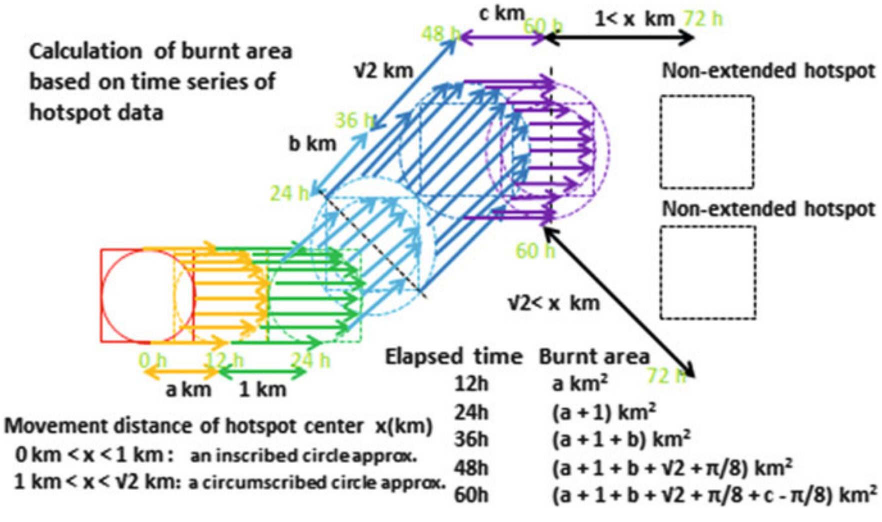

Fig. 26.8 Simplified fire-extension model based on time-series hotspot data

as the fire spread prediction result 2 with $E_O = 0.033$, $E_C = 0.46$. It is shown that the simulation results are improved by considering the vegetation and the commission error is smaller than 0.5.

(a) Workshop on practical fire operation (b) Explanation by Prof. H. Takahashi

(c) Launch of UAV by UAV team (d) UVA flight for fire monitoring

(e) Fire field for practical operation (f) Fire suppression activity by fire fighters

(g) Fire suppression report by fire-fighter team (h) UAV observation report by team leader

Fig. 26.9 Workshop on practical fire operation

26.3.2 Local-Scale Simulation Model for Fire Areas (4 × 4 km)

In order to predict the fire extension within the 2 km-radius area, the time sequence of 1 km^2 hotspot data was examined and the fire occurrence process in time was clarified. As a result, the simplified fire-extension model was developed based on the time-series hotspot data by satellite. Namely, by using the simplified fire-extension model, 1 km square hotspot is approximated by either an inscribed circle with the radius 1/2 km or a circumscribed circle with the radius $\sqrt{2}/2$ km, so that we can estimate the fire extension area as the movement distance of the hotspot center as shown in Fig. 26.8. In addition, Fig. 26.8 shows the calculation process of fire extension area based on time series hotspot data which are detected with time interval of 12 h a day. In addition, if the maximum of movement distance of the center of the hotspot is within $\sqrt{2}$ km for the time interval, i.e., the speed of the movement of hotspot is within about 2 m/min, then we can consider hotspot data as continuously connected time series data, and predicted fire spread coverage error becomes within 50 %. Otherwise, the hotspot data are considered as disconnected data.

26.4 Practical Fire Operation of Fire Detection and Prediction

The practical operation of fire detection and prediction based on both the integrated systems and SMS is carried out (Fig. 26.9a–d). The usefulness of the information system for suppression of real fires by fire fighters was confirmed (Fig. 26.9e, f). After suppression of fires, leaders of fire fighter teams reported to participants at meeting about the suppression activities based on fire information delivered through SMS, in which suppression starting and ending time, the type of fire, the fire burned area size and personal impression etc. are reported (Fig. 26.9g). In addition, leader of UAV monitoring team explained the UAV flight performance and current moving images of real fires taken by UAV (Fig. 26.9h). Stakeholders involved to the practical fire operation satisfied the reports from leaders and Q&A from the floor.

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Chapter 27
Compact Firefighting System for Villages and Water Resources for Firefighting in Peatland Area of Central Kalimantan

Hidenori Takahashi, Adi Jaya, and Suwido H. Limin

Abstract The quick extinguish in the incipient stage of fire is the most effective and important in peat fire in tropical peatlands. The compact fire extinguish systems, which are suitable for firefighting in peat/forest fires, were lent to the local firefighting teams in the tropical peatland. Quantity of water resources for firefighting in peatland were evaluated. Water of the receiver in the canal, the fire prevention pond and the confined groundwater are possible to use for firefighting in tropical peatlands. The performance of the water pump and fire hose were tested in the field and confirmed to be sufficient for the firefighting for peat fire. Method of monitoring for management and usage of the compact firefighting system is proposed. The evaluation method of the firefighting activity in the villages using the satellite information is also proposed in this paper.

Keywords Firefighting system • Peat fire • Incipient stage of fire • Water resource

27.1 Introduction

Fire in peatlands is categorized as ground fire (Adinugroho et al. 2005). This type fire spreads not only on the ground surface but also under the surface with very low spreading speed. The peat fire were categorized into three types, the surface fire, the

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surface peat fire and the deep layer peat fire (Usup et al. 2004). Tacconi et al. (2007) mentioned five types of fire causes, (1) environmental condition, (2) livelihood, financial, and economic interest, (3) bad governance, (4) lack of knowledge, and (5) accidental ignition. The most case of the peat fire in tropical peatlands caused through carelessness at the time of dry weather.

Fire extinguishing in the incipient stage is the most important for fire control not only in a case of peat fire but also general fire accidents. Especially in the case of peat fire, after the peat fire penetrate to underground, the fire extinction becomes very difficult because it is impossible to find the fire and spray water to the fire from the ground. Most of peat fires occur outside of town area, so then the fire extinguishing system/apparatus should be always own in local villages and communities. A compact fire extinguishing system is proposed and set up by JST-JICA project in Central Kalimantan. The system consists mainly of a three wheel motorbike, a large water tank, two water pumps, 30 fire hoses and 2 nozzles. The lectures and training for the six local firefighting teams in Central Kalimantan were carried on in University of Palangka Raya. The activity of the firefighting teams in villages were monitored by questionnaire.

The sources of water for firefighting are also very important for the extinction of peat fire because the most of peat fire occurs in the isolated field and forest from town. It is impossible to use the water supply system established in the urban area. We have to prepare the water resources for firefighting. We proposed three types of water resources for firefighting on peat fires. They are the groundwater, the water poor for firefighting and the canal water. The usefulness of the groundwater and the fire prevention pond are investigated by pumping test.

27.2 The Compact Firefighting System

The most of peat fire occurs along roads and canals because the human activity is high and therefore possibility of accidental fire is also high there. The incipient stage of fire along roads and canals is the surface fire. In the incipient stage of peat fire, the grass and surface woody debris on the ground are ignited by such accident as cigarette disposals. The fire should be extinguished in this stage as soon as possible. The amount of water for extinguish the fire is not necessary so much in this stage of fire. The very quick initial reaction is require for the firefighting. The compact firefighting system equipped in the villages are useful for fire extinguish in this stage with its mobility. The compact firefighting system consists to the equipment listed in Table 27.1.

The components of the compact firefighting system are used in different ways depending on the stages of peat fire. In the incipient stage, the quick extinction on fire near road/canal is the most important activity. The three wheel motorbike is used to carry the water in the tank, one water pump, fire hoses and nozzles immediately

Table 27.1 Components of the compact firefighting system for peat fire

Name of equipment	Quantity	Specifications
Three wheel motorbike	1	Dimension (mm): length 3570, width 1280, height 1480
		Engine displacement (cc): 196.9
		Total weight (kg): 375 maximum laden weight (kg): 300
Water pump	2	Dimension (mm): length 455, width 385, height 405
		Assembly weight (kg): 26
		Lift (m): 32, suction (m): 8, following volume (ℓ/min)
		Max. power (Kw/rpm, HP/rpm): 4.2, 6.5
Fire hose (model #40)	20	Dimension (mm): diameter 40, length 2000
		Weight (g/m): 120 adapter (g): 250 total weight (g): 2650
		Working pressure (MPa): 0.7
Nozzle (model #40)	2	Dimension (mm): length 380
Water tank	1	Dimension (ℓ): 750

Fig. 27.1 Three wheel motorbike and water tank

to the fire sites (Fig. 27.1). The other water pump is put near the water resource and supply water to the water tank. The water in the fire prevention pond, river and canal is used for firefighting.

Furthermore in the cases of peat fire and the deep peat fire stages, the fire sites locate far from the road/canal. Therefore the firefighters have to carry the water

Fig. 27.2 Donated 3,000 fire hoses for the compact fire fighting system from Japan

pump, fire hoses and nozzles from the road/canal to fire site in the field/forest. The weight of water pump, 26 kg, is not so heavy for the firefighter to carry to the fire sites on foot. Ten pieces of the fire hoses, 20 kg are also not so heavy for a firefighter. The groundwater is used as fire extinction water in the field/forest of peatland. The amount of groundwater in peat layer is not enough for fire extinction. Therefore the confined groundwater is used as fire extinction water. The water pump and plastic pipes of around 4 cm in diameter are used for digging well there. The depth of the confined aquifer and the amount of the confined groundwater in the object region should be surveyed in advance. The attrition rate of the fire hoses is very high because the hoses are used on the very rough ground surface in the field/forest. Therefore the fire hoses donated from Japan were used in the compact firefighting system (Fig. 27.2). Many Japanese companies donated the fire hoses which were set for 10 years as a part of the fire apparatus in buildings without using actually.

27.3 Water Resources for Firefighting

There are three important water resources, the river, water reservoir, fire prevention pond and confined groundwater, in tropical peatlands. The canals constructed in peatland have an effect on the groundwater level near the canal by lowering of

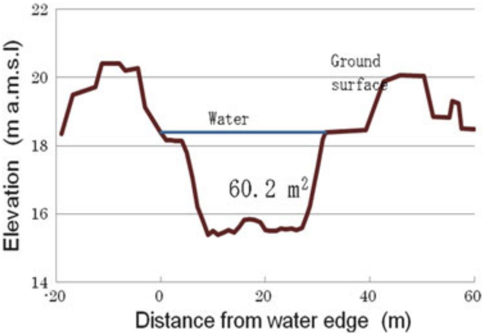


Fig. 27.3 The cross section of the Kalampangan canal

Fig. 27.4 A large volume of water in dam pond of canal

groundwater level. On the other hand, the dam constructed in the canal prevents discharge of groundwater and keep it in higher level in peatland. The water level of dam reservoir also keep in high level (Koizumi et al. 2013). The cross section of the Kalampangan canal, which was constructed in the Mega Rice Project area of Central Kalimantan, is shown in Fig. 27.3. The amount of water in reservoir between two dams, which were constructed 1,100 m away together, is estimated to be 66,220 tons, which is enough amount for fire the prevention water Fig. 27.4.

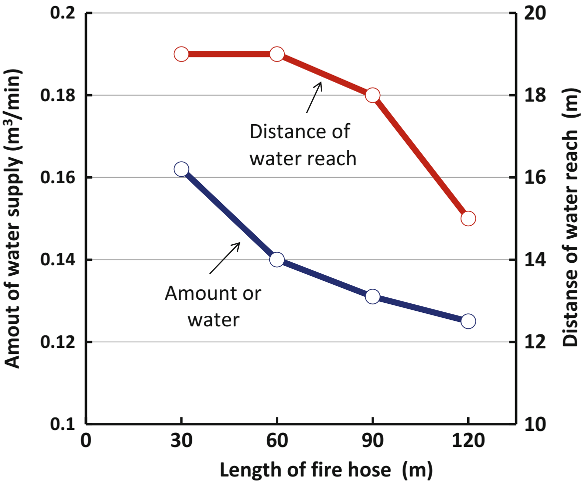
Fig. 27.5 A fire prevention pond used as a fish pond supplies enough water for firefighting

The fire prevention pond is also important for supplying water to the compact firefighting system. Figure 27.5 is the fire prevention pond, the width 10 m, length 20 m and depth 4 m, constructed in a firm land in the peatland of Central Kalimantan. The capacity of the fire prevention pond was measured by using the water pump of the compact firefighting system (Takahashi and Limin 2012). The amount of water pumped up was 0.309 m^3/min, which was equivalent to the lowering rate 0.154 cm/min of water level of the pond. But the observed lowering rate of water level in pond was 0.101 cm/min. The difference of two lowering rates 0.053 cm/min was caused by the supply of groundwater from the wall of the pond. Consequently, the amount of water supply of 200 m^3/h from the pond lowers the water level of 65 cm in the pond. The hydraulic conductivity of the aquifer below the peat layer measured by the pumping test (Fig. 27.6) at Kalampangan site was around 0.13 cm/s. The value means the aquifer in this area is pervious.

The distance of water jet from nozzle mouth measured using the compact firefighting system and the confined groundwater (Fig. 27.7). The fire hose can extend to 90 m and the water of 0.13 m^3/min was possible to supply to the fire target 18 m apart from the nozzle mouth (Takahashi and Limin 2012). Nii (1953a, b) reported that the water jet reached to 9.4 m far from the nozzle with the mouth of 13 mm in diameter and water pressure of 344 kPa.

Fig. 27.6 A large amount of water in the aquifer below peat layer

Fig. 27.7 Chang of the amount of water supplied from the confined groundwater and the distance of water jet from the mouth with length of fire hose



27.4 Training for Local Firefighters

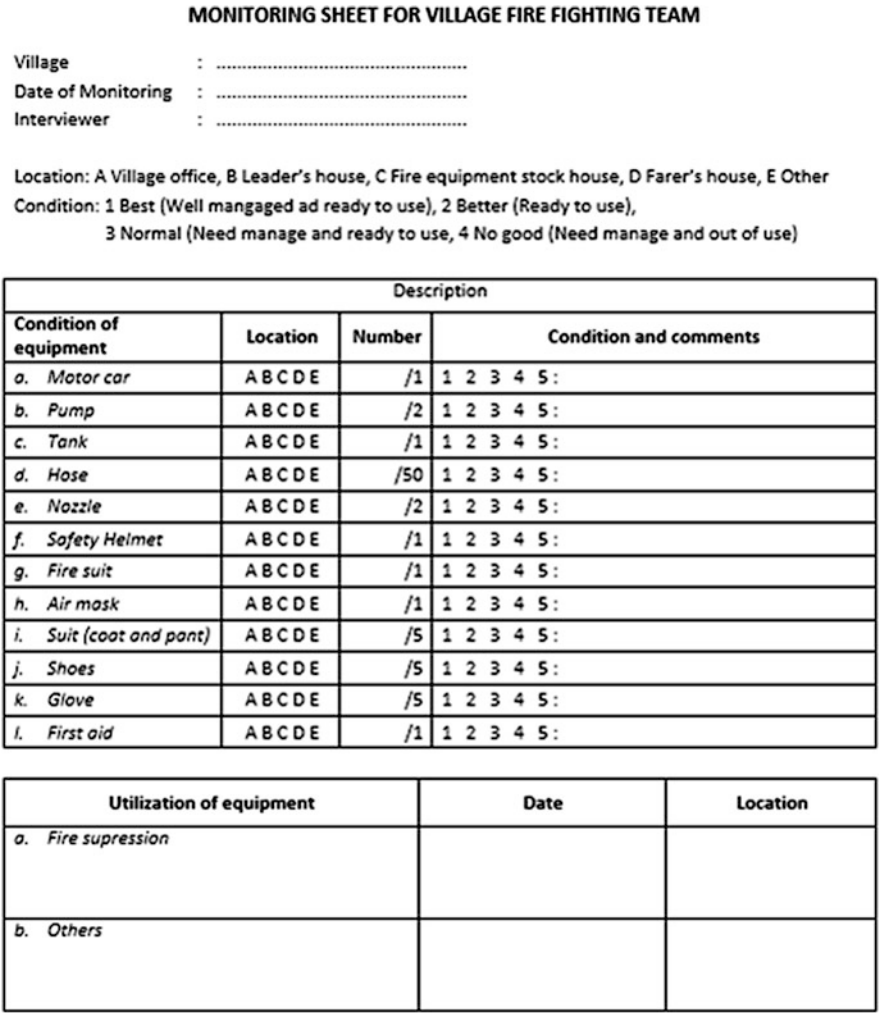
Six firefighting teams were selected to monitor the firefighting activity using the compact fire fighting system. Four teams were from local villages, Henda, Pilang, Tunbangnusa and Taruna jaya in Central Kalimantan. Two teams were from city area of Palangka Raya. Thirty participants from villages and Palangka Raya were given the lecture of firefighting theory and technology from the senior staff of the governmental forest management office in the lecture room of the university (Fig. 27.8) and given the exercise in the field (Fig. 27.9)

Fig. 27.8 Thirty participants from villages and Palangka Raya were given the lecture of firefighting theory and technology in the lecture room on a university

Fig. 27.9 The practice of peat firefighting in a peatland

27.5 Monitoring and Evaluation of Activity and Utilization of Facilities

Monitoring are carried twice a month during dry season and once in 2 months during rainy season. Items for monitoring are the date and purpose of another use of firefighting equipment etc. (Fig. 27.10). Satellite information will be the most useful for the evaluation of the firefighting activity (Fig. 27.11).



MONITORING SHEET FOR VILLAGE FIRE FIGHTING TEAM

Village : ....
Date of Monitoring : ....
Interviewer : ....

Location: A Village office, B Leader's house, C Fire equipment stock house, D Farer's house, E Other
Condition: 1 Best (Well mangaged ad ready to use), 2 Better (Ready to use),
3 Normal (Need manage and ready to use, 4 No good (Need manage and out of use)

Description			
Condition of equipment	**Location**	**Number**	**Condition and comments**
a. Motor car	A B C D E	/1	1 2 3 4 5:
b. Pump	A B C D E	/2	1 2 3 4 5:
c. Tank	A B C D E	/1	1 2 3 4 5:
d. Hose	A B C D E	/50	1 2 3 4 5:
e. Nozzle	A B C D E	/2	1 2 3 4 5:
f. Safety Helmet	A B C D E	/1	1 2 3 4 5:
g. Fire suit	A B C D E	/1	1 2 3 4 5:
h. Air mask	A B C D E	/1	1 2 3 4 5:
i. Suit (coat and pant)	A B C D E	/5	1 2 3 4 5:
j. Shoes	A B C D E	/5	1 2 3 4 5:
k. Glove	A B C D E	/5	1 2 3 4 5:
l. First aid	A B C D E	/1	1 2 3 4 5:

Utilization of equipment	Date	Location
a. Fire supression		
b. Others		

Fig. 27.10 Monitoring sheet used in 2013

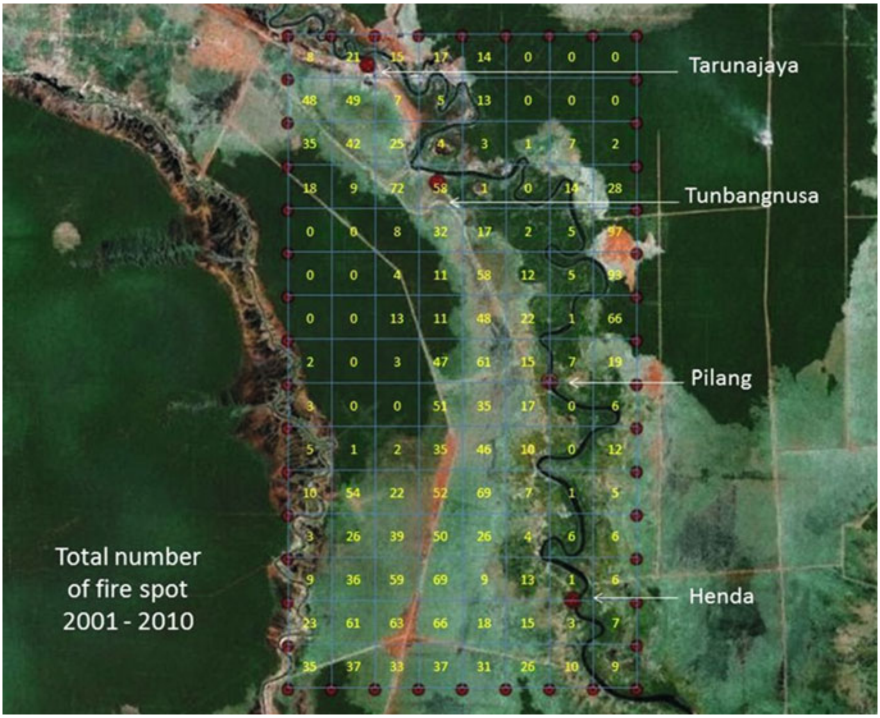


Fig. 27.11 Number of fire spots counted for 10 years from 2001 to 2010 near the village

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Part VII
Estimation and Modeling of Peatland

Nobuyuki Tsuji and Orbita Roswintiarti

Chapter 28
Contribution of Hyperspectral Applications to Tropical Peatland Ecosystem Monitoring

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Abstract Tropical peatland is a valuable and vulnerable ecosystem storing tremendous carbon in the form of above ground biomass and soil carbon. Hokkaido University and collaborative research group with Indonesian experts are conducting a long-term research on tropical peatland ecosystem since 1990s and they concluded that eight key elements need to be monitored for the comprehensive peatland assessment; (1) CO_2 flux and concentration, (2) Hotspots detection, (3) Forest degradation and species mapping, (4) Deforestation, forest biomass changes, (5) Ground water level and soil moisture, (6) Peat area and peat property, (7) Peat subsidence and (8) Water soluble organic carbon. As hyperspectral sensors which have more than 100 channels from VNIR (Visible Near Infrared) to SWIR (Short Wave Infrared) regions enable us to extract specific spectral information of various objects including above elements, its applications are expected to contribute to tropical peatland monitoring. Some examples of hyperspectral applications are introduced in this chapter.

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Keywords Hyperspectral sensor • Tropical peatland • Measurement • Reporting and verification (MRV) • Reducing Emission from Deforestation and forest Degradation (REDD+) • Dissolved Organic Carbon (DOC)

28.1 Introduction

Tropical peatlands preserve rich biodiversity with large carbon pool (81.7–91.9 Gt) and Indonesia especially has more than 60 % (50–60 Gt) of tropical peat carbon (Page et al. 2011). However, recent anthropogenic disturbances have had significant impacts to tropical peatland ecosystem. Particularly drainage system constructed in Pearland makes ground water level lower drastically. As a result, huge amount of carbon dioxide (CO_2) is released due to decomposition of soil carbon and peatland fire. It is thought that CO_2 emission will keep on increasing if no appropriate monitoring system is introduced into peatland monitoring. In Indonesia about 40 % of CO_2 emission was derived from peatland (DNPI 2010) and 25 % of which from peat fire (Ministry of Environment 2010). In 2009, Government of Indonesia made a commitment to reduce greenhouse gas (GHG) emissions by 26 % to Business as Usual (BAU) baseline with national support and by 41 % to BAU with international support by 2020. Subsequently, the enactment of the National Action Plan for Greenhouse Gas Emissions (RAN-GRK) and Local Action Plan for Greenhouse Gas Emissions (RAD-GRK) were made as a follow-up to the commitment. Since potential GHG reduction from forest and peat sector has been estimated to 88 % in the action plans, comprehensive monitoring system for peatland is needed.

Peatland monitoring can be conducted at three levels of altitude: from ground, airborne, and spaceborne. Hokkaido University and collaborative research group with Indonesian experts concluded that eight key elements are essential for reliable and comprehensive monitoring based on over 10-year long-term ground observation data in the peatland of Central Kalimantan, Indonesia. Proposed monitoring system is shown in Fig. 28.1 and the eight key elements are as follows;

1. CO_2 flux and concentration
2. Hotspots detection
3. Forest degradation and species mapping
4. Deforestation, forest biomass changes
5. Water level and soil moisture
6. Peat dome detection and peat thickness
7. Peat-subsidence
8. Water soluble organic carbon

All the eight elements are needed to form a comprehensive and full-scaled monitoring system in peatland. While for dry land forest monitoring system requires element of (3) and (4). Table 28.1 is a summarized matrix between target element and popular sensors/instruments at different monitoring layers. For example, CO_2

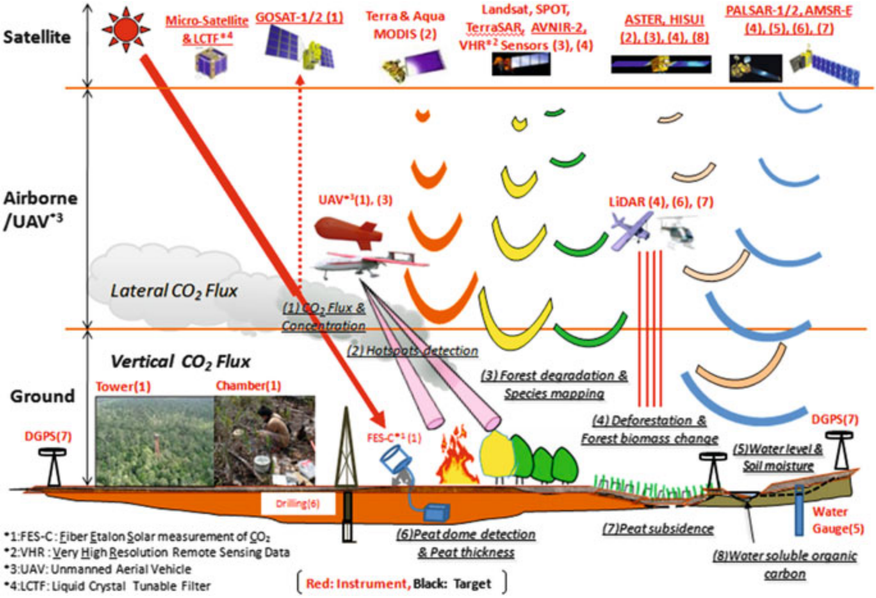


Fig. 28.1 Key elements of comprehensive MRV system in tropical peatland

concentration can be assessed by GOSAT-1, GOSAT-2 and OCO-2 at spaceborne layer, UAV at airborne layer and eddy covariance, closed chamber and fiber etalon solar measurement of CO2 (FES-C) at ground layer.

28.2 Hyperspectral Applications to Tropical Peatland Ecosystem Monitoring

Hyperspectral sensors have more than 100 channels in the VNIR to SWIR regions and enable us to differentiate specific spectral information of the objects. Hyperspectral Imager SUIte (HISUI), which has been developed by Ministry of Economy, Trade and Industry (METI) of Japan, is a spaceborne sensor which consists of a hyperspectral imager and a multispectral imager and it is planned to be launched after 2018. It has 185 bands (57 bands in VNIR, 128 bands in SWIR) with very high spectral resolutions (10–12.5 nm). Figure 28.2 shows a comparison of major multispectral sensors and HISUI hyperspectral sensor. It has the potential to allow not only forest species classification and forest degradation detection, but also estimation of water soluble organic carbon which plays an important role in the carbon cycle of tropical peatland. Thus HISUI hyperspectral sensor is expected to contribute to tropical peatland ecosystem monitoring. Some examples of forest and agriculture fields using airborne hyperspectral sensors are shown in Figs. 28.3 and 28.4.

Table 28.1 Popular sensors/instruments at different monitoring layers

Observation layer		Spaceborne										Airborne			Ground													
		Optical sensor					Radar				DEM		LiDAR	Unmanned arial vehicles (UAV)	Eddy covariance	Closed chamber	Fiber etalon solar measurement of CO2	Thermometer	Spectrometer	Tree allometry	Water gauge	Moisture meter	Leveling	Drilling	Differential GPS	Lazer range finder	TOC analyzer	CDOM analyzer
Type of sensor		GHGs measurement	Coarse resolution	Medium Resolution	Very High resolution	Hyper	L-Band	C-Band	X-Band	Other		Hyper																
Popular sensor		GOSAT-1/-2 OCO-2	MODIS	LANDSAT SPOT ASTER AVNIR-2	RapidEye Quickbird IKONOS	Hyperion HISUI	PALSAR PALSAR-2	ERS, Sentinel-1 RADARSAT	TerraSAR-X	AMSR-E	SRTM ASTER PRISM	HyMap CASI																
No.1	CO_2 Concentration	○												○	○	○	○											
	CO_2 Flux																											
No.2	Hotspot detection		○	○	○	○								○				○										
No.3	Forest degradation			○	○	○						○		○					○									
	Species mapping																											
No.4	Deforestation			○	○	○	○	○	○			○	○	○						○								
	Forest biomass change																											
No.5	Water level						○	○	○	○											○	○						
	Soil moisture																											
No.6	Peat dome detection						○	○			○		○										○	○				
	Peat thickness																											
No.7	Peat subsidence						○						○												○	○		
No.8	Water soluble organic carbon					○						○															○	○

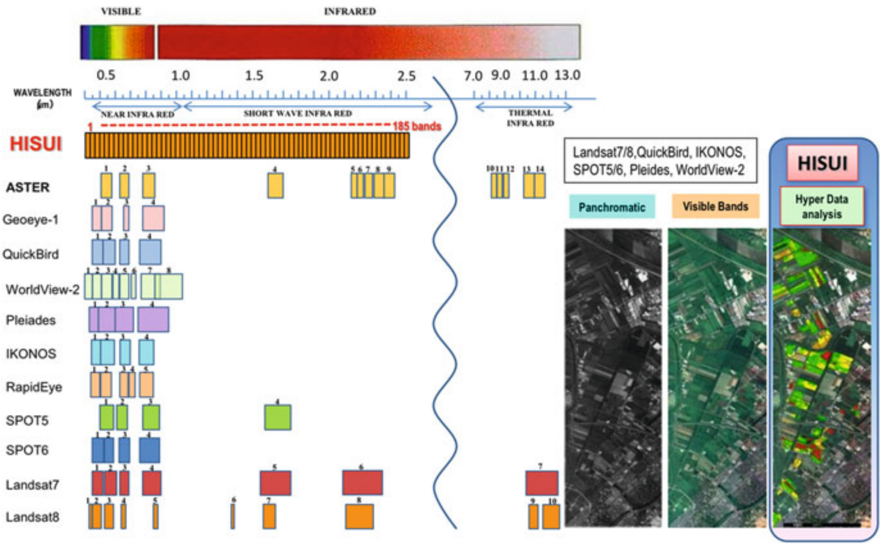
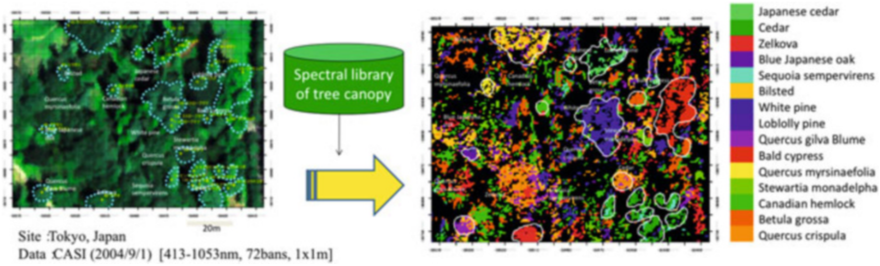


Fig. 28.2 Band distribution of major sensors in VNIR and SWIR



Site :Tokyo, Japan
Data :CASI (2004/9/1) [413-1053nm, 72bans, 1x1m]

Fig. 28.3 Example of forest species mapping by hyperspectral sensor (CASI)

Since hyperspectral sensors have more capacity by observing terrain objects with very high spectral resolutions, the following five elements are potentially assessed among the eight key elements on tropical peatland ecosystem monitoring.

(i) Forest degradation and species mapping
(ii) Deforestation, forest biomass changes
(iii) Water level and soil moisture
(iv) Peat dome detection and peat thickness
(v) Water soluble organic carbon

Most practical hyperspectral applications on climate change issues is to estimate (a) forest biomass, (b) ground water table from water index, and (c) determine the DOC concentration from estimated Colored Dissolved Organic Matter (CDOM) which have a great influence on the atmospheric carbon dioxide concentration.

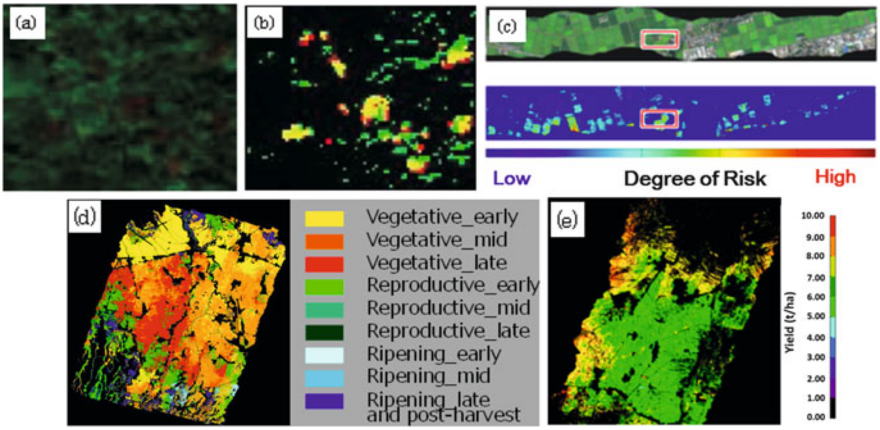


Fig. 28.4 Examples of forest and agriculture fields by hyperspectral sensors (AISA, CASI and HyMAP). (**a**) Oak tree observed by AISA, (**b**) Oak wilt areas detected by AISA (*Yellow* parts), (**c**) Early detection of rice blast, (**d**) Rice growth stage classification map, (**e**) Yield stage classification map

28.3 Study Area and Data Acquisition

This study was conducted in two sites located in Palangka Raya, Central Kalimantan, Indonesia (Site 1: Hampangen, Site 2: Taruna) and the Sebangau river (Fig. 28.5). Airborne hyperspectral images (HyMAP) were acquired in sites 1 and 2 on July 16 and July 15–16, 2011, respectively. HyMAP covers the visible to shortwave infrared regions with 128 bands. Spatial resolution and spectral resolution were at 4.2 m and 11–18 nm. As the preprocessing of data, each strip was atmospherically corrected by ATCOR4 and forest areas were extracted using non-parametric Support Vector Machine (SVM) method. Extracted forest areas were divided into the cross-track direction and tones were corrected so that the each strip has the similar pixel value and variance. Brightness variations between strips were adjusted based on the average pixel value and variance in the forest areas.

28.4 Field Data Analysis and Result

28.4.1 Biomass Estimation

A quadrat (20 × 20 m) was set considering the average height of trees in the area, and tree species, Diameter of Breast Height (DBH), tree height and canopy cover were recorded for estimation of the above-ground biomass. Methods used for measurement and analysis are summarized in Table 28.2. Least Absolute Shrinkage

Fig. 28.5 Study area

Table 28.2 Method of field survey and analysis

Parameters	Measurement	Analysis
Tree species	Tree species was recorded for individual trees with DBH ≥ 10 cm in a 20 m quadrat and for individual trees with 10 cm > DBH ≥ 5 cm in a 5 m sub-quadrat (A1,B1,C1,D1).	The number of trees and basal area were calculated by tree species for each quadrat to analyze the dominant species and biodiversity. Forest type classification was also performed by table manipulation.
DBH	DBH of trees was measured by a digital caliper for tree species survey.	The percentage of large-diameter trees among all trees in a quadrat was calculated.
Tree height	Considering the variance in DBH and tree species, 20 individual trees were selected from a 20 m quadrat and the tree height was measured by VERTEX.	A DBH-tree height model was developed from the height measurement of the 20 individual trees, which was then applied to estimate the height of all trees with DBH data.
Biomass		After biomass of each tree was calculated from DBH and tree height, biomass of the whole quadrat was estimated.
Canopy cover	Hemispherical photograph was taken by a fisheye camera near the center of a 10 m sub-quadrat.	Canopy cover was calculated from digital hemispherical photograph data using LIA32 software.

and Selection Operator (LASSO) regression was applied to develop the biomass estimation model using 86 bands reflectance data and texture analysis (Grey Level Co-occurrence Matrices: GLCM) as independent variables and biomass of each quadrat as an objective variable. Figure 28.6 shows the relationship between the estimated biomass values and field measured biomass values for all quadrats and quadrats under 300 t/ha. The results demonstrated high accuracy with RMSE of 49.10 t/ha when training data more than 300 t/ha were included and RMSE of 37.12 t/ha when data were limited to quadrats under 300 t/ha.

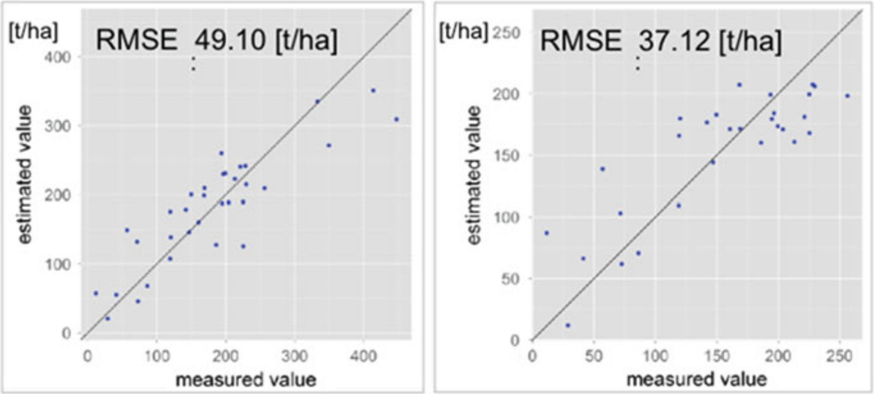


Fig. 28.6 Accuracy of biomass estimation model by LASSO regression. (*Left* Model using all quadrats, *Right* Model using quadrats under 300 t/ha)

28.4.2 Ground Water Level Estimation

For investigationof the ground water level, the upper branches in top layer canopy were collected, placed in water and taken to the hotel. Then, spectrum and water potential of a leaf were measured for every 3 h. Leaf weight was also measured using the electronic balance and water content was calculated from the ratio of fresh and dry weight. For some leaves, spectrum and water potential were measured in the field by portable field spectrometer (ASD FieldSpec 3FR) and psychrometer. Ground water level was determined using a water gauge made of a PCV pipe and by a vinyl hose. Numbers of trees used for sampling and leaves are shown below by tree species.

- *Combretocarpus rotundatus* (Miq.) Danser (Local name: Tumih):3 trees, 73 leaves
- *Cratoxylum glaucum* Korth. (Local name: Grunggang) :3 trees, 72 leaves
- *Palaquium leiocarpum* Blume:3 trees, 94 leaves
- *Shorea belangeran* Burck:3 trees, 73 leaves

28.4.2.1 Estimation of Ground Water Level from Water Index

For ground water level estimation, relationships between single leaf spectra, water content, water potential, and ground water level were analyzed with various water indexes. Water Band Index (WBI) and Normalized Multiband Drought Index (NMDI) were calculated for determination of water potential and water content as Eqs. 28.1 and 28.2 by adopting reflectance values at various spectral wavelengths.

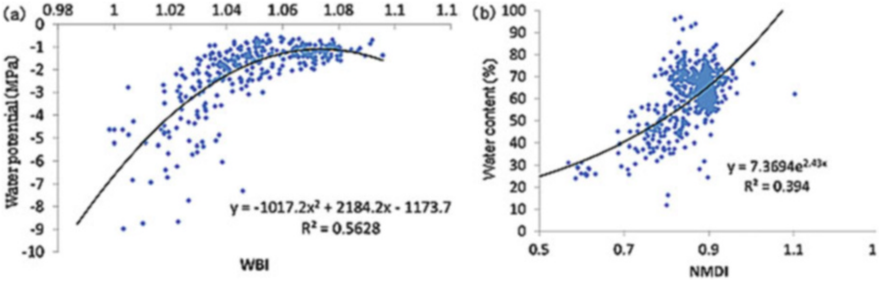


Fig. 28.7 All tree species samples for (**a**) water potential-WBI, (**b**) water content-NMDI

$$WBI = \frac{R_{970nm}}{R_{900nm}} \tag{28.1}$$

$$NMDI = \frac{R_{860nm} - (R_{1640nm} - R_{2130nm})}{R_{860nm} + (R_{1640nm} - R_{2130nm})} \tag{28.2}$$

Estimation equations were developed using a polynomial model to account for the relationship between water potential and WBI (Fig. 28.7a) and the relationship between water content and NMDI (Fig. 28.7b). While water potential and water content both showed association with the water index, the coefficient of determination for water content was lower than that for water potential, indicating the difficulty for modeling with water content. As the water table gets lower the water potential is decreased to maintain the flow of water from the soil to the leaf (Eamus 2009). It suggests that water potential can serve the indicator of ground water level when water potential is estimated from WBI.

28.4.3 Dissolved Organic Carbon (DOC) Estimation

Peat water samples were simultaneously collected in conjunction with the HyMAP overpass on July 15–16, 2011. Sample sites were located in the two rivers, Sebangau River and Kahayan River, and in the inland ponds and canals. At each sample site, the location was recorded by GPS and the depth of river and the water quality data (pH, Total Dissolved Solid (TDS), conductivity, Dissolved Oxygen (DO), Oxidation Reduction Potential (ORP), temperature) was measured with water reflectance by spectrometer (ASD FieldSpec 3FR) from 400 to 2,500 nm. Water samples were collected in pre-rinsed sample bottles which were stored in an ice-box immediately to preserve the samples' original condition. Before the laboratory analysis, the collected water samples were filtered with 0.2 and 0.45 μm membrane filter.

DOC is identified as the most significant form of carbon export from peatlands, and it has been found to be between 51 and 88 % of fluvial carbon export (e.g. Hope et al. 1997; Dawson et al. 2002). Moore et al. (2013) found that leaching of dissolved

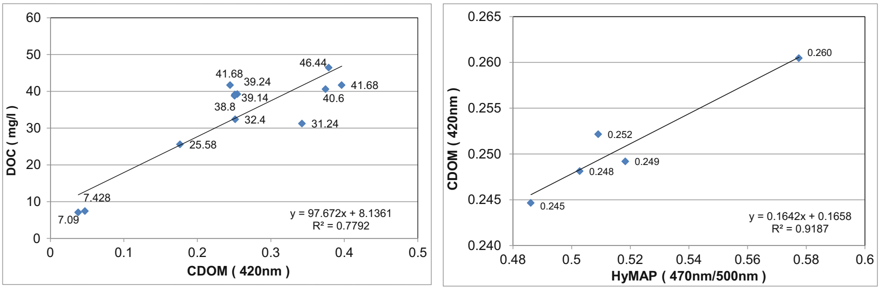


Fig. 28.8 *Left* Correlation of DOC and CDOM (*Right*) Correlation of CDOM and HyMAP

organic carbon from intact peat swamp forest is derived mainly from recent primary production (plant growth). In contrast, dissolved organic carbon from disturbed peat swamp forest consists mostly of much older (centuries to millennia) carbon from deep within the peat column. Thus, monitoring DOC is an essential process to estimate dynamic carbon flux in a peatland ecosystem. As concentrations of CDOM and DOC are strongly correlated (Tranvik 1990), DOC is estimated by CDOM from the satellite data (Kutser et al. 2005). Figure 28.8 shows the correlation between DOC and CDOM absorption at 420 nm by laboratory analysis of water samples. Figure 28.8 shows the strong correlation between CDOM at 420 nm in laboratory analysis and the spectral ratio at 470 and 500 nm acquired by HyMAP. These results demonstrated that DOC can be estimated by CDOM absorption suggested by hyperspectral data. Thus, it is expected that entire fluvial peatland carbon loss as DOC can be evaluated using hyperspectral data. In peatland, DOC concentration depends on soil carbon content and the degree of peat degradation. Monitoring DOC is an important process to estimate dynamic carbon flux in a tropical peatland ecosystem.

As the conclusion, hyperspectral applications contribute to tropical peatland ecosystem monitoring and the Measuring, Reporting and Verification (MRV) system in the context of Reducing Emission from Deforestation and forest Degradation (REDD+).

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Chapter 29
Land Change Analysis from 2000 to 2004 in Peatland of Central Kalimantan, Indonesia Using GIS and an Extended Transition Matrix

**Yan Gao, Robert Gilmore Pontius Jr., Nicholas M. Giner,
Takashi S. Kohyama, Mitsuru Osaki, and Kazuyo Hirose**

Abstract This chapter analyzes the land cover transitions for a tropical peatland in Central Kalimantan, Indonesia. We constructed a transition matrix using land cover maps derived from classified Landsat images obtained from the years 2000 to 2004, and analyzed the transitions among Forest, Bare land, and Grass land. The results give insights of interpretations of land cover transitions and intensity analysis. Forest is involved in most of the changes; however, it is the only dormant category. The systematically avoiding transitions were from Forest to Bare land and from Bare land to Forest, in spite of the fact that the largest transition was from Forest to Bare Land. The systematically targeting transitions were from Bare land to Grass land and from Grass land to Bare land. In order to develop a deeper understanding of land cover transition, it is recommended to combine this method of analyzing the patterns of change with other types of research concerning the processes of change.

Keywords Deforestation • Transition matrix • Central Kalimantan

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29.1 Introduction

Tropical forests have garnered increased attention from scientists and resource managers due to the influence of these forests on biodiversity, atmospheric greenhouse gas concentrations, and regional climate (Fuller 2006). In places such as the Brazilian Amazon, southern Central America, the Congo Basin in Africa, and Southeast Asia, tropical forests are undergoing rapid anthropogenic changes, the most important of which is deforestation (Alves et al. 1999; Achard et al. 2002; Lambin et al. 2003; Guild et al. 2004). Worldwide, the highest annual rates of deforestation occur in Southeast Asia, particularly in the humid tropical forests of Sumatra, Vietnam, Cambodia, Myanmar, and Borneo (Achard et al. 2002; Lambin et al. 2003). In the Central Kalimantan province of Indonesian Borneo, commercial logging started during the 1960s, and by 1980, one-fifth of Kalimantan forests had been logged (Ramankutty et al. 2006). Additional forest losses occurred during the droughts of the 1982–1983 El Niño, when 2.7 million hectares tropical rainforest burned (Barber and Schweithelm 2000), and during the 1997–1998 El Niño when almost 5 million hectares of forests were damaged (Barber and Schweithelm 2000). Large areas of tropical peat swamp forests have been destroyed, this is land that supports the local population and contains huge amounts of carbon and supports biodiversity (Nuri et al. 2011; Hecker 2005). Tropical peat swamp forests naturally co-exist with tropical peatlands, which have accumulated huge stocks of soil carbon over millennia (Sorensen 1993; Hirano et al. 2007). However, land management practices have impaired the natural resource functions of the peatland ecosystem and increased its susceptibility to fire (Page et al. 2002). The Ex-Mega Rice Project (EMRP) resulted in the conversion of 1.7 million hectares of peat swamp forest into agriculture and the opening of over 4,000 km of canals (Hecker 2005). The canals drained water from the peatland and left the peat areas drier and more susceptible to fire. Fires cause carbon contained in peat soil to transfer to the atmosphere (Osaki et al. 2010). Deforestation and swamp forest fires cause peat degradation as tropical peatland switches from being a carbon sink to become a carbon source (Sorensen 1993). Deforestation in this region has the potential to lead to serious global consequences, since peat swamp forest ecosystems host exceptionally high biodiversity and immense amounts of carbon (Miettinen et al. 2011).

A number of recent studies have used geographic information systems (GIS) and remote sensing data and to examine spatial-temporal changes in forest cover in Central Kalimantan and the potential influence on biodiversity, atmospheric greenhouse gas concentrations, and regional climate of the changes. For example, Moderate Resolution Imaging Spectroradiometer (MODIS) data showed that nearly 3 million hectares of Kalimantan's forest were lost between 1996 and 2002 as a result of the major El Niño event of 1997–1998 and the subsequent drought and fires (Fuller et al. 2004). In a similar study, MODIS data showed that over 7 million hectares of forest were lost across the entire island of Borneo between 2002 and 2005, at an average rate of 1.7 % per year of the total area (Langner et al. 2007).

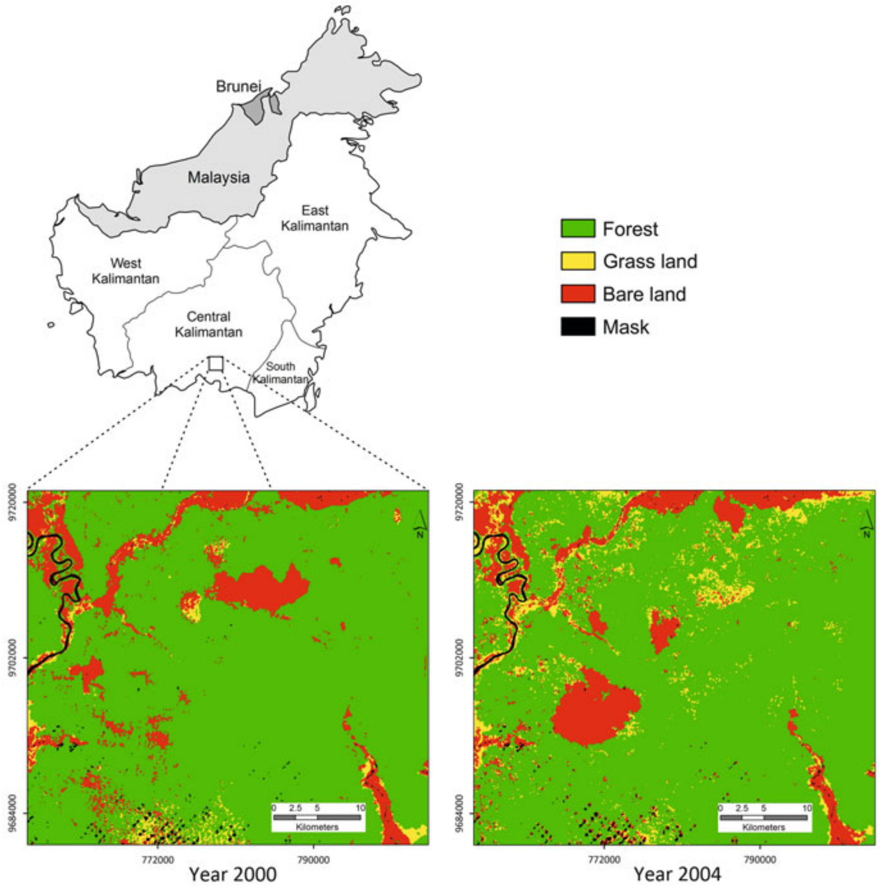
Another important finding is that 98 % of all forest loss during this period occurred along forest edges, which is the area most accessible to farmers and illegal logging operations (Langner et al. 2007). Landsat imagery revealed rates of deforestation in East Kalimantan from three time intervals: 1983–1990, 1990–1998, and 1998–2000 (Dennis and Colfer 2006). The 2,160 km^2 study area experienced a mean deforestation rate of 6 % per year between 1983 and 2000, while 70 % of areas classified as forest in 1983 had changed to non-forest by 2000 (Dennis and Colfer 2006). Deforestation rates were 1 % of the total area in insular Southeast Asia with the main changes being to plantations and secondary vegetation during 2000–2010 according to a pair of 250 m spatial resolution land cover maps (Miettinen et al. 2011). Peatland/forest experienced an average annual loss of 2.2 % of the total areas, which was greater than the loss of mangrove, lowland evergreen forest, lower montane forest, and upper montane forest (Miettinen et al. 2011).

In recent years, advances in GIS and remote sensing have allowed scientists to develop a number of methods and metrics for detecting and measuring land-cover changes such as deforestation. In its simplest form, land-cover change detection involves the comparison of spatially registered maps from two or more time points (Rogan and Chen 2004). Changes in land-cover can be analyzed by overlaying maps from two time points to derive a change matrix, where the matrix rows show the map categories from the initial time point, i.e. time 1, and the columns show the categories from a subsequent time point, i.e. time 2. The row totals and column totals indicate the category level totals from times 1 and 2, respectively. Previous studies have used these matrices to analyze land-cover changes over time (Eiden et al. 2002; Vasconcelos et al. 2002; Lo and Yang 2002; Wardell et al. 2003; Guild et al. 2004; Currit 2005; Mundia and Aniya 2005; Dennis and Colfer 2006; Koh et al. 2011), yet one must be careful to interpret the results. For example, reporting only net quantity change in a land-cover category can be misleading because the net quantity change allows for gross gains and gross losses in a land-cover category to cancel each other out (Manandhar et al. 2010). Put differently, gross gains in a category on one part of the landscape may be cancelled by gross losses in that category in a different part of the landscape, resulting in an overall lack of net quantity change in that category, even though true land-cover changes actually occurred. Allocation change occurs when a category experiences gross gains in some places and gross losses in other places (Pontius et al. 2004). Therefore, failing to account for Allocation changes can cause researchers to potentially ignore important signals of land-cover change (Pontius et al. 2004).

Intensity Analysis allows systematic detection of targeting or avoiding transitions (Aldwaik and Pontius 2012). Applications of Intensity Analysis span six continents, for example in: Africa (Alo and Pontius 2008), Asia (Villamor et al. (2014), Australia (Manandhar et al. 2010), Europe (Pérez-Hugalde et al. 2011), North America (Pontius et al. 2004), and South America (Romero-Ruiz et al. 2011).

29.2 The Study Area and Data

The study area in this paper is located in Central Kalimantan province, Indonesia, on the island of Borneo (Fig. 29.1). It covers 1,896 km^2 between the Sebangau and Katingan Rivers, where is mainly peatland. The climate is hot and humid year round, with an annual rainfall of about 2,400 mm, and the daily temperature varying from 25 to 33 °C (Mirmanto 2010). The natural vegetation is composed mainly of tropical peatland/forest under permanently wet conditions. Tropical peatland/forest has important ecological functions and it contains a unique flora and fauna (Miettinen et al. 2011). The natural vegetation has been reduced to a degraded state through continuing deforestation and land-cover changes (Langner et al. 2007). The main driving force in the forest cover loss are illegal logging, forest fires, and small-scale agricultural expansion (Miettinen et al. 2011). Large-scale peatland fires occurred in Central Kalimantan from August to October of 2002, because of the drought caused



Year 2000

Year 2004

Fig. 29.1 The *upper* part shows the location of the study area and the *lower* part shows the land cover classified images in 2000 which is *below left* and 2004 *below right* by El Niño and the Southern Oscillation (ENSO) (Siegert et al. 2004; Hirano et al. 2012). After fire events, peatland/forest is destroyed and vegetation regeneration takes place promptly because of the warm and humid weather condition. Fern grass is the pioneer vegetation after fire destruction.

The data for this study includes two Landsat scenes from path 118 and row 62: one ETM+ scene from 16 July 2000 and one TM scene from 17 June 2004. We chose these dates because we carried out a field survey in this region during July 2011, and we assumed similar phenology conditions for the land-cover types. We used the image from June because we could not identify a cloudless image for July 2004. The satellite images were geometrically corrected with ground control points that were evenly distributed throughout the study area, and the correction error was within 1 pixel. Atmospheric correction was performed using the FLAASH module, available in the ENVI 4.0 software. The atmospheric correction removed the influence of aerosols that primarily affect reflectance values in the short wavelength regions of the electromagnetic spectrum.

We applied unsupervised image classification using the ISODATA clustering algorithm (Lo and Yang 2002; Mundia and Aniya 2005) to the two Landsat images. The spectral clusters were labeled using the information from the Landsat-derived color composites and NDVI images, land-cover spectral reflectance characteristics, and field knowledge. Three land-cover categories were assigned: Forest, Grass land, and Bare land. A mask eliminates water and clouds at both time points. Figure 29.1 shows the two classified images. We do not have information concerning the accuracy of the maps because we do not have ground information to assess the classified images for 2000 and 2004.

29.3 Total Change, Gain, Persistence and Loss

After we obtained the classified maps, we constructed a transition matrix by cross-tabulating the two land-cover classification maps. Table 29.1 shows the matrix in terms of both number of pixels and percent of the map. The nine entries in the upper left show the transitions. The three diagonal entries indicate persistence of categories, and the six off-diagonal entries indicate transition from one category to a different category. We appended a column on the right that shows the category totals in 2000 and a row at the bottom that shows the category totals in 2004. We also appended an additional column on the right that indicates loss by category, and an additional row at the bottom that indicates gain by category. The size of a category in 2000 is the sum of its persistence and loss. The size of a category in 2004 is the union of its persistence and gain. The entry in the extreme lower right indicates total change as a percent of the map.

As shown in Table 29.2, the sums of the change information from Table 29.1 as gain, persistence, and loss for each category give a total change as happening in 16.9 % of the map and 83.1 % of the map remain shows persistence. For each individual category, with Forest as an example, it gains in 5.1 % and loses in 9.7 % of the map. The actual change of Forest happens in 14.8 % of the map, and of

Table 29.1 Transition matrix from 2000 to 2004, in both number of pixels (normal font) and percent of map (italic font)

		2004				
		Forest	Grass land	Bare land	Time 2000	Loss
2000	Forest	1,601,831	84,152	118,230	1,804,213	202,382
		76.8	*4.0*	*5.7*	*86.5*	*9.7*
	Grass land	23,758	18,816	6,596	49,170	30,354
		1.1	*0.9*	*0.3*	*2.4*	*1.5*
	Bare land	82,504	36,597	114,070	233,171	119,101
		4.0	*1.8*	*5.5*	*11.2*	*5.7*
Time 2004		1,708,093	1,39,565	2,38,896	2,086,554	3,51,837
		81.9	*6.7*	*11.5*	*1.00*	*16.9*
Gain		106,262	1,20,749	124,826	351,837	
		5.1	*5.8*	*6.0*	*16.9*	

Table 29.2 Components of change and persistence in terms of the percentages of the map

Land/cover	Gain	Persistence	Loss	Category total	Swap location change	Net quantity change
Forest	5.1	76.8	9.7	14.8	10.2	4.6 (loss)
Grass land	5.8	0.9	1.5	7.3	3.0	4.3 (gain)
Bare land	6.0	5.5	5.7	11.7	11.4	0.3 (gain)
	16.9	83.1	16.9			

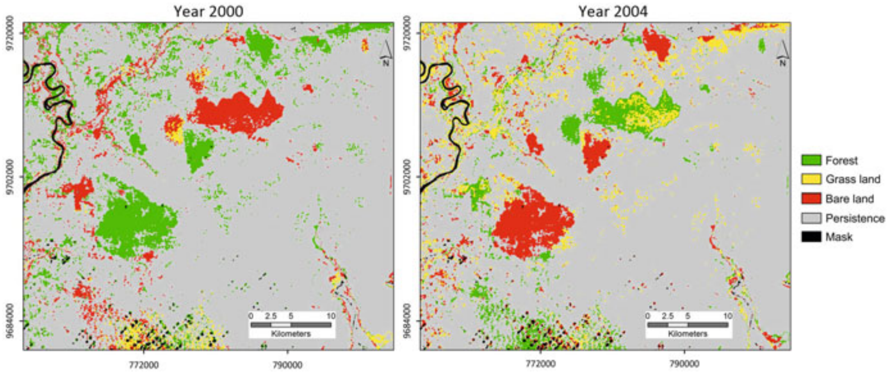


Fig. 29.2 Gain, persistence, and loss in 2000 and 2004 (The figure on the *left* shows the losses and the figure on the *right* shows the gains of the three land cover categories in the land changes for 2000–2004)

this 10.2 % is cancelled out, resulting in a net change of a forest loss of 4.6 % of the map area. Most noteworthy is the change in Bare land where a total change of 11.7 % as the sum of its gain and loss becomes only 0.3 % of net gain, with 11.4 % disappearing by the changes in gains and losses.

To illustrate the gains, losses and persistence of each category, Fig. 29.2 shows the losses in 2000 and the gains in 2004 as reflected in the three categories and persistence information.

29.4 Intensity Analysis

Based on the change matrix (Table 29.1), we calculated the intensity of the gains and losses by category as shown in Table 29.3.

The loss intensity of a category is calculated by dividing the loss of a category with the size of the category in 2000. The gain intensity of a category is calculated by dividing the gain of a category with the size of the category in 2004. The uniform change intensity for all three category is 16.9 %. and if a category's gain or loss intensity is smaller than this uniform change intensity, then the category is dormant in terms of the gain or loss process. If a category's gain or loss is larger than the uniform change intensity, then the category is active. Forest is dormant in terms of both gain and loss since both of its loss and gain intensity is smaller than the uniform intensity. On the other hand, Grass land and Bare land are active in terms of both gain and loss since both of their loss and gain intensity are larger than the uniform intensity.

Tables 29.4, 29.5 and 29.6 compare the observed transition intensities to the hypothesized uniform transition intensities. Taking transition intensity of Forest as an example (Table 29.4), the transition intensity of Forest to Grass land is calculated by dividing the area of the Grass land in 2004 which is 6.7 of the domain with the area of the loss of Forest to Grass land which is 4.0 of the domain, and we obtain

Table 29.3 Intensity of gains and losses by category

	Forest	Grass land	Bare land
Loss	9.7	1.5	5.7
2000 total	86.5	2.4	11.2
Loss intensity	11.2	62.5	50.9
Gain	5.1	5.8	6
2004 total	81.9	6.7	11.5
Gain intensity	6.2	86.6	52.2
Uniform change	16.9	16.9	16.9

Table 29.4 Transition intensity of forest

Forest transition	Percent of map	Intensity (percent of category)
Lose to grass land	4.0	59.7
Grass land 2004	6.7	
Lose to bare land	5.7	49.6
Bare land 2004	11.5	
Uniform loss		53.3
Gain from grass land	1.1	45.8
Grass land 2000	2.4	
Gain from bare land	4.0	35.7
Bare land 2000	11.2	
Uniform gain		37.5

Table 29.5 Transition intensity of grass land

Grass land transition	Percent of map	Intensity (percent of category)
Lose to forest	1.1	1.3
Forest 2004	81.9	
Lose to bare land	0.3	2.6
Bare land 2004	11.5	
Uniform loss		1.5
Gain from forest	4.0	4.6
Forest 2000	86.5	
Gain from bare land	1.8	16.1
Bare land 2000	11.2	
Uniform gain		5.9

Table 29.6 Transition intensity of bare land

Bare land transition	Percent of map	Intensity (percent of category)
Lose to forest	4.0	4.9
Forest 2004	81.9	
Lose to grass land	1.8	26.9
Grass land 2004	6.7	
Uniform loss		6.5
Gain from forest	5.7	6.6
Forest 2000	86.5	
Gain from grass land	0.3	12.5
Grass land 2000	2.4	
Uniform gain		6.7

the loss intensity of Forest to Grass land of 59.7 %. The hypersized uniform loss intensity of Forest is calculated by dividing the sum of Grass land and Bare land in 2004 with the sum of loss of Forest to Grass land and to Bare land. If a transition is smaller than the uniform transtion, then the transition avoids. If a transition is larger than the uniform transition, then the transition targets. The Gain intensity of Forest from Grass land is calculated by dividing the size of Grass land in 2000 with the gain of Forest from Grass land. In a similar way we calculate the gain intensity of Forest from Bare land and the hypersized uniform gaining intensity. Table 29.4 shows that the gain of Forest targets Grass land and avoids Bare land since the gain intensity of Forest from Grass land, 45.8 %, is higher than the uniform gain intensity, 37.5 %, and the gain intensity of Froest from Bare land, 35.7 %, is smaller than the uniform gain intensity, 37.5 %. Table 29.4 also shows that Grass land targets and Bare land avoids the loss of Forest since the loss intensity of Forest to Grass land, 59.7 %, is larger than the uniform loss intensity, and the loss intensity of Forest to Bare land is smaller than the uniform loss intensity. Table 29.5 shows that the gain of Grass targets Bare land and avoids Forest, while Bare land targets and Forest avoids the loss of Grass land. Table 29.6 shows that the gain of Bare land targets Grass land and avoids Forest, while Grass land targets and Forest avoids the loss of Bare land. Thus the systematically targeting transitions are from Grass to Bare land and from Bare land to Grass land; while the systematically avoiding transitions are from Bare land to Forest and from Forest to Bare land.

29.5 Discussion

Forest in peatland is the natural land cover in the Kalimantan study site due to the its biophysical factors. When Forest in peatland losses to Bare land, we assume the natural recovery process in peatland of Kalimantan is a sequence of transitions from Bare land to Grass land to Forest, in which case researchers might anticipate that the transition from Bare land to Forest would be smaller than the transition from Grass land to Forest. However, the transition from Bare land to Forest is larger than the transition from Grass land to Forest (Table 29.1). Intensity Analysis explains the relative sizes of these two transitions by considering the sizes of Bare land and Grass land at the initial time. There is more Bare land than Grass land at the initial time; thus, if Forest were to gain with uniform intensity from both non-Forest categories at the initial time, then the transition from Bare land to Forest would be larger than the transition from Grass land to Forest. Intensity Analysis shows that the gain of Forest targets Grass and avoids Bare (Table 29.4), which matches our assumed process of Forest gain. The main causes of Forest loss in this region of Kalimantan are forest fires, agricultural expansion, and illegal logging. Uncontrolled fires often cause deforestation, which is likely to produce Bare land, whereas intensive logging and agricultural expansion degrade forest into secondary vegetation, which is likely to produce Grass land. The transition from Forest to Bare land is larger than the transition from Forest to Grass land (Table 29.1), which seems initially to indicate that fire is more responsible than other drivers for Forest's loss. However, transition intensities indicate that Bare land avoids the loss of Forest while Grass land targets the loss of Forest (Table 29.4), which seems to indicate that fire is less responsible than other drivers for Forest's loss. Proper interpretation requires proper understanding of how the sizes of the categories at both time points influence the transition intensities, and how the selection of the study site influences the sizes of the categories at both time points.

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Chapter 30
Estimation Model of Ground Water Table at Peatland in Central Kalimantan, Indonesia

Wataru Takeuchi, Takashi Hirano, and Orbita Roswintiarti

Abstract This research is investigating the ground water table at forested peatland in Kalimantan which is expected to be an indicator for better wild fire control. Firstly, modified Keeth-Byram drought index (mKBDI) was computed by incorporating satellite-based precipitation GSMaP and MTSAT land surface temperature (LST). Secondly a regression analysis was carried out between mKBDI and near surface ground water table (GWT) measurements at drained forest (DF), un-drained forest (UF) and drained burnt forest (DB) respectively. Overall a modeled GWT at forested peatland showed very good time-series of behaviors along with that of in-situ measurement. A modeled GWT was more sensitive to precipitation resulting in a drastic water table rise-up and more calibration is indispensable to get a better result. A comparison of GWT and hotpot detected by MODIS showed that lower GWT areas clearly have more fire occurrences. It was found that mKBDI was well calibrated with GWT at the above mentioned three measurements sites and a very good indicator for peat fire risk zone mapping at forested peatland. These modeling results are updated in a near-real time fashion and all the database are open to public at http://jica-jst.lapanrs.com/GWT/.

Keywords Evapotranspiration • Precipitation and hotspots

30.1 Introduction

Tropical forests in peatland grow over tropical peatlands, which are widely distributed in at lowlands in Southeast Asia. Deforestation and drainage have been in progress on a large scale because of growing demands for timber and farmland

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since 1980s. In addition to that, the El Nino drought and its consequent fires are accelerating the forest devastation. The forest devastation alters energy balance and will influence regional climate (Hirano et al. 2005).

Tropical vegetation is a major source of global land surface evapotranspiration, and can thus play a major role in global hydrological cycles and global atmospheric circulation (Mu et al. 2007). Accurate prediction of tropical evapotranspiration is critical to our understanding of these processes under changing climate (Fisher et al. 2009). A tropical ombrotrophic peatland ecosystem is one of the largest terrestrial carbon stores. Flux rates of carbon dioxide (CO2) and methane (CH4) were studied at various peat ground water table (GWT) depths in a mixed-type peatland floor in Central Kalimantan, Indonesia (Jauhiainen et al. 2005). GWT is one of the most important factor to control floor peat fire as well. Since water balance in peat ecosystem is still uncertain, it is indispensable to devise a method for the estimation of the ground water table in forested peatland.

A method to assess spatial and temporal patterns of actual evaporation was carried out by relating water balance evaporation estimates to satellite-derived radiometric surface temperature (Bouwer et al. 2008). Evapotranspiration (ET) data measured using micrometeorological equipment were obtained from three separate studies conducted in arid and semi-arid shallow groundwater environments in California, New Mexico and Colorado (Groeneveld et al. 2007).

The Keetch-Byram drought index (KBDI) is a continuous reference scale for estimating the dryness of the soil and duff layers. The index increases for each day without rain (the amount of increase depends on the daily high temperature) and decreases when it rains. The scale ranges from 0 (no moisture deficit) to 800. The range of the index is determined by assuming that there is 8 in. of moisture in a saturated soil that is readily available to the vegetation (Keetch and Byram 1968). KBDI is world widely used for drought monitoring for national weather forecast and a wild fire prevention. Tall evergreen trees and herbaceous vegetation on the land surface limit the use of satellite remote sensing for the direct measurements of land surface soil moisture or underground water table condition. Our scientific hypothesis is that KBDI represent a condition of evapotranspiration of tropical vegetation and peatlands, and it could be an indicator of ground water.

30.2 Ground Water Table Estimation by KBDI

Figure 30.1 shows an area of interest in this study which covers a central Kalimantan from 1S to 4S in latitude and 113E–116E in longitude. The study site is located near Palangkaraya, the capital city of Central Kalimantan province, Indonesia. The tropical peatland is located between the Sebangau River and the Kahayan River. A canal runs in the forest and functioned as drainage and the terrain is very at, with no undulations, and its elevation is only about 30 m above sea level (Hirano et al. 2007). There are three in-situ ground water table measurement sites including drained forest (DF), un-drained forest (UF) and drained burnt

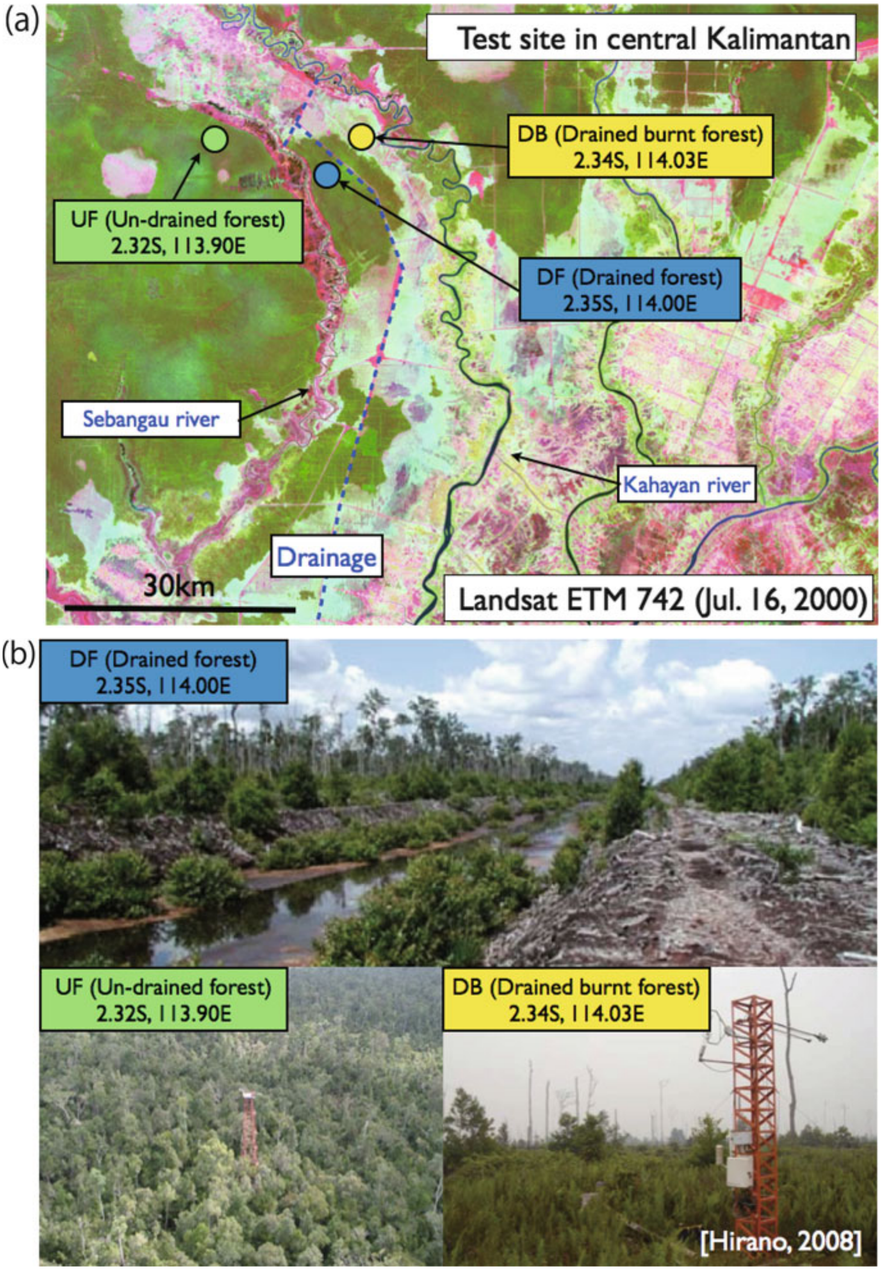


Fig. 30.1 An area of interest in this study which covers a central Kalimantan from 1S to 4S in latitude and 113E–116E in longitude. (**a**) Area of interest in a central Kalimantan (**b**) Pictures taken at in-situ ground water table measurement sites

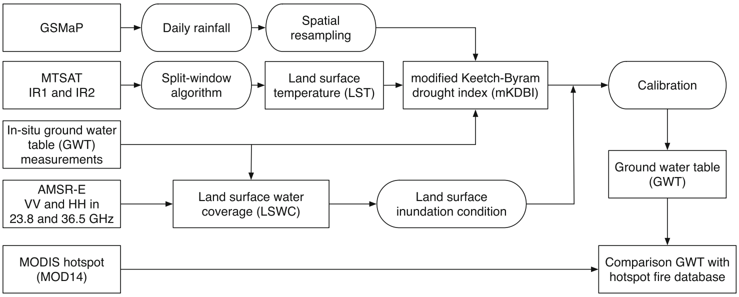


Fig. 30.2 Flowchart of a framework of ground water table (GWT) mapping

forest (UB). Annual average temperature of the test site is 28–33 (degrees in Celcius) and evapotranspiration is 3.5–3.8 (mm/day) measured by the flux tower measurement.

Figure 30.2 shows a framework of ground water table (GWT) mapping using drought index. Five types of data are prepared including; (a) Global Satellite Map of Precipitation (GSMaP), (b) MTSAT IR1 and IR2 for land surface temperature retrieval (Oyoshi et al. 2010), (c) In-situ ground water table measurements (GWT) (Hirano et al. 2005), (d) AMSR-E VV and HH polarization data in 23.8 and 36.5 GHz to compute land surface water coverage (LSWC) (Takeuchi et al. 2009) and (e) MODIS host spot product (MOD14) to map wild fire occurrence at forested peatland.

Firstly hourly GSMaP maps are summed up to compute daily rainfall and they are resampled from 10 to 4 km resolution via bi-linear interpolation method. Secondly MTSAT IR1 (10.5 μm) and IR2 (11.5 μm) channels are used to computer land surface temperature (LST) by using split-window method (Oyoshi et al. 2010). LST maps are computed on hourly basis in 4 km resolution and a daily maximum LST map is derived by a maximum compositing of 24 scenes in 1 day observations. Thirdly modified Keetch-Byram drought index (mKBDI) is computed by using the Eq. 30.1. Since (Keetch and Byram 1968) defines KBDI as a partial derivative formula only, we have originally defined mKBDI by adding a daily rainfall **r** (mm/day) in addition to maximum daily temperature **T** (degrees in Celcius) and an annual rainfall **R** (mm/year) as shown in Eq. 30.1.

$$\boldsymbol{mKBDI} = \times 100\boldsymbol{r} + \frac{0.968\,(800 - \boldsymbol{mKBDI}_0)\,exp\,(0.486\boldsymbol{T})}{1.00 + 10.88 exp\,(-0.441\boldsymbol{R})} \tag{30.1}$$

$$\boldsymbol{GWT = -0.0045 \times mKBDI}, \tag{30.2}$$

where $\boldsymbol{mKBDI}_0$ stands for a initial value of $\boldsymbol{mKBDI}$ which is calibrated with in-situ measurements of ground water table.

A linear regression analysis is carried out between Satellite-based daily mKBDI values and in-situ ground water table (GWT) measurements. AMSR-E polarimetric measurements are used to compute land surface water coverage (LSWC) and its performance to identify land surface inundation conditions are used as a supplemental data for GWT map. Finally GWT is estimated as shown in Eq. 30.2 and daily GWT map from 2007 to 2012 are compared with hotspot fire database at forested peatland by using MOD14 product.

A Fig. 30.3 shows a comparison of in-situ measurement of ground water table (GWT), modeled GWT and rainfall at three reference sites including drained forest (DF), drained burnt forest (DB) and un-drained forest (UF). A positive value of

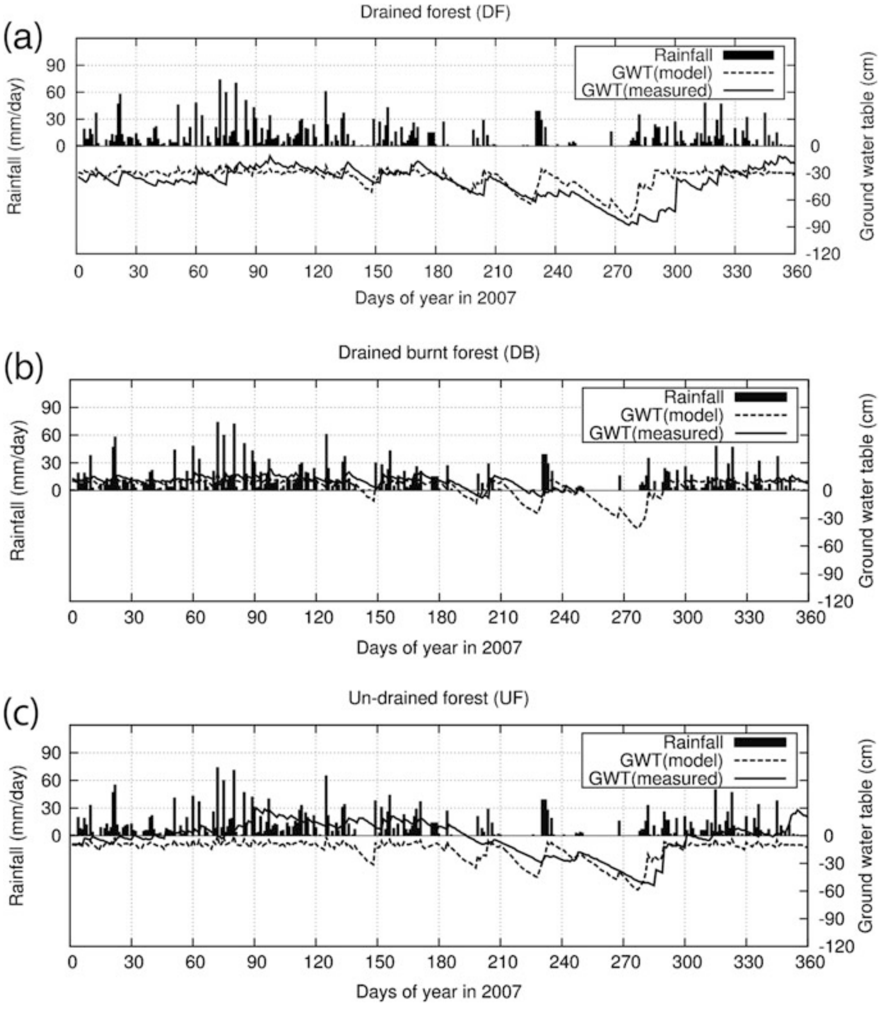


Fig. 30.3 Comparison of in-situ measurement of ground water table (GWT), modeled GWT and rainfall at three reference sites. (**a**) Drained forest (DF), (**b**) Drained burnt forest (DB) (**c**) Un-drained forest (UF)

GWT shows that land surface is totally inundated during that period. Overall a modeled GWT at three sites shows very good time-series of agreements along with those of in-situ measurements. A modeled GWT is more sensitive to rainfall resulting in a drastic water table rise-up around days of year (DOY) 220 and 280 for DF site and DOY 190 and 240 in UDF site. This implies that a daily rainfall **r** is overestimated and more calibration data is indispensable to get a better results. A modeled GWT tends to overestimate than that of in-situ measurements in greater GWT values, however, those are to be safely estimates to show drier peat soil conditions from peat fire prevention and mitigation point of view.

30.3 Spatio-Temporal Characteristic of a Modeled GWT

Figure 30.4 shows a comparison of ground water table map and land cover classification in Oct. 10, 2007. Lower GWT area shown in Fig. 30.4a mainly corresponds to croplands shown in Fig. 30.4b. It is very interesting that the forested area in the Southeast of our test site has very low GWT values less than 1.5 m in contrast to that of in the Northwest where GWT is higher than 0.5 m.

Figure 30.5 represents a comparison of ground water table map from 2007 to 2010. A GWT map of 2007 and 2010 are shown as an example of La Nina year, that of 2008 normal year and that of 2009 El Nino year. A horizontal transect of GWT from point A and B shows very clear contrast among those 3 years of measurements. The point A is covered mainly by forest and B by croplands. It is very interesting that GWT at A (forested area) of 2009 is higher than that of 2008 whereas GWT at B (croplands) of 2009 is much lower than those of 2007 and 2008.

Table 30.1 shows an area statistics of GWT in the central Kalimantan as shown in Fig. 30.5. We classified all the areas into three zones with safe (GWT is higher than −0.5 m), moderate (GWT is between −0.5 and −1.0 m) and dangerous (GWT is lower than −1.0 m) with respect to peat fire subjectivity. Those 3 years statistics shows clear contrast in safe and dangerous zones so that comparatively larger danger zone are found in La Nina year 2007, less area in El Nino year 2009 and 2008 in-between of those. It is very surprising that around 25–30 % of this area are identified as dangerous zone and are subject to peat fires at high risk.

30.4 Relationship Between Fire Occurrence and GWT

Figure 30.6 is a relationship between hotspot detected by MODIS and ground water table from 2007 to 2011. Circle stands for an average value of GWT and error bar shows a standard deviation of GWT in 1 year. We found that GWT and the number of hotspots are in a clear relationship with the fact that there are more peat fire events where GWT is lower GWT can be a very good indicator for peat fire risk zone mapping at forested peatland.

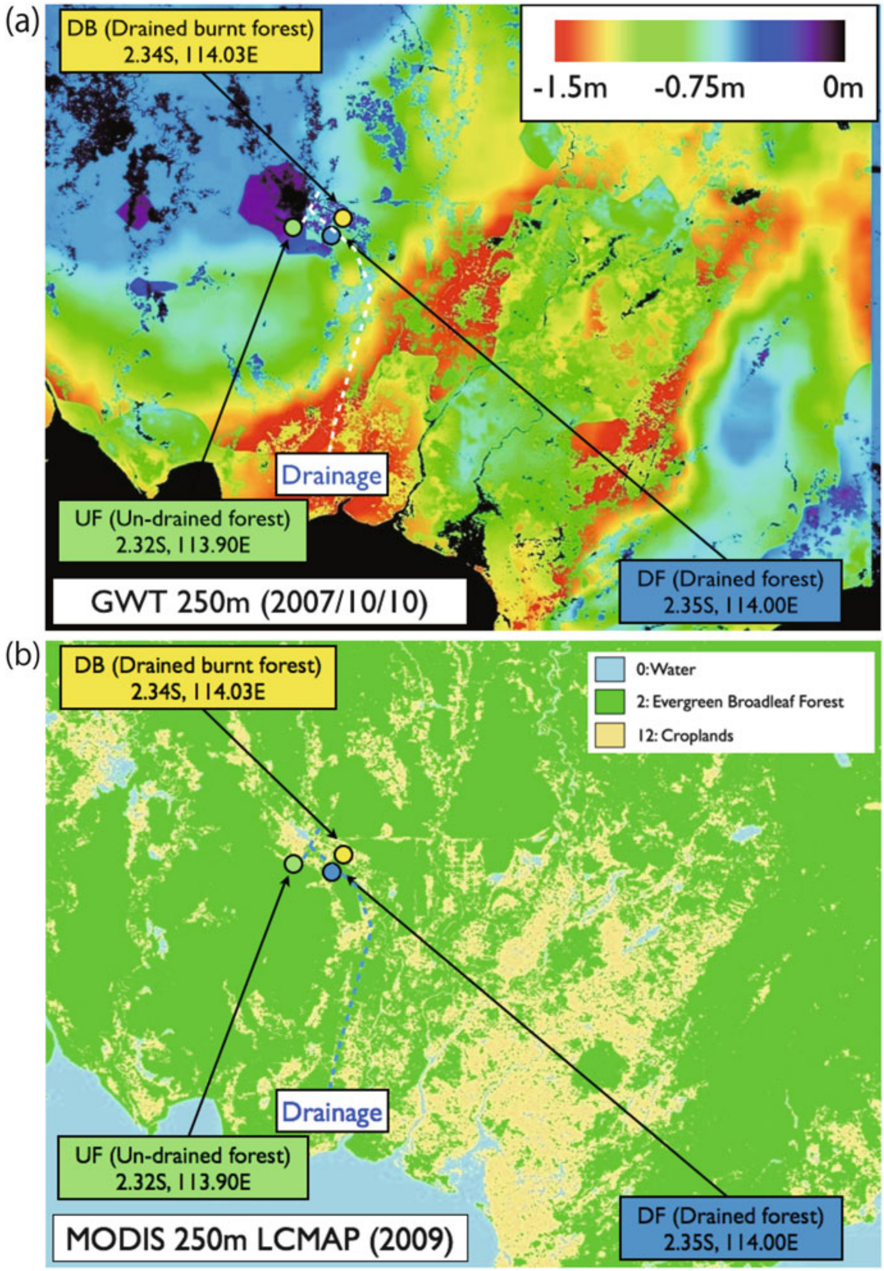


Fig. 30.4 Comparison of ground water table map and land cover classification. **a** Ground water table (GWT) **b** Land cover classification

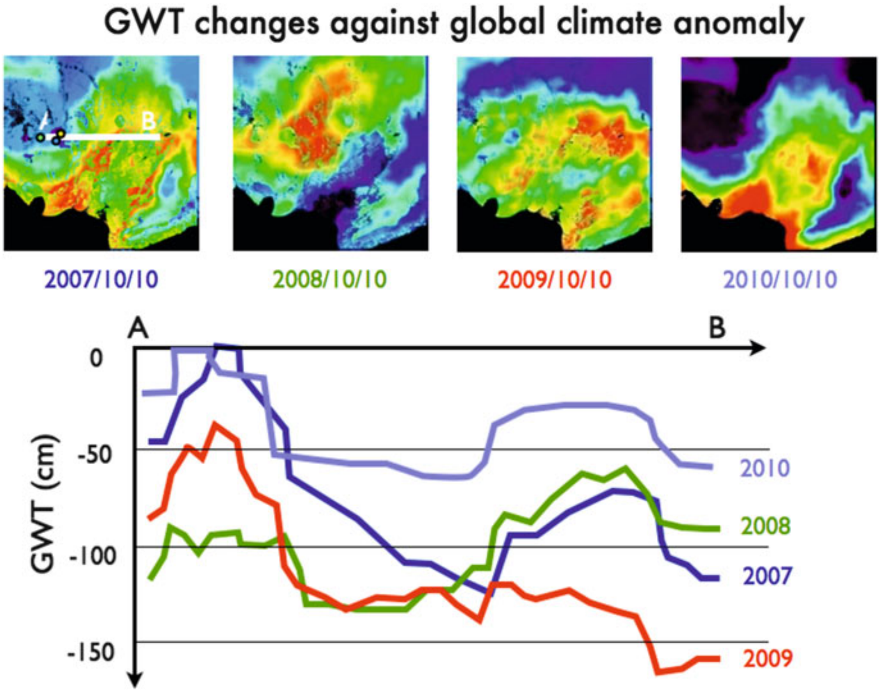
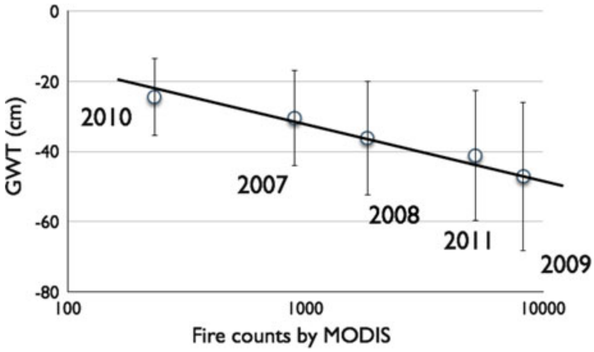


Fig. 30.5 Comparison of ground water table map from 2007 to 2010

Table 30.1 Area statistics of ground water table in the central Kalimantan

Year	Safe [−0.5–0 m]	Moderate [−1.0 to −0.5 m]	Dangerous [deeper than −1.0 m]
2007 (La Nina)	12 (%)	59 (%)	30 (%)
2008 (Normal)	22 (%)	58 (%)	20 (%)
2009 (El Nino)	37 (%)	39 (%)	24 (%)

Fig. 30.6 Comparison of hotspot detected by MODIS and ground water table



Acknowledgement This study is partially supported by SATREPS (Science and Technology Research Partnership for Sustainable Development) project entitled as “Wild fire and carbon management in peat-forest in Indonesia” founded by JST (Japan Science and Technology Agency) and JICA (Japan International Cooperation Agency).

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Chapter 31
Peat Mapping

Sawahiko Shimada, Masayuki Takada, and Hidenori Takahashi

Abstract This chapter reports the review we conducted on Indonesian peat distribution maps and mapping techniques by using remote sensing and existing peat maps. Existing and available peat maps are listed and introduced how those distributions were derived, viz. Digital Chart of the World (ESRI. The digital chart of the world for use with ARC/INFO software. ESRI, Redlands, 1993), Digital Soil map of the World (FAO. FAO-Unesco Soil Map of the World, 1:5 000 000, Vol. 1, Legend. UNESCO, Paris, p 1, 1974), Land System Maps (RePPProT. Land systems and land suitability series at 1:250,000 scale, Accompanying Maps of Review, Central Kalimantan, Irian Jaya, East whti South Kalimantan, West Kalimantan, Sumatra, Sulawesi, Maluku with Nusa Tenggara, and Jawa with Bali. Regional Physical Planning Programme for Transmigration. UK Overseas Development Administration and Directorate Bina Program. Jakarta, Ministry of Transmigration Programme for Transmigration, 1985–1989), peatland distribution and carbon content maps (Wetlands International 2003–2006) and primeval forests and peatlands moratorium maps (Kementrian Kehutanan. Peta Moratorium Rev. 1–5 Indeks Peta Indikatif Penundaan Izin adalah Peta Lampiran SURAT KEPUTUSAN MENTERI KEHUTANAN REPUBLIK INDONESIA. Skala 1:250.000, Ministry of Forestry, Indonesia http://webgis.dephut.go.id/, 2011–2013). A method and the output map of the peat thickness distribution were also introduced. Peat thickness of Central Kalimantan peat swamp forest was predicted from forest phonology type classified map derived from multi-seasonal NOAA-AVHRR remote sensing imagery.

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Keywords Kalimantan • Peat thickness • Peatland distribution • Remote sensing imagery

31.1 Introduction

Remote sensing is the most effective tool for peat mapping because of the difficulty to access peatlands. However, the upper layers of tropical peatlands are mostly hidden under forests, and it is extremly difficult to identify and map the boundaries of peatlands accurately. A highly precise technique to make accurate maps of peatlands is required to evaluate the impact of destruction caused by forest fires due to the burnt surface soil and forest of the top layers of peatlands, and the drastic changes in land-use due to the recent development to transform peatlands into oilpalm plantations. For tropical peatlands in Southeast Asia, the distribution map of Polak (1975) (Fig. 31.1) has been used for years. Also, the Digital Chart of the World (ESRI 1993) and the Soil Map of the World (FAO 1994) (Fig. 31.2), which were created for all of the world, have been used widely. These maps show distributions of Peat (Polak 1975), Wetland (ESRI 1993), and Histosols (FAO 1994), respectively, and the positional information provided by these three is roughly consistent although the categories of classifications differ. Further, if available data are only for specific areas, they are insufficient for an evaluation of water resources, biodiversity, and carbon stocks, and they must be supplemented with information on the status of peat layers including the type of peat forest and peat thickness. This chapter reports the review we conducted on peat distribution maps and mapping techniques by using existing peat maps and focusing on the Kalimantan island in Indonesia which is subject to the influence of drastic land use changes.

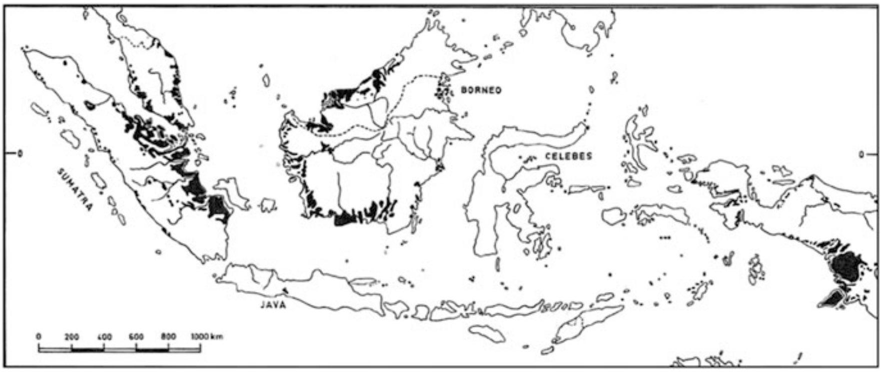

Fig. 31.1 Indoesian peat distribution map of Polak (1975)

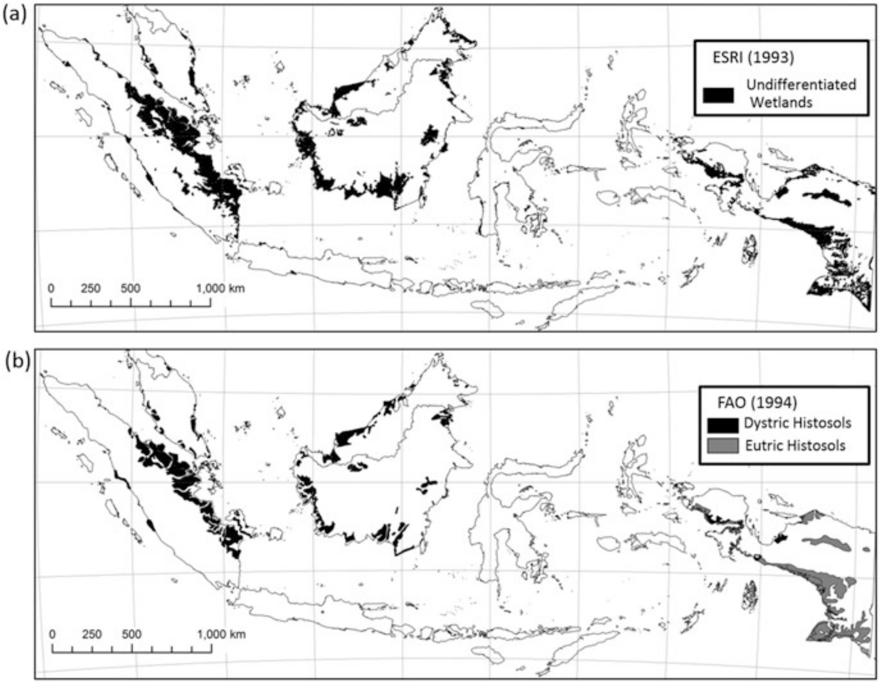

Fig. 31.2 (**a**) Undiffentiated wetland distribtion of the Digital Chart of the World (ESRI 1993) and (**b**) Histosol soil type distribution of the Soil Map of the World (FAO 1994) over Indonesia, Malaysia, and Brunei

31.2 Existing and Available Peat Map

31.2.1 Digital Chart of the World (ESRI 1993)

This is a vector map that covers all of the globe in 1:1,000,000 scale, the main data source is the US Defense Mapping Agency's (DMA) Operational Navigation Chart (ONC) series. Satellite images of DMA Digital Aeronautical Flight Information Files (DAFIF) for airport features and NOAA-AVHRR are used for areas outside that coverage (DMA 1992). "Undifferentiated Wetland" of the Land Cover for Thematic Layers indicates peatland (Fig. 31.2a). Mapped years differ for different areas (middle of the 1960s – early 1990s).

31.2.2 Digital Soil Map of the World (FAO 1994)

This is a vector map that covers all of the globe in 1:5,000,000 scale, and the original map is the Soil Map of the World (FAO 1971–1981), which was created under a project started in 1961 and which is composed of 19 separate maps. Successive drafts of the soil map and of the legend were prepared from a compilation of existing material, combined with systematic field identification and correlation (FAO 1997). Histosols (with 40 cm or more of organic soil on the surface) in Soil unist Legend (FAO 1974) indicates peatlands (Fig. 31.2b).

31.3 Land System Maps (RePPProT 1985–1989)

These are vector maps that cover the whole of Indonesia in 1:250,000 scale, and were created from 1984 to 1989 by the Indonesian National Coordination Agency for Surveys and Mapping (BAKOSURTANAL) and the Ministry of Transmigrationooperated with the collaboration of the Ministry of Transmigration and the Government of the United Kingdom.

Land mapping was mainly conducted using aerial photographs of 1:50,000–1:100,000 scales, and for the areas that were not covered by aerial photographs, 1: 250,000 scale images by Landsat-MSS or SAR (STAR I system) were used (RePPProT 1990). The land systems interpreted from the imageries were then transferred to the JOG (Joint Operations Graphic) topographic maps at scale 1: 250.000.

Property information including accuracy of lithology, hydrology, climate, topography, forest types, land use, and soil is stored in the RePPProt land system unit as seperate data (Poniman et al. 2004). Page et al. (2011) used the “GBT”, “MDW”, “BRH”, “KHY”, and “KLR” of Land areas with “Peat Depth” above 51 cm as peatland to estimate the carbon stock. Figure 31.3 shows the distributions of land type with peat thickness of more than 11 cm in Kalimantan, and Table 31.1 shows details of the information for each land type.

31.4 Peatland Distribution and Carbon Content Maps (Wetlands International 2003–2006)

These are peatland distribution maps, which the Wetlands International Indonesia Programme (WIIP) created under a program funded by the Canada Climate Change Development in 2002–2006, and cover Sumatra (Wahyunto et al. 2003), Kalimantan (Wahyunto et al. 2004), and Papua (Wahyunto et al. 2006). In this mapping program, field surveys were not conducted but various inventory data and remote sensing

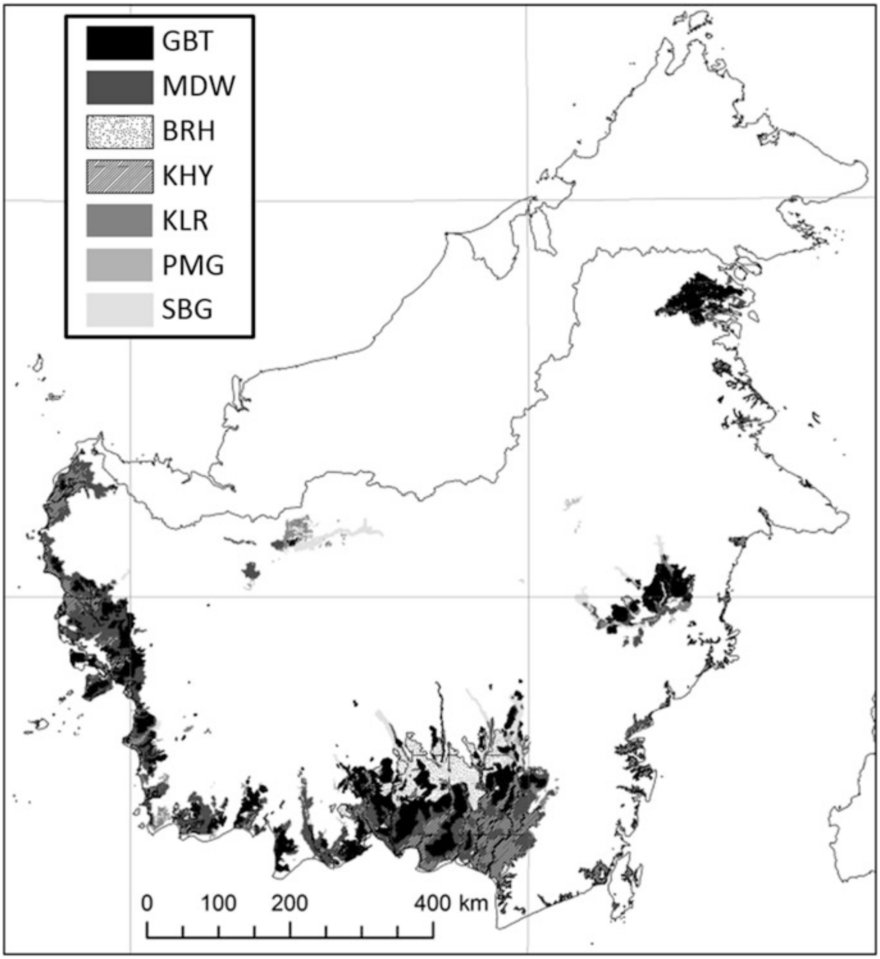

Fig. 31.3 Peat distributions derived from the Land System Map (RePPProT 1985) over the Kalimantan area (see Table 31.1 for detailed legend)

images in Indonesia were used. Reference data for Sumatra, Kalimantan, and Papua were collected in 1990–2002, 2000–2002, and 2000–2002, respectively. According to Wahyunto and Suryadiputra (2008), the inventories of the map media they used are as follows:

(a) Atlas Peta Tanah Eksplorasi Indonesia skala 1:1.000.000 (Exploration soil map atlas of Indonesia) published by Puslitbang Tanah dan Agroklimat, 2000

Table 31.1 Legend of land system units (RePPProT 1985–1989) in Kalimantan peatland regions (see Fig. 31.3)

Land system (Abbr.)	Land type	Peat depth (cm)	Rainfall (mm year^{-1})	Rock type	Vegetation and land use
Gambut (GBT)	Deeper peat swamps, commonly domed	>200	1,700–3,900	Peat	Peat swamp forest
Mendawai (MDW)	Shallower peat swamps	51–200	1,700–3,900	Peat	Peat swamp forest
Barah (BRH)	Flat, sandy terrace covered by shallow-peat	26–50	1,900–3,000	Alluvium, old sands, peat	Swamp forest, peatswamp forest
Kahayan (KHY)	Coalescent estuarine/riverine plains	26–50	1,600–3,900	Alluvium 30 %, peat, alluvium 29 %	Riparian forest of meanderbelt, bush, rainfed wetland rice, rubber, coconut, settlements
Klaru (KLR)	Permanently waterlogged floodplains	26–50	1,700–3,500	Alluvium, recent riverine, peat	Swamp forest, swamp including sedges, pandanus, lakes
Paminggir (PMG)	Back swamps of inland floodplains	11–25	2,200–4,000	Alluvium, recent riverine	Swamp forest, lakes
Sebangau (SBG)	Meanderbelt of large rivers with broadlevees	11–25	1,700–3,500	Alluvium, recentriverine	Riparian forest of meanderbelt, swamp includin sedges, pandanus, rainfed wetland rice

(b) Peta tanah eksplorasi Pulau Kalimantan skala 1:1000.000 (Exploration soil maps for Kalimantan) published by Puslit Tanah dan Agroklimat, 1997
(c) Peta Lahan Rawa Pulau Kalimantan skala 1:1000,000 (Maps of swamp land in Kalimantan) published by Puslit. Tanah dan Agroklimat, 2000
(d) Peta tanah tinjau mendalam wilayah pengembangan lahan gambut sejuta hektar (PLG), Kalimantan Tengah skala 1:100,000 (Detailed reconnaissance soil maps for million hectare peatland project in Central Kalimantan) published by Puslit Tanah dan Agroklimat 1998

(e) Peta dan buku Keterangan Satuan Lahan dan Tanah skala 1:250,000 (Map and explanatory booklet on soil and land mapping units) published by Land Resources Evaluation Project (LREP), Pusat Penelitian Tanah Bogor, 1990.
(f) Land System and Land Suitability Map published by RePPProT, Department for Transmigration, 1986 for Sumatra and Kalimantan.
(g) Peta Rupabumi Indonesia (RBI) scale 1:250,000 published by Bakosurtanal, 1996–2000 as spatial data (for basic map)
(h) Soil and land mapping (Peta Satuan Lahan dan Tanah) units scale 1:250,000 for the whole of Sumatra Island, published by Pusat Penelitian Tanah dan Agroklimat (Puslitanak), 1990

In addition to the maps, satellite image data (Landsat-TM and ETM+) are also used. A visual interpretaion of the image, tone, texture, performance and spectral signature that appear on the image of each site was extrapolated. As an example interpretation is reported for the case of a peat forest covered with uniformly fine tone and texture vegetation, a dark tone is interpreted as a place with thick peat (Wahyunto and Suryadiputra 2008). Some maps, which were drawn by using all the data and based on validation, and include information about the most probable peat types and thickness distribution, are available to the public as a final map. Figure 31.4 shows one such peat distribution maps in the Kalimantan island (see also Fig. 23.4).

31.5 Moratorium Maps (Kementrian Kehutanan 2011–2013)

The Moratorium Map (Penundaan Pemberian Izin Baru Pemanfaatan Hutan) (Kementrian Kehutanan 2011–2013) was updated and organized by the Indonesia presidential decree from 2011 to 2013 as a part of the REDD+ Task Force mandate for the purpose of improving the governance of primeval forests and peatlands. All the versions of this map (ver .05, as of 2014) (the vector file of 1:250,000 scale) are available by downloading from the Web (Fig. 31.5).

31.6 Predicted Map of Peat Thickness

In tropical peatlands, data on peat thickness is lacking because of the difficulties in accessing swamp areas. However, it is possible only by field measurements to obtain peat thickness data, which is sometimes up to 10–20 m deep (Bruenig 1990; Page et al. 2002). The uncertainty of peat thickness value, which affects the

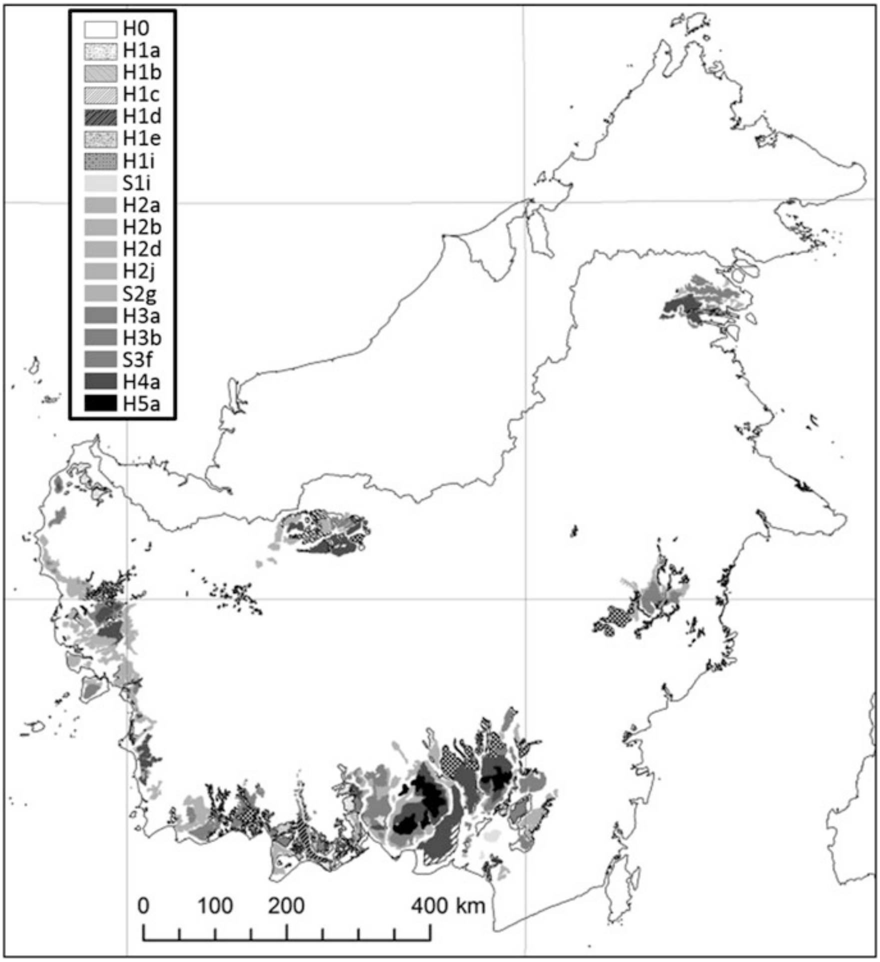

Fig. 31.4 Peatland Distribution and Carbon Content Map Wetland International (Wahyunto et al. 2004) over the Kalimantan area (H and S refer respectively to hemic and sapric peat decomposition status, and the number following the letter indicates the peat thickness in meters)

calculation of C stock estimation in a linear fashion, makes it difficult to derive an accurate estimate of C mass within tropical peatlands. Peatland maps of both RePPProT (1985–1989) and Wetlands International (2003–2006) contain the peat thickness information within their attribute tables for Indonesia (Figs. 23.3 and 23.4; cf. Fig. 31.3, Table 31.1 and Fig. 31.4) and Jaenicke et al. (2008) also derived a peat thickness distribution map for Central Kalimantan. However, those peat

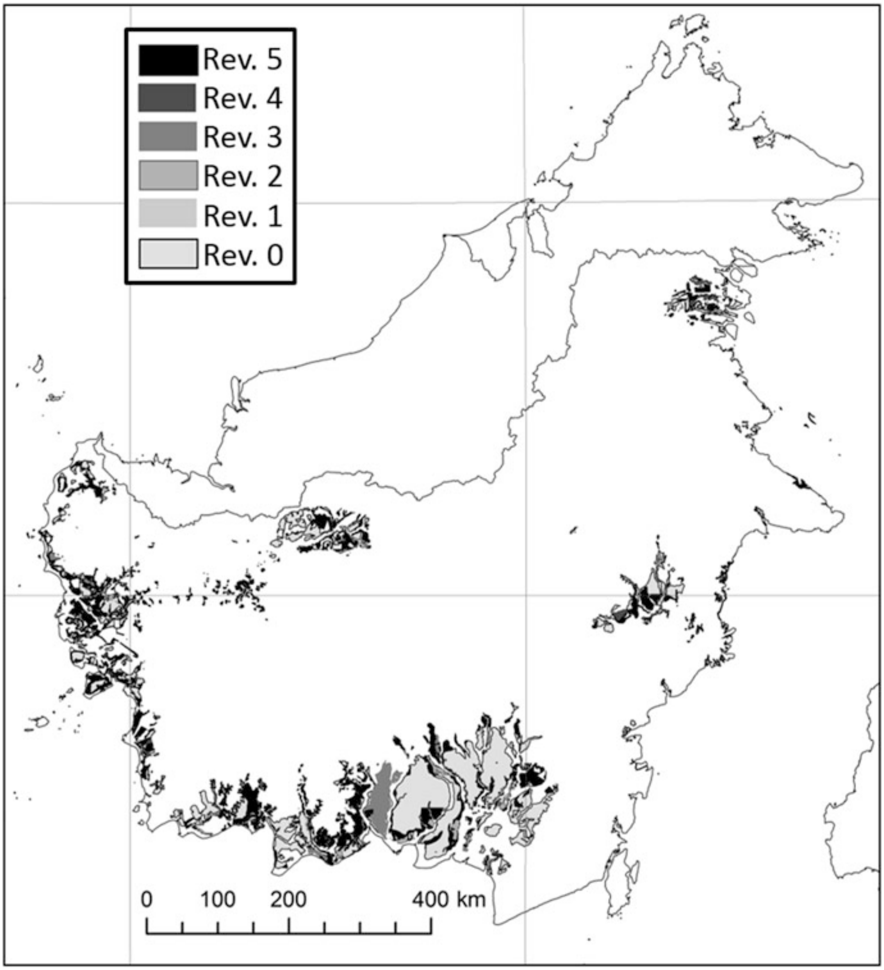

Fig. 31.5 Peatland distribution in the Moratorium Maps developed by the REDD+ Task Force (Kementrian Kehutanan 2011–2013) for the Kalimantan area

thickness data weren't derived from methods that can be extrapolated and applied to other regions since the estimates were derived only by interpolation methods with empirical observations.

According to the study of Central Kalimantan peatland (Shimada 2003; Shimada et al. 2004), peat thickness is found to be predictable by the forest phenology type above the peat layer. Peat swamp forest (PSF) phenology type in Central Kalimantan was classified into eight major types (viz. PHIL, W1, W2, W2D-A, W2D-Z, W1D, PHOB-Z, PHOB-V) using multi-temporal (1992–1993) monthly NOAA Advanced Very High Radiometers (AVHRR) data. Specifically, the fluctuation pattern of the

Table 31.2 Phenological pattern, mean peat thickness and percentage of areal extent among eight peat swamp forest types in Central Kalimantan

	Phenological pattern*						
Phenology type	WET1 → WET2 → DRY					Mean peat thickness (m)	Percentage of areal extent (%)
PHIL	1	(+) (−)	1	(−)	0	0.75	0.5
W1	1	(−)	0	(+)(−)	0	–	0.8
W1D	1	(−)	0	(+)	1	1.56^{bc}	9.1
W2	0	(+)	1	(−)	0	4.70^{ab}	6.4
W2D-A	0	(+)	1	(−)	1	4.59^{a}	13.6
W2D-Z	0	(+)	1	(+)	1	2.64^{b}	47.2
PHOB-Z	0	(+)	0	(+)	1	1.35^{c}	13.3
PHOB-V	0	(−)	0	(+)	1	0.84^{c}	9.1

*WET1: period of former half rainy season (Sep. 1992–Jan. 1993)
WET2: period of latter half rainy season (Feb.–Jun. 1993)
DRY: dry season and the second half (July–August 1993)
0: NDVI at a seasonal period is smaller than 1 year mean NDVI
1: NDVI at a seasonal period is greater than 1 year mean NDVI
(+): the gradient between seasonal period is positive
(−): the gradient between seasonal period is negative
a >b >c: values followed by the same letter are not significantly different at the $P < 0.05$ significance level (Sheffé's test)

normalized difference vegetation index (NDVI) among three seasonal periods (i.e., former half 5-month rainy season, latter half 5-month rainy season, and 2-month dry season) were classified (see Table 31.2). Tropical peatlands have their characteristics for high groundwater level and its seasonal fluctuation. The condition of high groundwater level usually leads to a decrease in vegetation activity owing to the anoxic stress to the plant roots (e.g., Vartapetian and Jackson 1997). Considering the hydrological buffer function of the peat layer, phenological difference due to the hydroperiodical difference of PSF and its relation to peat thickness was focused on. Riverine PSF and PSF fringing on shallow peat layers characteristically have greater water flow and seasonal groundwater level fluctuations in comparison with inner forests on deeper peat layers, which tend to have permanently high groundwater levels that fluctuate moderately (Lugo et al. 1990). Since the hydroperiod is a seasonal characteristic of peatlands in Southeast Asia, the phenology of the PSF was hypothesized to be a predictor of underlying peat thickness. The result of the association of ombrophobous PSF phenology types (PHOB-Z and PHOB-V) with significantly shallower peat layers (Table 31.2) indicates the influence of PSF's flooding stress due to a waterlogged situation in the rainy season, and this supports a part of the hypothesis (Fig. 31.6). However, the physiology of PSF plants with respect to the peatland hydroperiod needs to be clarified in order to substantially prove this hypothesis.

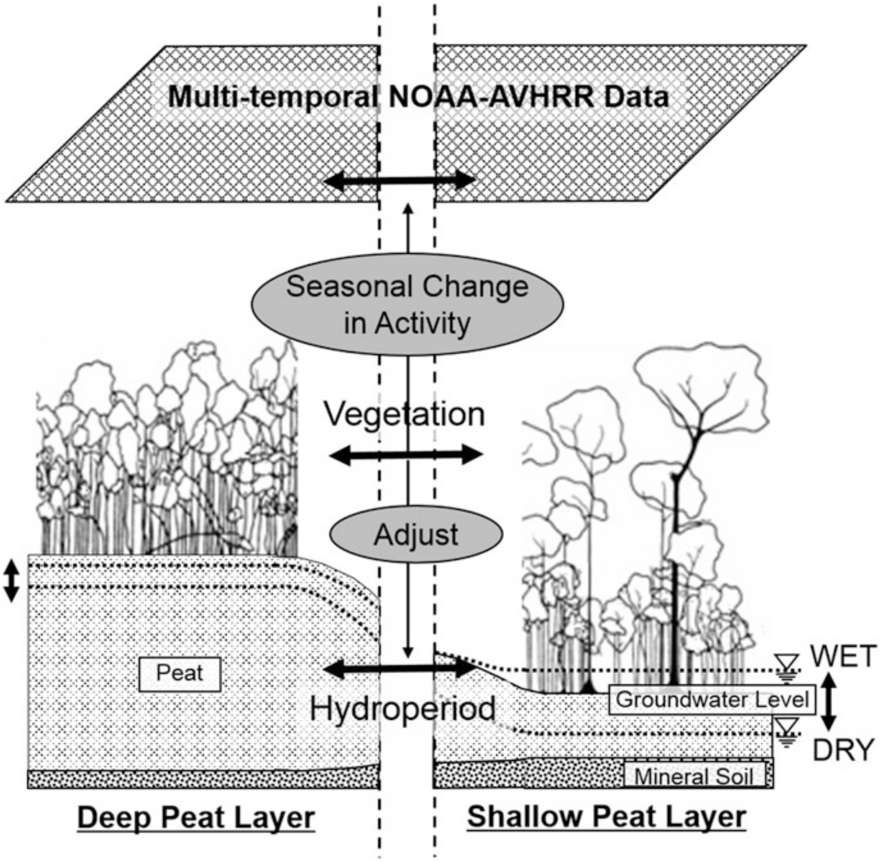

Fig. 31.6 Hypothetic image of peat thickness estimation via peat swamp forest phenology by using multi-temporal satellite imagery (After Shimada 2003; forest images cited from Whitmore 1975)

The PSF phenology types that have maximum NDVI activity during the latter rainy season (i.e., W2 and W2D-A) are found to occur on relatively deeper peat layers from the result (Table 31.2). The root mean square error (RMSE) for the peat thickness estimation map, derived by assigning each associated mean peat thickness value (cf. Table 31.2, Fig. 31.7) in Central Kalimantan, is calculated at 2.49 m. Individually, the phenology types on deeper peat layers (i.e., W2, W2D-A, and W2D-Z) tend to have greater errors (RMSE = 2.33 m, 3.17 m, and 2.77 m, respectively) for peat thickness estimation.

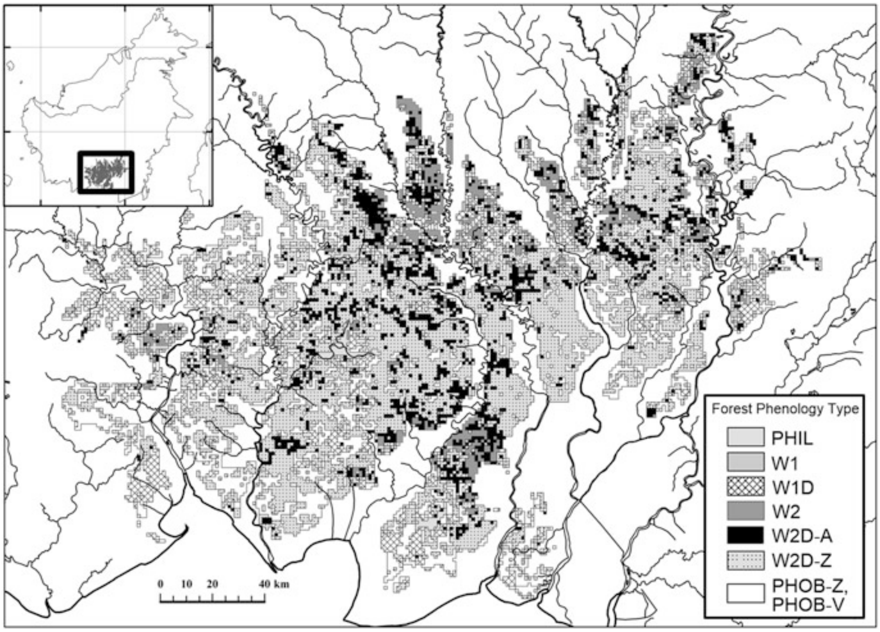

Fig. 31.7 Distribution maps of forest phenology type of peatlands in Central Kalimantan. Phenology type, PHIL, W1, W1D, W2, W2D-A, W2D-Z, PHOB-Z, and PHOB-V correspond to the mean peat thickness 0.75, no data, 1.56, 4.70, 4.59, 2.64, 1.35, and 0.84, respectively (see also Table 31.2)

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Chapter 32
Modeling of Carbon and GHG Budgets in Tropical Peatland

Ryuichi Hirata, Minaco Adachi, and Akihiko Ito

Abstract We summarize the current status of carbon and GHG budget estimates in tropical ecosystems at different spatial scales by using a process-based terrestrial ecosystem model. First, carbon balances of tropical peatland forest were simulated at the site scale. Second, we evaluated changes in carbon budgets of Borneo Island taking land-use changes into account. Third, we evaluated methane emissions from wetlands on a global scale.

Keywords VISIT • Eddy covariance • Land-use change • Methane emission

32.1 Introduction

Tropical ecosystems are among the most important sources of greenhouse gases (GHGs), which have feedback effects on the climate of the earth through biogeochemical interactions. Because of suitable conditions and large accumulated substrate stores, tropical wetlands are thought to release a substantial amount of methane (CH_4) throughout the year (Bousquet et al. 2006). Whereas models simulating carbon and GHG balances in temperate regions are well developed, similar models for tropical regions are still inadequate, because the number of measurements needed for parameterization is insufficient, and a full understanding of the relevant biogeochemical processes is lacking (Farmer et al. 2011). Carbon emissions associated with land-use changes, which have occurred mainly in developing tropical countries, account for about 20 % (IPCC 2007) of the total anthropogenic emissions worldwide. Evaluation of carbon emissions from land-use changes in the tropics is an urgent task among the activities related to the Reducing

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Emissions from Deforestation and Forest Degradation (REDD+) initiative. More reliable estimates of carbon budgets in tropical ecosystems, including the impact of deforestation, is an important goal for environmental researchers. In this chapter, we summarize the current status of carbon and GHG budget estimates in tropical ecosystems at different spatial scales (i.e., site, regional, and global scales), placing emphasis on model development and application.

32.2 Simulating the Carbon Balance of Tropical Peatland Forests

One of the most important components of ecosystem models in both temperate and tropical peat lands is hydrology, especially changes in the depth of the water table, which regulates the rate of peat decomposition and photosynthesis (Hirano et al. 2007, 2012). Farmer et al. (2011) have discussed kinds of processes that should be considered in modeling tropical peat lands, including, inter alia, hydrology, temperature, and litter quality. They indicated that one of the most obvious differences between tropical and temperate peat lands is the "lumpiness" of the soil. In tropical peat land the lumps consist of refractory organic matter supplied from woody debris; in temperate peat easily decomposable organic matter supplied from moss. They also mentioned that some models developed for temperate peat lands are useful for tropical peat lands, and they listed some potential models for estimating the carbon and GHG balances of tropical peat forests.

However, most of these models do not take into account changes in the depth of the water table, because they assume the soil to be mineral soil. Sulman et al. (2012) applied seven ecosystem models to three peat lands in North America and pointed out the need to modify the hydrological process by taking the depth of the water table into account. Grant et al. (2012) simulated water table depth from water flow in a three-dimensional distribution of bogs and hollows by adopting a system of multiple soil layers. They described the complicated processes that include carbon oxidation, nitrogen mineralization, and O_2 uptake by roots constrained by dissolved oxygen derived from hydrological processes. Bond-Lamberty et al. (2007) did not adopt a process to simulate water depth but modified a scalar function of soil water content in the Biome-BGC terrestrial ecosystem process model. Some specific models for peat lands that describe peat accumulation have also been developed (Frolking et al. 2010).

In our preliminary study, we applied an ecosystem model named VISIT (Vegetation Integrated SImulator for Trace gases; Ito and Oikawa 2002; Ito et al. 2006; Ito 2008) to flux tower data from a drained tropical peatland forest in Parankaraya, Indonesia (Hirano et al. 2007) to elucidate the current issues to simulate the carbon balance of tropical peatland forest using ecosystem models. The VISIT is an ecosystem model that simulates the balance of specific GHGs (CO_2, CH_4, N_2O), biogenic volatile organic compounds (BVOC), and dissolved organic carbon

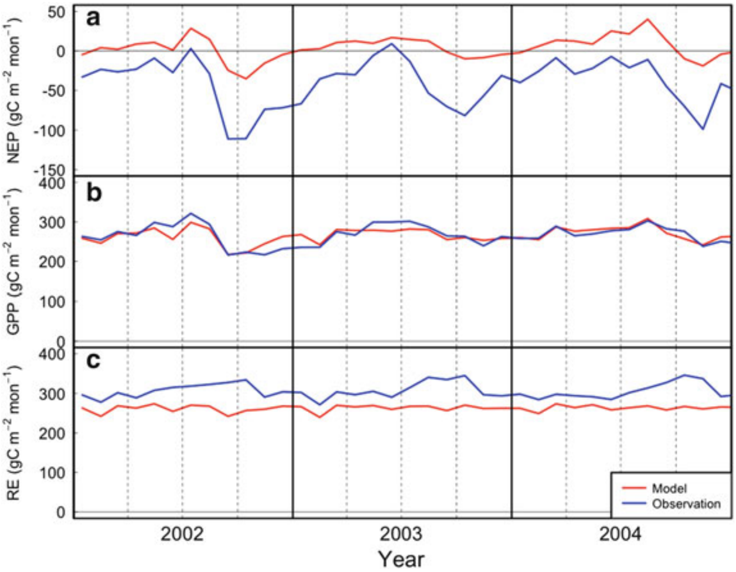

Fig. 32.1 Temporal variations in monthly (**a**) net ecosystem production (*NEP*), (**b**) gross primary production (*GPP*), and (**c**) ecosystem respiration (*RE*) obtained from model calculation (*red line*) and tower flux observations (*blue line*)

(DOC). The VISIT has been validated with data from tropical forests on mineral soil (Adachi et al. 2011), which implies that the model has the potential capacity to describe carbon and GHG balances of tropical peat lands.

We compared net ecosystem production (NEP), gross primary production (GPP), and ecosystem respiration (RE) of tropical peatland forest observed on a flux tower and simulated by VISIT (Fig. 32.1). Details about the fluxes and a description of the Parankaraya site have been provided by Hirano et al. (2007, 2012) and are partly shown in Chap. 21. Although the simulated and observed NEP showed similar seasonal patterns, the simulated NEP overestimated the observed one (Fig. 32.1a). The simulated and observed GPP were in good agreement with respect to both seasonality and magnitude (Fig. 32.1b). In contrast, there were large differences between observed and simulated RE values. Whereas the observed RE increased during the rainy season and decreased during the dry season, the simulated RE showed small seasonal and inter-annual variations (Fig. 32.1c), which indicates that the model did not simulate the decomposition process adequately.

The difference between the observed and simulated RE was correlated with changes in the groundwater table (Fig. 32.2). When the water table depth was above about −0.5 m, the difference decreased as the water table became deeper. In contrast, when the groundwater table was below about −0.5 m, the difference increased as the groundwater table lowered. This pattern suggests that the large discrepancy between observed and simulated RE was caused by changes in the groundwater

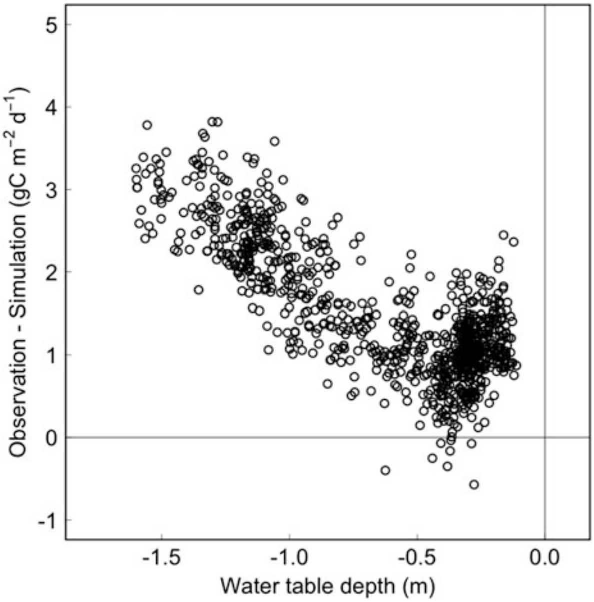

Fig. 32.2 Relationship of the difference between observed and simulated RE and water table depth

table. The mechanism responsible for the effect of the groundwater table on peat decomposition is evidently complicated, and the results indicate that hydrological and respiratory processes are inadequately described by VISIT. In future studies, we therefore need to modify the simulation of these processes by carefully considering changes in water table depth and the mechanism of peat decomposition.

32.3 Regional Simulation of Land-Use Impact on the Carbon Budget of Borneo Island

Worldwide, net carbon emissions from land-use change has been estimated to be 1.5 Pg C year^{-1} (P = 10^{15}) from 1990 to 2005 (Le Quéré et al. 2009), and Southeast Asia is one of the regions of the greatest land-use change. The total aboveground biomass of carbon stock in the tropics of Asia is smaller than in other the tropical regions: i.e., of Africa and South America (Baccini et al. 2012). However, the area-based normalized stock of forest carbon stock on Borneo Island, the largest island of Southeast Asia, is greater than that of the Amazonian forests (Slik et al. 2010). This comparison suggests that the impact of deforestation in Borneo would be larger than in other areas. Additionally, land use of Borneo Island has been changing to oil palm plantations (Fitzherbert et al. 2008) and other human-managed ecosystems.

Koh et al. (2011) reported the area of closed canopy oil palm plantations on Borneo Island and Kalimantan (Indonesian Borneo) to be 23,768 km^2 and 11,001 km^2 in 2010 using MODIS (MODerate resolution Imaging Spectroradiometer; spatial resolution: 250 m). The area of oil palm plantations on Kalimantan was estimated using LANDSAT (Land Satellite, spatial resolution: 30 m) to be 31,640 km^2 in 2010, of which 87 % was on mineral soils and 13 % on peat soils (Carlson et al. 2012). Although estimation of oil palm plantation area was dependent on the accuracy of satellite data, the carbon budget of Borneo Island would change by land use conversion to oil palm plantation from natural forest. In the present study, we used a process model and satellite data with 1-km resolution to estimate the impact of land-use change on the carbon budget of the area of mineral soils on Borneo.

To develop a regional-scale system of forest carbon monitoring, we used a time series of forest coverage data derived from satellite remote-sensing images to track transitions through the history of forest disturbance. For this purpose we used the active radar sensor PALSAR (Phased-Array L-Band Synthetic Aperture Radar) on board the ALOS (Advanced Land Observing Satellite) and MODIS satellite data from 2002 to 2008 ('land-use map' hereafter; Yamagata et al. 2010). The deforestation ratio was equated to the percentage decrease of forest area between 2 years at 1-km resolution. The deforestation ratio in 2004 is shown in Fig. 32.3. As a control, we used a land cover map (MOD12Q1) at 1-km resolution developed by Boston University (http://duckwater.bu.edu/lc/mod12q1.html). This 'control map' categorized most of the land cover of Borneo Island as evergreen broadleaf forest.

We calculated the carbon (C) budget by using a process-based terrestrial biogeochemical model (VISIT), which was originally developed for long-term C dynamics, including the impacts of conversion from tropical forest to oil palm plantations (Adachi et al. 2011). We repeatedly used 1948–2010 climate data to conduct 500-year spin-up calculations to create appropriate initial states for the ecosystem C pools and budgets. We then applied the VISIT model and forest coverage to every grid point to estimate the atmosphere–ecosystem exchange and internal dynamics of the carbon at spatial and temporal resolutions of 1 km and 1 day, respectively. When forest coverage increased from the previous year, we defined the increase to reflect a conversion to oil palm plantations (Fig. 32.4). Carbon budgets for oil palm plantations from 2003 to 2008 were calculated by using the areas of oil palm plantations and carbon budgets for oil palms as a function of age.

The difference of gross primary production (GPP) in 2004 between the control and land-use maps is shown in Fig. 32.5. The mean GPPs were 34.5 and 26.8 Mg C ha^{-1} $year^{-1}$ for the control and land-use maps, respectively. However, the land use map we used shows that almost all of Borneo Island is covered with evergreen broadleaf forests that have high productivity, and then we suppose this may result in overestimation of the GPP by the model. During the period 2003–2008 the overestimate of the net ecosystem production (NEP) of the control was highest in 2004 (29.9 %). We estimated the decrease of NEP induced by land-use change to be 2.2 Tg C $year^{-1}$ ($T = 10^{12}$), and biomass and soil carbon losses were estimated to

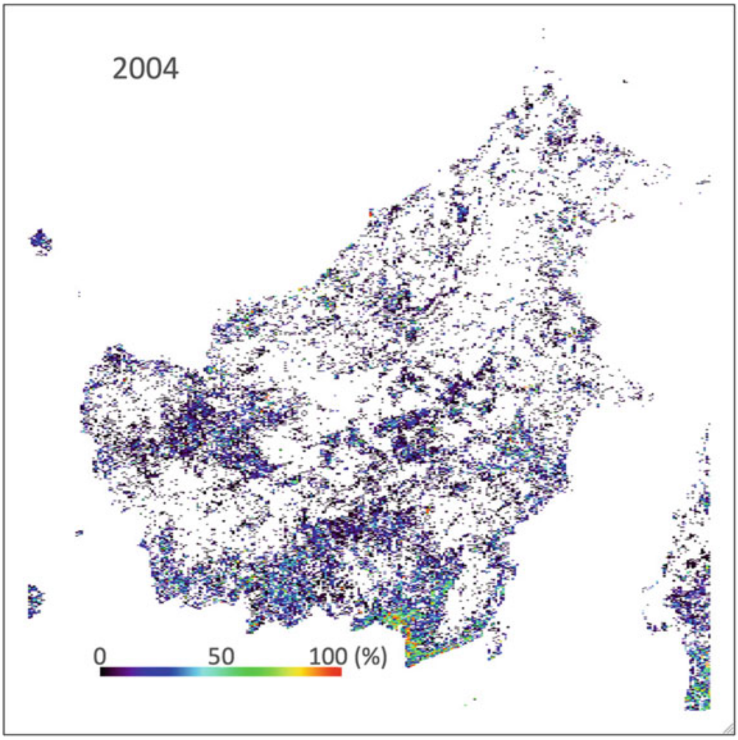

Fig. 32.3 Deforestation ratio (%) at 1-km resolution on Borneo Island in 2004. White areas are forest or ocean

be 227.1 and 162.4 Tg C for all of Borneo Island in 2004. Carlson et al. (2012) suggested that the average emissions associated with land-use change increased by 320 Tg C year^{-1} during the period 2000–2010 as a result of land-use change in Kalimantan. Our result would be an overestimation compared with the result of Carlson et al. (2012). There are some issues for more accurate estimation of carbon budget of the present study : (1) the areas of oil palm plantations would be overestimated in the present study, (2) both carbon emissions (soil respiration) and absorption (GPP) decreased at an the early stage of oil palm growth in the VISIT model (Adachi et al. 2011), and (3) the present study did not consider carbon losses from peat land. For instance, the net biomass and peat carbon loss were estimated to be 155.5 and 5.2 Mg C ha^{-1} year^{-1} on Borneo Island, respectively (Koh et al. 2011). In contrast, temporal variation of NEP was smaller on the control map than on the land-use map; the coefficients of variations were 23.3 % for the control map and 34.8 % for the land-use map from 2003 to 2008. These results suggest that the effect of land-use change on the carbon budget in the study area was larger than that of the climate variability, and that land management to reduce carbon emissions is very important for mitigation of global warming.

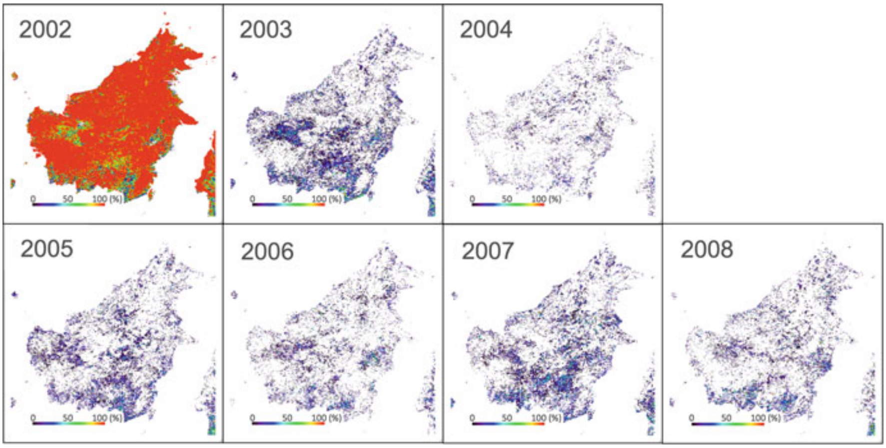

Fig. 32.4 Temporal variations of oil palm plantation coverage (%) from 2003 to 2008. The 2002 map shows the forest coverage (%) in Borneo Island. When the forest area increased from the previous year, we assumed the increase of the oil palm plantation area. White areas are forest or ocean

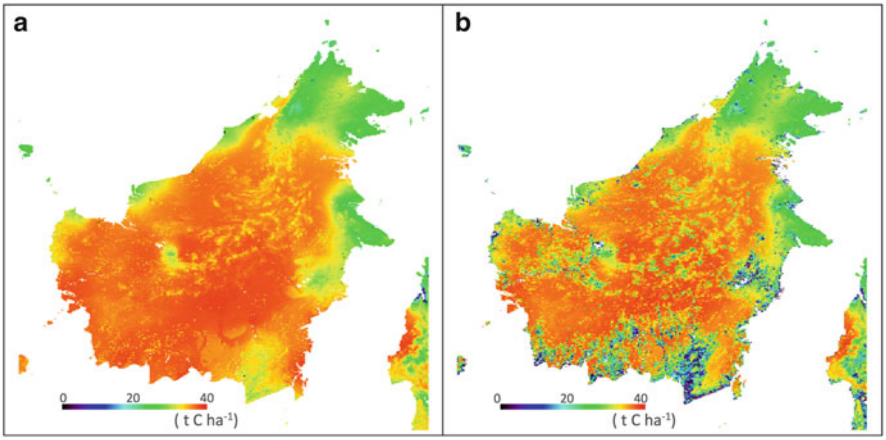

Fig. 32.5 Estimation of gross primary production (tC ha^{-1}) based on (**a**) the control map, and (**b**) the land-use map in 2004

32.4 Global Simulation of Methane Emission from Wetlands

Wetlands, including peat land, swamps, bogs, and other types of waterlogged terrestrial ecosystems, are arguably the largest natural sources of emissions of CH_4, one of the most important greenhouse gases, to the atmosphere. Northern peat lands in Eurasia and North America are strong (highly active) sources of CH_4 and are responsible for the clear seasonal changes in atmospheric CH_4 concentrations

(Bousquet et al. 2006). Quantifying the CH_4 emissions from wetlands is critically important for understanding the interaction between the climate and biogeochemical cycles and for predicting future changes in climate. Current land-use and climate changes may have exerted strong influences on the atmosphere-ecosystem exchange of CH_4 and other trace gases. However, because of the high spatial and temporal variability, it is still difficult to quantify the CH_4 emissions on a broad scale.

Process-based models are among the essential tools for investigating biogeochemical cycling in relation to global change, because they allow analysis, integration, and prediction of complicated material dynamics. Models that simulate CH_4 emissions from wetlands at a broad scale were developed and implemented during the 1990s (Cao et al. 1996; Potter 1997) but they used limited data volumes. Ito and Inatomi (2012) evaluated the global CH_4 emissions from natural wetlands and paddy fields by using the VISIT model including the empirical scheme of Cao et al. (1996) and the mechanistic scheme of Walter and Heimann (2000) for comparison. Both schemes are sensitive to temperature and depth of the water table, which affects the soil redox state and microbial activities. The scheme of Cao et al. (1996) estimates the bulk CH_4 flux at the soil surface in a simplistic manner, while the scheme of Walter and Heimann (2000) estimates the soil vertical gradient of the CH_4 concentration and considers different transport pathways (diffusion, ebullition, and plant-mediated transport). We derived the global distribution of wetlands and lakes from the Global Lake and Wetland Database (Lehner and Döll 2004), and the global simulation was performed for the period 1901–2009 by using the CRU TS3.1 climate dataset and the observed atmospheric composition data.

Global total CH_4 emissions from wetlands and paddy fields around 2000 were estimated to be 170–192 Tg CH_4 years^{-1} and 31–45 Tg CH_4 years^{-1} ($T = 10^{12}$), respectively. The distribution of the estimated CH_4 emissions (Fig. 32.6) reveals

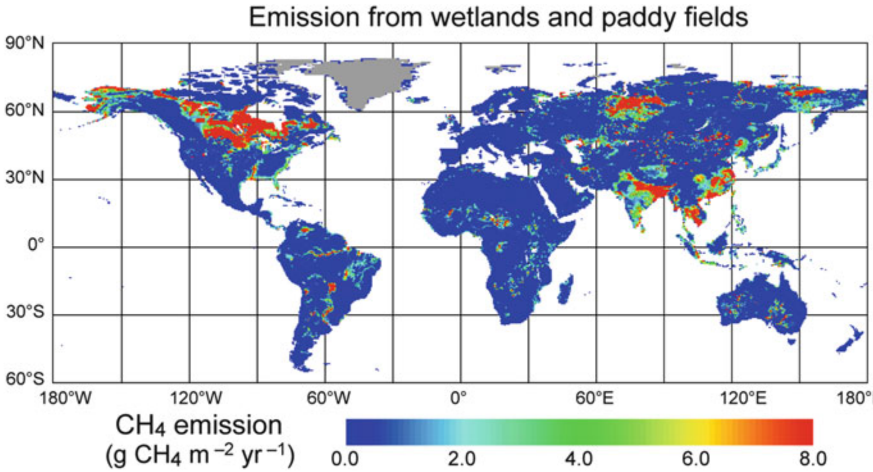

Fig. 32.6 Global map of the estimated CH_4 emissions from natural wetlands and paddy fields (Ito and Inatomi 2012)

extensive sources in northern wetlands and Asian paddy fields. There are also many small but strong sources (i.e., hot spots) in tropical areas such as the tropical wetlands in the Pantanal and the hinterlands of large rivers such as the Amazon and the Mississippi. In Asia, substantial areas of tropical wetlands (in the Ganges Delta, Mekong Delta, and seashore lowlands) were estimated to be strong sources of CH_4.

The model-based estimates of CH_4 emissions from wetlands and paddy fields provide information that is useful for understanding the present global CH_4 cycle, for predicting future CH_4 feedback, and for planning mitigation of climate change. However, there remain large uncertainties in our present model estimates (Melton et al. 2013). First, biogeochemical processes related to CH_4 production, consumption, and transportation are very complicated and existing models do not fully incorporate them in an explicit, detailed manner. Second, we could not access sufficient observational data for model calibrations and validation; the data volume is too limited not only in tropical but also in temperate and boreal regions, because of technical difficulties associated with continuous measurement of surface CH_4 fluxes. Recent advances in the measurement of CH_4 fluxes by micrometeorological methods should make available increasing amounts of observational data for model studies. The rapidly advancing satellite-based observational technologies for monitoring wetland inundation and atmospheric CH_4 concentrations will also assist in the integration of broad-scale observational and model simulations and the use of results for better ecosystem, carbon, predictions and management.

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Chapter 33
Field Data Transmission System by Universal Mobile Telecommunication Network

Yukihisa Shigenaga, Hideyuki Saito, Hidenori Takahashi, Ronny Teguh, Wisnu Kencana, Adi Jaya, and Bambang Setiadi

Abstract The new field data transmission system using universal mobile telecommunication network, SESAME-II system, was developed and applied to monitor the items which related to global warming in tropical peatlands, Indonesia. The transmission system is mainly composed of the sensor, the data logger, the data communication module and the battery system. The sensors for water depth, distance, moisture tension and length of circumference were combined with SESAME- II, used to measure the groundwater and ground surface levels in peatlands, the water levels in the river and the dam lake, the soil moisture and the growing process of trees in a plantation, in Indonesia. The interval of monitoring was 10 min, and the data were transmitted successfully to the data server in Japan with 3–6 h interval. The data in the server was downloaded in Japan and Indonesia through the domestic internet network and analyzed.

Keywords M2M system • SIM free • Real time monitoring • Sensors • Internet

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33.1 Introduction

The population of mobile phone user increased remarkably not only in developed countries but also in developing countries in recent 10 years. It seems the mobile phone communications network is established at frightful speed in the world. Especially the data transmission system using a mobile phone communications network can build telemeter system easily and cheaply. Moreover, comparing with the conventional infrastructure, it is pointed out that the restoration is earlier than normal wired telecommunication system at the time of disasters.

To conserve and manage tropical peatlands all activity must start from the correct understanding of the present conditions. Specifically in the efforts to solve global warming, the importance of carbon management in tropical peatlands has been emphasized (Page et al. 2002). The most important environmental factor for peat management is water in peatland. Especially, groundwater level and peat moisture are closely related to peat/forest fires (Takahashi et al. 2003), and carbon flux on the peatland (Hirano et al. 2012). The hydrological information in the river catchment is also important for regional water management to keep the water condition in the farmland in suitable condition for plant growth. However, the conventional monitoring method of environmental item in the field was not convenient in the local area with the poor accessibility. The poor accessibility to the sites in the field conduces the poor emergency use of the data. Especially in case of tropical peatlands, the accessibility is very poor with high groundwater level and muddy and peaty ground surface.

Field data transmission system by using mobile phone network has been developed around 10 years ago. But the quality and speed of data communication were not enough to send smoothly and quickly the amounts of data from the field to user. But the data communication system by mobile phone network is remarkably developed from the second generation 2G to 2.5G and 3G since recent a couple years ago. The digital data communication system became possible to use in the network after 2.5G. The data transmission from the field to user became easily using the mobile phone network after 2.5G.

Population of mobile phone user has increased very rapidly not only in the developed countries but also in the developing countries. It is estimated that the prevalence rate has reached more than 50 % of the world population (eMarketer 2013). The area of the mobile phone network is also spreading widely year by year not only in developed countries but also in the developing country.

Getting this opportunity, we developed the new field data transmission system, SESAME-II, using universal mobile telecommunication network (Shigenaga et al. 2013).

33.2 Data Transmission System

Data transmission systems can be largely classified into P2P (Peer to Peer) and M2M (Machine to Machine) systems. The P2P system used to a communication method in which data is received and transmitted by directly connecting two terminal

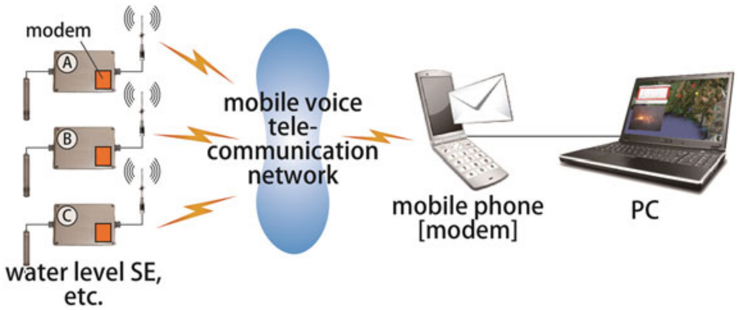

Fig. 33.1 Diagram of P2P system

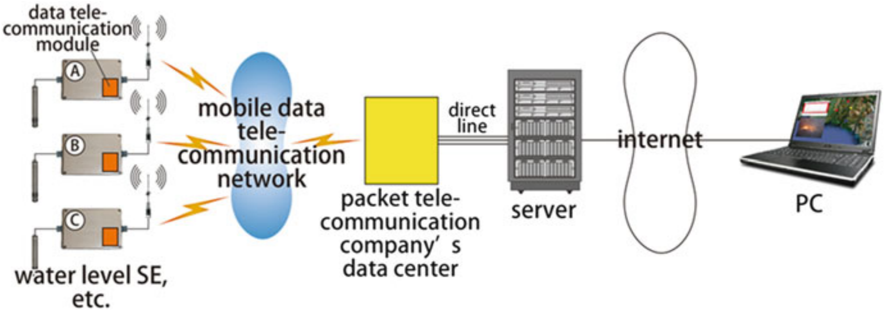

Fig. 33.2 Diagram of M2M-1 system

devices which have an equal relation on a network (Fig. 33.1). This technology was established a long time ago, and is commonly used. However, it has the shortcoming in the system. It takes a long time to complete data transmission if the number of terminals increases. Because the host has to acquire the data by calling out each terminal.

The M2M system uses an advanced data transmission system that enables an autonomous control and operation in the data transmission. This makes it possible for machines to exchange information mutually through a communication network. This enables monitoring and collecting data in remote area, by mounting a sensor, a processing unit, and a communication apparatus in a machine. With this method, a large volume of data can be processed in a very short time. This has become possible because a server can communicate simultaneously with many channels, and it is the technology of the internet that make the data communication easier. Therefore, for future data communications, the M2M system is advantageous, taking communication expenses and time restrictions into account.

The M2M system-1 shown in Fig. 33.2 was used in the SESAME-I, which was the first version of the development of SESAME series. However, if an SIM-free data communication card is used taking advantage of the liberalization of SIM regulations, the communication expenses will be very low. With a modem that

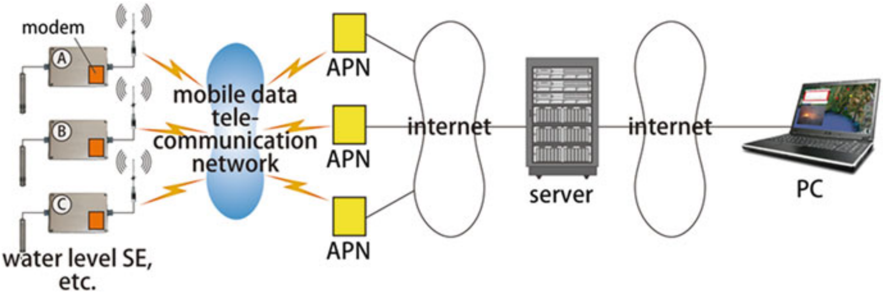

Fig. 33.3 Diagram of M2M-2 system

enables communication both in the home country and abroad as the M2M system-2 shown in Fig. 33.3, we can easily transmit data abroad. The SESAME-II adopted the M2M system-2.

33.3 System Development

In the process of system development, it is important to pay attention to the following points: (1) administrative and maintenance expenses are low, (2) equipment costs for the entire system also low, (3) future maintenance and repair are easy, and (4) it is possible to operate without connecting to a power grid (self-contained solar cell driven). If we develop the system using universally available components and the cloud server which does not require a data management in an office, the maintenance fee of the data transmission system will be kept in low cost.

Most of present communication modules have a GPS function and can display the information where the instrument are installed using the GPS function. Using this function, the locations of the devices are informed to the server, and it becomes possible to map the data to the existing GIS data. With such a system, it will be possible to monitor observation sites from anywhere by using an internet connection. SESAME-II has developed following the policy mentioned above (Fig. 33.4).

33.4 SESAME System in Indonesia

The field data transmission system, SESAME-II, was applied to monitor the many kinds of environmental items, such as groundwater and ground surface levels, precipitation, air and soil temperatures, water levels of river and dam lake, soil moisture in crop field and diameter of tree in Indonesia. SESAME-II used the M2M-2 system with two types of SIMs, Telekomsel and Indosat for internet communication, which were popular in Indonesia.

Using the M2M-2 system, SESAME-II can send data periodically to the server with high security. The process of transmitting data to a server in Japan is as

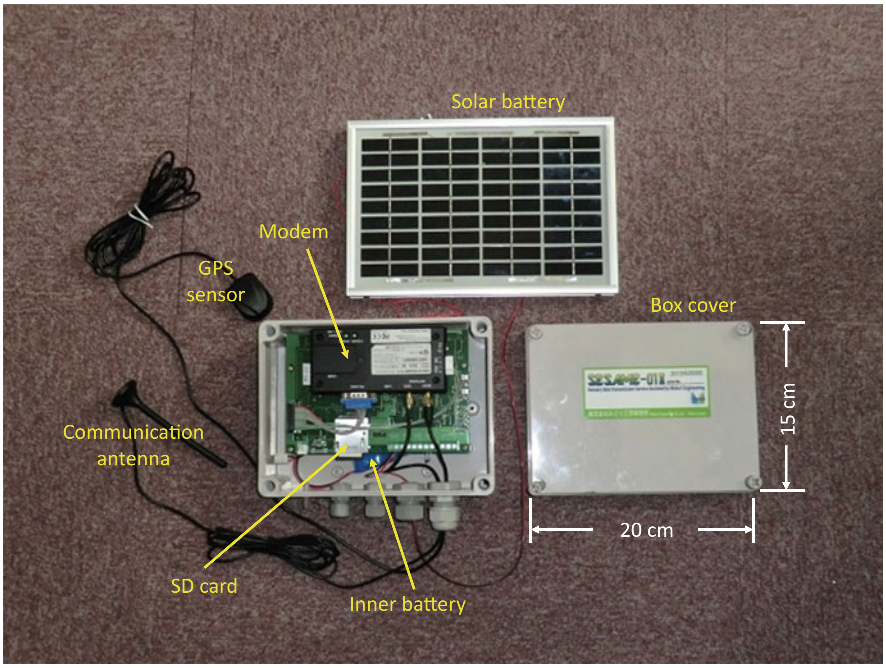

Fig. 33.4 Size and component of SESAME-II

follows: at first, the local SIM is inserted in the modem in SESAME-II, then the communication module connect to the APN (access point name which is specified by a mobile phone company), and finally SESAME-II is connected to the internet using the mobile phone network of GSM/GPRS widely used in Southeast Asia. The observation interval is possible to change from 1 min to 24 h in 14 steps. And data transmission interval also possible to change from 5 min to 24 h in 11 steps. The transmitter is programmed to send event data when the data exceeds the threshold value. This function is useful for emergency announce in the case of natural disasters. Figure 33.5 shows the system structure.

33.5 Case Studies in Indonesia

33.5.1 Groundwater and Ground Surface Level in Peatland

A water pressure gauge (ATM.1ST/N, STS, hydrostatic water level sensing type, output: 4–20 mA), a rain gauge (RT-5E, Ikeda Keiki), a laser distance meter (IL-1000, Keyence) and a thermistor sensor were installed in the SESAME-II. The system was set on a peatland near Palangka Raya city, Central Kalimantan, Indonesia. Measurement of the groundwater level, rainfall and air temperature started on 1st June, 2012 and the measurement of the ground surface level started

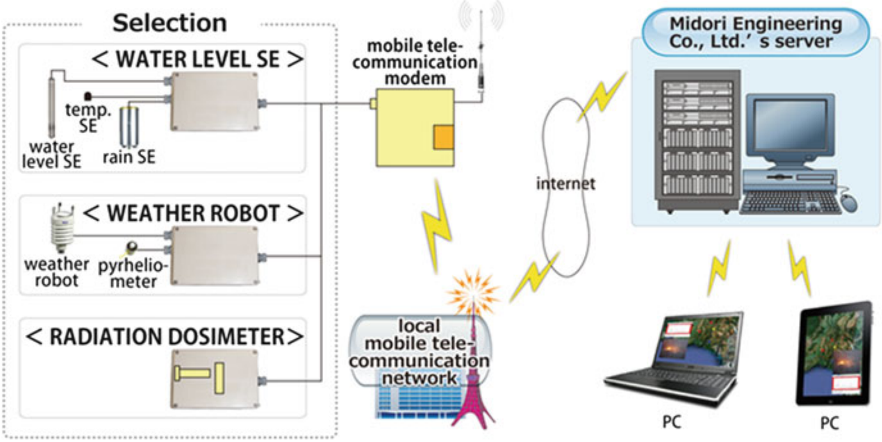

Fig. 33.5 Diagram of M2M-2 system used in Indonesia

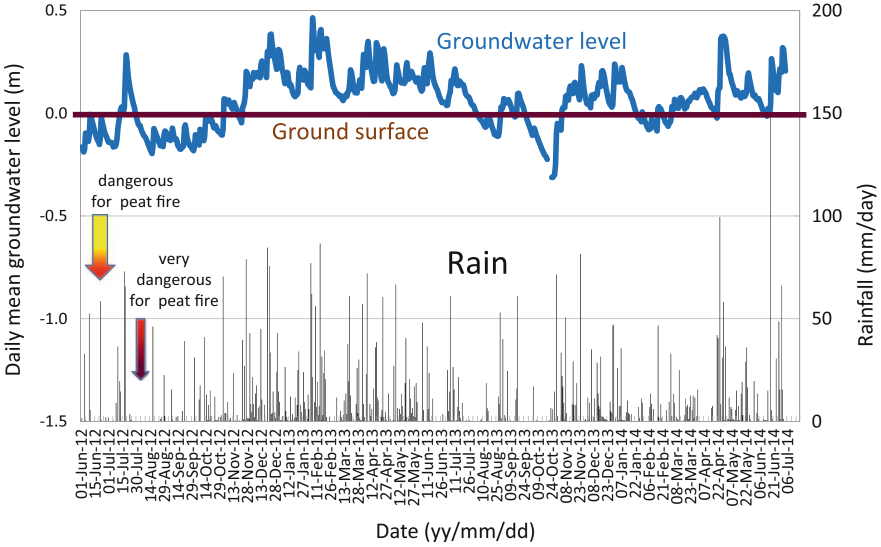

Fig. 33.6 Daily mean ground water level and daily total rainfall in a tropical peatland in Central Kalimantan, Indonesia

on 13 October, 2013. The daily mean groundwater level and daily total rainfall measured by SESAE-II is shown in Fig. 33.6. Using the ground water level and the amount of rain in a tropical peatland, the hazardous groundwater level for peat/forest fire is possible to estimate easily (Takahashi and Limin 2012). The daily changes of ground surface of the peatland was monitored and shown in Fig. 33.7. Ground surface level changed with changing the ground water level. The change of the both levels has a linear regression with the determination coefficient 0.766.

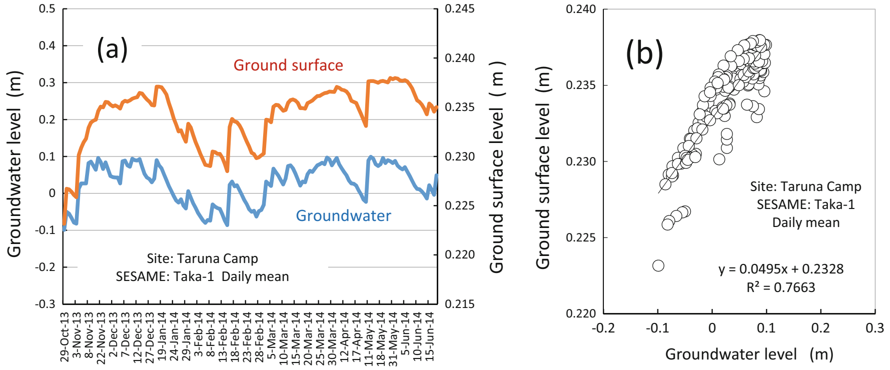

Fig. 33.7 Changes of groundwater and ground surface levels in a tropical peatland in Central Kalimantan, Indonesia (**a**), and the correlation between both levels (**b**)

33.5.2 Water Level in a River and a Dam Lake

The observations of water level of a river and the amount of rainfall are the basic of flood control in a watershed. The water level of the Kahayan River, which flows the middle of a tropical peatland in Central Kalimantan, Indonesia, is monitoring since September, 2012 without any trouble and supply of electricity. The data from this observation point was downloaded in Japan and shown in Fig. 33.8. The observation point is located in the upstream of the river, where the mobile phone is the only communication system and no stable commercial electricity is used. The water level fluctuation of the river was very large and very fast there. The water level has sometimes been higher than the river bank. This information is very useful for the early warning of flooding in the middle stream and downstream areas.

The management of water level of a dam lake is very important for flood control, irrigation and electrical power supply. The Jatiluhur Dam is a multi-purpose embankment dam on the Citarum River in West Java, Indonesia (Fig. 33.9). It is located 70 km east of Jakarta and 50 km northwest of Bandung. Water of the dam lake is used for electric power plant, irrigation for rice field, daily life water, and fish culture. The real time monitoring of water level is very important for the governmental office which has a responsibility of water management of the downstream area. The water level of the Jatilufur Dam, which is monitoring with 1 h interval is shown in Fig. 33.10.

33.5.3 Soil Moisture

The observations of soil moisture is important not only for the management of plant growth but also for understanding and estimating the activity of microorganisms in the soil. The moisture of surface layer of peatlands is a key information for estimating the ignitability of peat and warning the peat/forest fire in tropical peatland

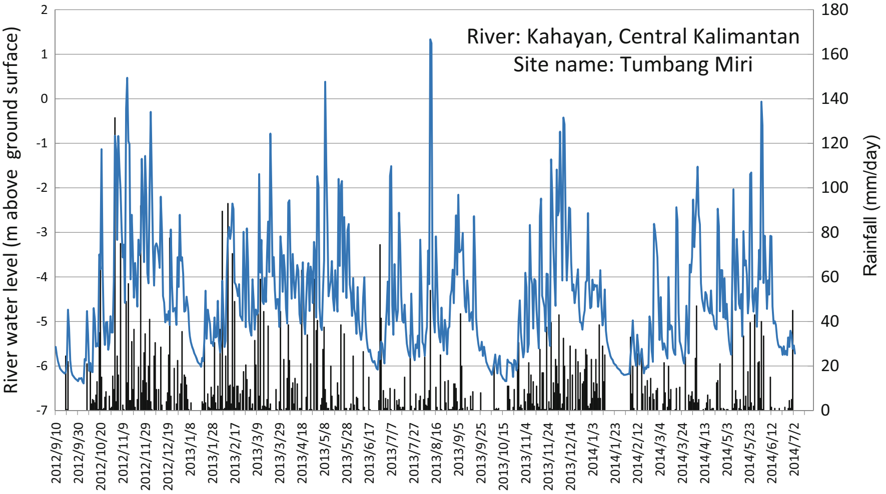

Fig. 33.8 Change of water level of the Kahayan River and rainfall at Tumbang Miri site in the upper flow area of the Kahayan River, Central Kalimantan, Indonesia

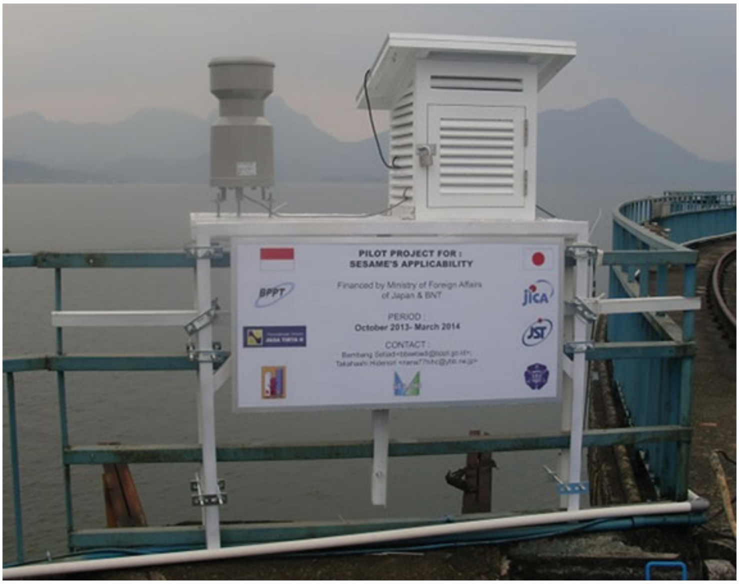

Fig. 33.9 The arrangement of the instrument shelter and the rain gauge at the Jatiluhur Dam in West Java, Indonesia. The set of SESAME-II shown in Fig. 33.4 is put in the shelter

(Adi Jaya et al. 2012). From the view point of plant growth, the water potential in soil is important. The tensiometer, which is consist of a porous cup and pressure gauge, is popular for measuring water tension in soil. The tensiometer (SS-203A, Rogu Denshi) which has a semiconductor pressure gauge was combined with

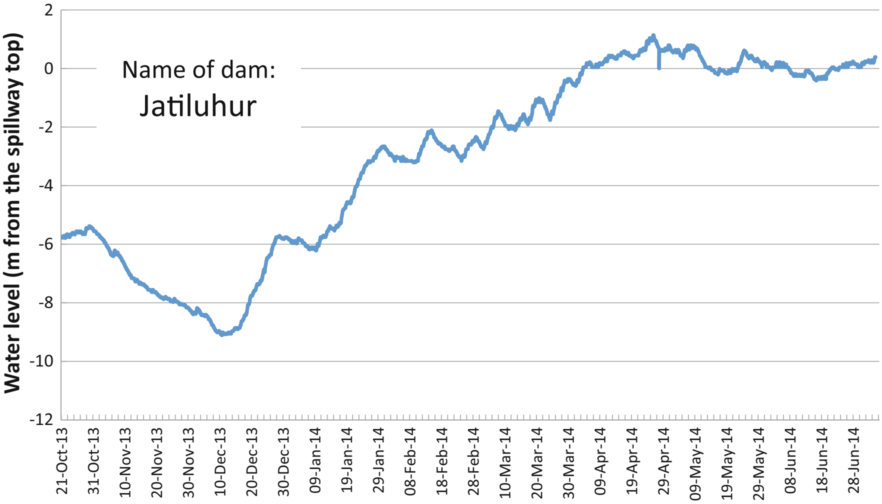

Fig. 33.10 Change of water level of the lake of the Jatiluhur Dam, West Jawa, Indonesia

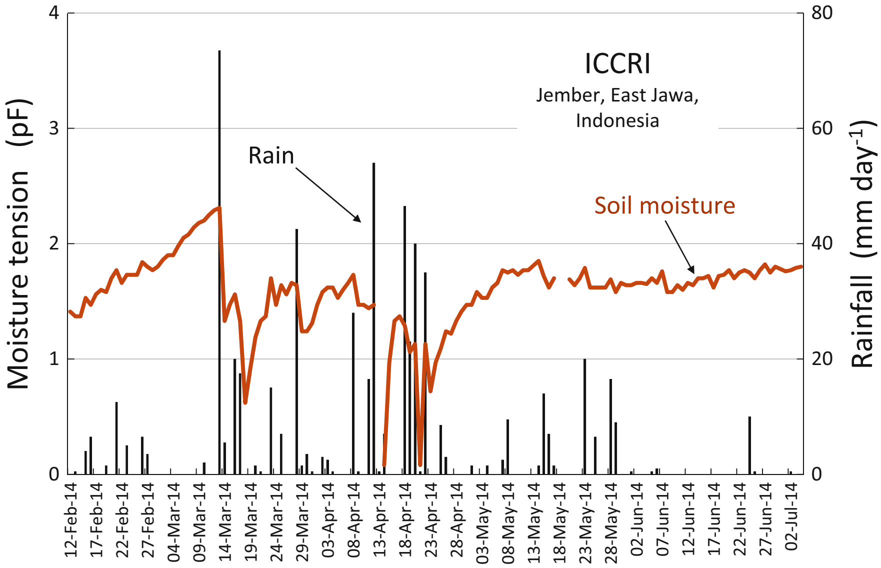

Fig. 33.11 The changes of the moisture tension pF and daily total rainfall at the field observatory of Indonesia Coffee-Cacao Research Institute, ICCRI, West Jawa, Indonesia

SESAME-2 and set in the field observatory of the Indonesian Coffee and Cacao Research Institute, Jember, East Jawa, Indonesia. The soil moisture in the field observatory in the institute is shown in Fig. 33.11. The moisture tension is converted from the height of water column to pF value with following equation.

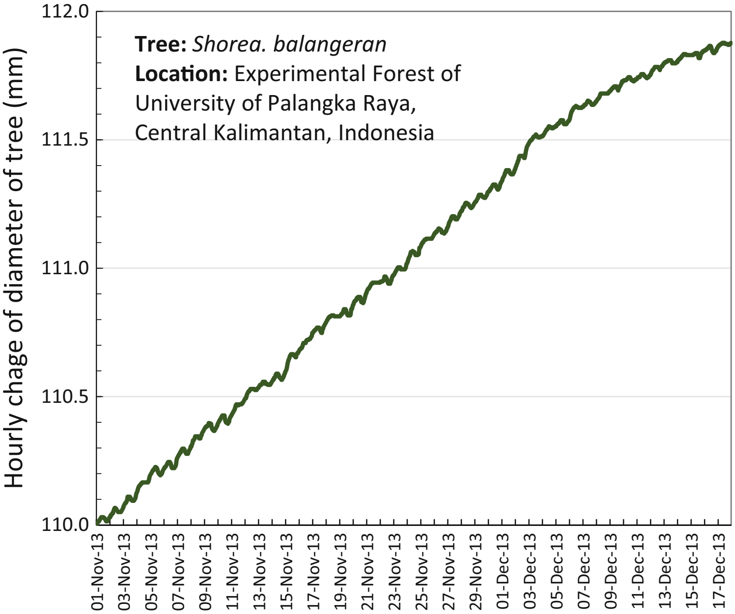

Fig. 33.12 The hourly change of radial growth for *Shorea balangeran* trunk planted in a peatland, Central Kalimantan, Indonesia. The stand age was 7-years-old and the height of sample tree was 6.8 m. The dendrometer was mounted on the trunk with 11.0 cm of diameter at 1.3 m height above ground level

$$\mathrm{pF} = \log H$$

where, H: soil moisture tension in cm H_2O

Using this system, we can easily monitor the soil moisture in the field from the office not only in the country but also from foreign country through internet.

33.5.4 Tree Growth

The wire dendrometer, which consist of the stainless wire, potentiometer and data logger, is suitable for monitoring of the radial growth of trees (Yamashita et al. 2006). They mentioned that the wire dendrometer detected the start of xylem growth, and a slow growth period. The new wire dendrometer was designed for combining to SESAME-2. The strait potentiometer, effective stroke of 50 mm and accuracy of ±0.5 % FS, and the stainless wire having low linear thermal expansion coefficient, $\alpha = 1.4 \times 10^{-6}$ K, were used for the new dendrometer. The tree diameter of *Shorea balangeran* growing in a tropical peatland in Central Kalimantan, Indonesia were measured by this system. The result is shown in Fig. 33.12.

Acknowledgements Results shown in this paper were mainly obtained from SATREPS (Science and Technology Research Partnership for Sustainable Development) project entitled as "Wild fire and carbon management in peat-forest in Indonesia" founded by JST (Japan Science and Technology Agency) and JICA (Japan International Cooperation Agency).

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Part VIII
Sustainable Management of Peatland

Mitsuru Osaki and Dedi Nursyams

Chapter 34
Peatland Management for Sustainable Agriculture

Dedi Nursyamsi, Muhammad Noor, and Eni Maftu'ah

Abstract Utilization of peatlands for agriculture in Indonesia has a long history. It was started from success of indigenous peoples who initially looked to peatland as a resource to produce traditional food crops, fruits, and spices and eventually large-scale operations such as lucrative palm oil plantations. Greenhouse gas (GHG) emissions issues, however, motivated the government to limit peatland utilization, which turned out to be a primary source of emissions. The benefits of peatland for agriculture are closely related to the properties and characteristics of the soil, water, and GHG emissions. These factors should be considered when determining policy and peatland utilization for agriculture. To achieve a productive and sustainable land, peatland management should be implemented and integrated with effective water management, soil amelioration, and fertilization.

Keywords Agriculture • Management • Peatland • Sustainable

34.1 Introduction

Indonesia has a fairly extensive peatlands area, which was about 14.91 million hectares. They were spread out in Sumatera island 6.44 million ha (43 %), Kalimantan island 4.78 million ha (32 %), and Papua 3.69 ha (25 %) (Ritung et al. 2012). Most or about 11 million ha of peatlands were in tidal swampland areas and the remaining land approximately 3.9 million ha were in swampland and beach area.

Utilization of peatlands for agriculture in Indonesia has a long historic foundation. Indigenous peoples, particularly in Kalimantan relied on peatland to produce food (rice, corn, sago, cassava), fruits (*durian*, *rambutan*, mango, etc.) and spices. In the history of swampland development, the success of peatland used by local indigenous peoples inspired the government to consider extending its usage. Controversy arose when cultivation of peatlands in new areas was mismanaged.

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Mismanagement led to deplete and degrade peatlands, which became a serious concern for domestic and international environmentalists and agriculturalists due to soil subsidence and greenhouse gase (GHG) emission. Decreasing land area for agriculture in Java Island and the rapidly increasing national population forced the Indonesian government to promote peatland as an alternative land resource. Government is seeking a voluntary 26 % reduction in GHG emissions from domestic growers and up to 41 % with international collaboration by 2020, where about 9.5–13.0 % of the reduction is from peatlands.

Peat soils of the peatland areas have specific properties that are different from other soils (mineral soils) and not all peatland can be used for agricultural crops. The dome part of peat should not be opened because it can contribute to subsidence and greenhouse gas emissions. Only at selected sites can agricultural activities be done. Peatland suitable for farming has certain requirements such as (1) its thickness should be <100 cm, (2) sapric-hemic maturity is necessary, (3) 20 cm thickness of peat at the top layer is needed because the peat mixes with the mineral soil, (4) the mineral soil materials should contain <25 % organic matter after reclamation or drainage, and (5) a water level of <70 cm is preferable. Research results have shown that rice productivity in peat decreases with increasing soil thickness up to 100 cm, because this produces low levels of mineralization and soil fertility (Noor et al. 1991; Noor 2001). Rice crops cultivated on thick peat soil continuously decline over time, so the land is frequently abandoned. To maintain its productivity, appropriate and sustainable soil, water and plant management are needed, all of which are matters this paper discusses in light of the aim to achieve sustainable farming.

34.2 Properties and Character of Peatland Soil

The main factor of peatlands for agriculture is closely related to properties and character of the soil, water, and GHG emissions that are released from peatlands into the atmosphere. Understanding those factors is important when making decisions/policy about agriculture utilization, including development of management technologies.

34.2.1 Soil Factors

As a plant growth medium, peat soils have several constraints in terms of soil's physical, chemical, and biological properties. Peat soils fertility level can vary depending on peat thickness, maturity, and nutrient content. In general, peat soil with minor, moderate, and major constraints are group into moderate (S2), marginal (S3), and not suitable (N) for agriculture, respectively.

Peat soil sensitivity to environmental change is very high. Specifically, improper use of the land or recklessly land clearing will cause physical soil problems such as land subsidence, irreversible drying, as well as hydrophobic, soil chemical problems, as indicated by acidification (pH 2–3), an increase in levels of toxic elements and compounds, such as Al, Fe, Mn, organic acids, and sulfide. Peat soils contain very low nutrients, particularly intensively utilized peatlands for crop cultivation. Therefore, amelioration and fertilization are critical because the more extensively used the peat soil, the lower the soil fertility due to soil acidification, leaching, flushing, and fixation.

Opening or reclaiming peatlands essentially involves managing the water settings to optimize plant growth. This means to make sure there is not too much flooding during the rainy season and preventing drought during the dry season, as well as minimizing GHG emissions. Reclamation at an early stage aiming to drain excessive water may result in over drainage and instigate irreversible drying conditions and subsidence. Therefore, this needs to be followed up by making canal blocks or a *tabat* system to maintain the water level and keep the soil moist.

Regarding agricultural practices, particularly using peat land for crops, there is indigenous knowledge about the management of organic matter that combines minimum tillage known as *tajak*, *puntal*, *hambur* systems, followed by application of ash, salt, and manure. This farming practice is essentially the farmers' response to the wetland conditions including peat soils, which are easily flooded, contain a high content of organic acids, but are quite low in nutrients. Availability of fertilizers is very limited due to its hefty cost, so farmers mostly provide nitrogen enriched fertilizer to their farmland using animal urea without phosphorous and potassium components. This condition can lead to a decrease in the production of crops and biomasses as well as land degradation (Noor 2012).

34.2.2 Water Factors

Peatlands, especially those in the swampland areas, are generally flooded for up to 3–5 months every year. The water in peatlands come from rain, rivers, sea water, swamps forests or their surrounding area, and delivery from headwaters. Therefore, the quality of water in the peatland is predominantly influenced by its source and circulation. Peatlands that are in B flood type regions with periodically moving water, the water quality is better than peatlands that are in waterlogged conditions. Similarly, regarding swampy peatlands, in Lunang, West Sumatra, the soil gains enrichment from water carrying volcanic material. In general, the quality of the water at high tide or during the rainy season is better than at low tide and in the dry season because water quality in the latter is more acidic (pH 2–3), containing higher levels of toxic elements and or compounds, such as sulfate (SO_4^{2-}), organic acids, and Fe^{2+}(Anwar and Mawardi 2012).

In management practices, especially in reclamation areas equipped with floodgates (canal blocks), most of the flood gates were already broken and did not function well so that the water flowed freely, thus there was drought in the dry season as well as heavy flooding in the rainy season. Improving floodgates (dam overflow) by local communities independently needed to be encouraged more widely to prevent drought or flooding (EMRP 2009; Noor 2010). In addition, *tabat* was prepared to retain water, prevent fires, minimize GHG emissions and reduce land degradation, especially annual crops on a plantation. In order to increase food crop intensity and optimize land productivity, water management is strongly required.

34.2.3 GHG Emission Factors

The opening and utilization of natural peatlands may cause biological, physical, and chemical changes in the ecosystem. Global warming and extreme climate change have come about due to rising GHG concentrations (CO_2, CH_4, N_2O) in the atmosphere derived in part from the peatlands. Consequently, the utilization of peatlands requires a stute management; otherwise the peatlands may adversely impact global warming, climate change and humanity.

Peatlands contain decomposed biomass from organic matter and store about 200 tons of carbon that may be a source of GHG emissions when burned or decomposed (Rahayu et al. 2005 *in* Harsono 2012). Therefore, utilization and management of peatlands should be accompanied by mitigation of GHG emissions. Research results showed that water management, while maintaining the water table at a depth of less than 30 cm, significantly reduced GHG emissions and prevented fires. Use of local mature chicken manure also suppressed GHG emissions and increased plant yield. Adaptive varieties of plants, such as pineapples also produced lower GHG emissions. Pineapple is known as a very adaptive plant to acidic peatlands (pH 2–3) with their poor drainage and thick peat soil, because it can produce about 3 t/ha (Ambak and Melling 2000; Noor 2004).

34.3 History of Utilizing Peatland

The opening and development of peatlands were started in the thirteenth century of the *Majapahit* Kingdom era. The King of *Prabu Jaya* as a descendant of King *Brawijaya* of the *Majapahit* Kingdom sought to expand his empire to the *Pawan* river basin, in West Kalimantan. The peatland was opened to settlement and farming to provide the necessities of life. This was followed by the Dutch government, in the 1920s colonizing and placing Javanese peatland in Tamban and Serapat, and in South Kalimantan where they were “forced” to plant coconut and rubber. Road construction by Javanese workers along about 40 km of territory from Banjarmasin to Martapura Regency (Aluh-Aluh, Kurau, Gambut) was where peatland was sown. Because it was very difficult to access some food at that time, then workers opened and planted peatland with rice.

After independence, Indonesia began surveying and collecting detailed data about peatlands supported by some Dutch experts who had remained in Indonesia, among them: P. M. Driessen, B. Polak, and Schophuys (Noor 2010; Nugroho 2012). Opening peatlands was originally started with the *Handil* system in 1920 on just a small area of about ten hectares. Then, the government developed the *Anjir* system (1945–1960), Fork system and Comb system (1969–1995) with extensive development of thousand hectares of peatland, and finally mega rice projects with one million hectares of peatland in *PLG*. Central Kalimantan was opened as a rice estate with a one-way water management system (1996–2000). In the beginning, a small scale development (community scale) of food crops and horticulture was established that grew into a large-scale business of agricultural crops and plantations of jelutung, rubber and palm oil on thousand hectares of peatlands.

Fortifying swampland, including peatlands, through biodiversity and genetic resources, carbon storage, (as a source of GHG emissions) and the development and management of peatland to attain sustainable agriculture required integrating several important aspects to optimize the peatlands' potency and function. The aspects include agricultural production, socio-economic and environment function, as well as acceptance of surrounding communities. Development of peatlands for agriculture should be in line with the government's commitment to achieve food security and cleaner energy (self-sufficiency) including reduction of GHG emissions.

Fertile peatlands and bountiful human resources are the major forces in Indonesia needed to reach the objectives. In addition, environmental conditions and supporting technologies are also conducive and readily available to support the quest. The development of peatlands for agriculture can be classified by commodity, as the following: (1) food crops, (2) annual crops (plantations) and (3) a mixture of plants such as trees and cereal crops (mixed farming).

Cultivating peatlands was a means to support a national policy to increase food production. Each transmigrant was allotted a 2.25 ha plot, which was divided into 0.25 ha for planting rice, vegetables and horticulture, 1 ha for farm land in which annual crops of mainly rice and grains were planted, and 1 ha used as a secondary farmland where trees were growing. It was reported that in some areas of opened land, such as: in Pangkoh (Central Kalimantan), Rasau Jaya (West Kalimantan), Siak (Riau), Wendang (Jambi), and Air Sugihan (South Sumatra), transmigration programs were less successful. It was because of some factors, i.e.: a majority of peat was >3 m in thickness, there was a layer of pyrite substratum or sand found on the bottom, as well as a sea water intrusion during the dry season so that the government had to relocate the transmigrants to a better place. But most of the peatland areas developed well and became centers of rice production and plantations as the peat soil thinned and matured. Water management improved as well, in the following regions, Delta Upang (South Sumatra), Silaut Lunang (West Sumatra), Pulau Burung (Riau), Suryakanta and Gambut Kertak Hanyar (South Kalimantan).

The research results of Balittra (2007) showed that the utilization of peatlands was very diverse depend on understanding, experience, or view point of the farmers and their communities to manage the lands. Each person who lived in the peatlands had a different notion of how to utilize them as agricultural land resources. These included ethnic migrants from Java, Madura, Nusa Tenggara, Bali and other islands, who are habitual dryland farmers and whose perceptions of the peatlands are different from those of indigenous communities. For example, Banjarese (indigenous peoples) use a peatland suitable for growing paddy rice, but Javanese (farmers from Java) generally look for a peatland suitable for growing crops and vegetables. Similarly, other tribes, such as the Bugis cultivate peatlands to grow paddy rice, pineapples and coconuts. In Riau and East Kalimantan, the Dayak of Central Kalimantan (indigenous peoples) develop peatlands for planting rice, rubber, rattan, *jelutung*, *nibung*, sago, as well as fruit crops, such as: durian, *cempedak*, and the like. The Bali tribe living on Kalimantan Island use a peatland appropriate for fruit crops, like pineapples, *cempedak*, and the like, but in West Sulawesi, they cultivate a peatland conducive to citrus and chocolate plants. Chinese people living in West Kalimantan generally use peatland for planting leafy vegetables, such as: mustard greens, chives (a type of scallion), celery, and Aloe Vera, while Malays living in Riau use peatlands for planting pineapple, coconut, rubber or palm oil. Figure 34.1

Fig. 34.1 Successof rice, maize (intercropping with citrus)), peanuts, vegetables, Aleo Vera, pineapple, banana, papaya, and palm oil at peatlands of Lamunti (Central Kalimantan), Mamuju Utara (West Sulawesi), Siantan and Pontanak (West Kalimantan) (Balittra 2008)

shows a variability of crops, vegetables, and horticultural planted in peatlands at various locations in Kalimantan, Sumatra, and the Sulawesi Islands.

In the last decade, development of plantations, especially palm oil have proceeded very rapidly in wetlands, particularly peatlands. Their management, however was not proper so that caused soil subsidence and increased GHG emission. Presently the government needs to restrict it with releasing the Minister of Agriculture (MoA) Regulation No. 14/2009, Presidential Decree No. 10/2011, and Presidential Decree No. 6/2013 describing a moratorium on peatland expansion. This confirms that peatland should not be opened to agricultural land with improper management. Managing and developing peatlands should consider the specific properties and character of the peatland, such as its tendency to dry out and burn easily, ranging from barely providing subsidence to achieving optimal productivity.

34.4 Peatland Management for Sustainable Agriculture

Sustainable agriculture is a farming system that increases agricultural production. It is economically profitable, socially and culturally acceptable, and ecologically adaptive to the environment. According to Radjagukguk (2004), farming systems in sustainable peatland should have three main benefits, (1) they maintain the economic value of the agricultural system, (2) preserve land resources, and (3) sustain other ecosystems that are affected by agricultural activities. Incorrect management practices of peatlands are not sustainable, because they contribute to rapid degradation of peatlands, increased GHG emissions and subsidence.

Exploitation of peatlands can be successful and yield sustainable peatland agriculture when done with correct organizational concepts that integrate water management, soil improvement or remediation and fertilization on a selected plot of land.

34.4.1 Water Management

There are two water management systems in the peatlands, the macro-scale and the micro-scale. The macro-scale water management is a reclamation process known as *anjir*, or a fork and comb systems. Micro-scale water management utilizes tertiary and quarteriary canals as well as farm plots. Water management of food (rice) crops has two main objectives, (1) to provide sufficient water for rice growth and (2) minimize peatland decomposition (Notohadiprawiro 1981).

Water management in peatlands for agriculture is basically to maintain the water table to supply water to plants and reduce GHG emissions and decomposition. For example, food crops require a channel with a depth of 10–50 cm. A deeper canal faces some risks, for example, it could dry peat soil, accelerate oxidation, and decompose the peat soil surface. Exposed peat soil is easily or rapidly oxidized and

Fig. 34.2 Floodgates or tabat are very important in maintaining water levels of peatlands (Noor 2011)

Table 34.1 Total emission of CH_4 and N_2O, GWP, paddy yield, and emission index at several type of swampland

Flood type	Org. C (%)	Emission (g C.m^{-2} per season)		GWP (g C.ha^{-1}. th^{-1})	Yield (t DW.ha^{-1})	Emission index (g C/t DW)
		CH_4	N_2O			
A	37.1	9.95	0.07	242.6	1.10	220
B	54.3	−0.59	0.10	19.6	1.91	10
C	31.8	−0.13	0.00	−7.8	1.84	−4
D	34.3	0.37	0.19	45.7	1.59	29

Source: Hadi et al. (2007)
GWP Global Warming Potential, *DW* Grain dry weight

decomposed resulting in subsidence and thinning. Keeping peatland wet or damp is essential to preventing or reducing land degradation. Therefore, flood gates have an important role in maintaining ground water level at a shallow level (<70 cm) or near soil surface level (Fig. 34.2).

It is recommended that the drainage canal not be too deep (Minister of Agriculture Regulation No.14/2009). Preparation of drainage canals will not only reduce the moisture in the peat soil, but it also reduces GHG emissions, such as CO_2. Wösten research results in Hooijer et al. (2006) showed that rate of GHG emissions, in particular CO_2 was proportional to the depth of the drainage channels where it might be linear (Rieley and Page 2005) or logarithmic (Agus 2009). The deeper the water table (30–90 cm), the higher the CO_2 emission, depending on the type of peatland environment. Hadi et al. (2007) also showed that the flood type influenced CH_4 and N_2O emissions. The highest CH_4 emissions occurred with a flood type A followed by flood type D, whose levels were 9.95 and 0.37 g cm^{-2} per growing season, respectively (Table 34.1). CH_4 emissions were positively correlated with soil moisture content and bulk density. This reinforce show water management is integral to mitigating CH_4 emissions.

34.4.2 Soil Improvement

Soil improvement or amelioration plays an important role in creating favorable conditions and making nutrients available to plants to ensure an optimal yield. Application of ameliorant material into the soil to improve the environment for plant growth may result in an increase in soil pH and fewer toxic ions (Attiken et al. 1998). Good ameliorant materials for increasing peat soil productivity have several criteria, such as a high base saturation, capability to significantly increase the soil pH level, ability to reduce toxic compound or element effects, especially organic acids and GHG emissions, and a capacity to contain many nutrients and thus function as a fertilizer (Najiyati et al. 2005). The ameliorant materials used for peat soil generally include, limestone (dolomite, calcite), rock phosphate, the ash of agricultural waste, biochar compost, manure (cow, goat, chicken), volcanic ash, mud and mineral soil material.

Effect of Lime Application of lime or dolomite may increase soil pH up to a range of 4.5–5.5. This application is not only intended to achieve soil pH 4.5 (Noor 2001), but also to increase the availability of soil nutrients (N, P, K, Ca, Mg, Cu, Zn) and improve soil balance such that the nutrients can be absorbed efficiently by the plants (Brown et al. 2007). The lime will release OH^-, and reduce H^+ causing an increase in soil pH with a reaction as follows:

$$\mathrm{CaMg(CO_3)_2} \rightarrow \mathrm{Ca^{2+}} + \mathrm{Mg^{2+}} + 2\ \mathrm{CO_3}^{2-}$$

$$\mathrm{CO_3}^{2-} + \mathrm{H_2O} \rightarrow \mathrm{HCO_3}^{-} + \mathrm{OH^-}$$

$$\mathrm{H^+}\ (\text{soil solution}) + \mathrm{OH^-} \rightarrow \mathrm{H_2O}$$

Use of lime may also donate Ca^{2+} ions thus form complex compounds with humic acid, where the amount of the compounds depend on the amount of protons in the soil solution (Jeong et al. 2005). The reaction may be described as follows:

$$2\ \mathrm{RCOOH} + \mathrm{Ca^{2+}} \rightarrow \mathrm{(RCOO)_2Ca} + 2\ \mathrm{H^+}$$

$$2\ \text{Phenol} + \mathrm{Ca^{2+}} \rightarrow \text{Phenol-O-Ca-O-Phenol} + \mathrm{H_2O}$$

Excessive use of lime (over liming) to achieve a pH >5.5 may cause soil dispersion. In addition, liming may also accelerate soil decomposition and mineralization resulting leach of nutrients and GHG emissions. Therefore, determination of lime dose and its application should be careful.

Several research results showed that use of lime with a 0.2 % dose of dry weight peat soil could increase P store capacity by 45 % (Maas 1993). Suryanto (1994) reported also that liming in peat soil increased P store capacity up to 55 %. However, increasing doses of lime does not always improve the ability of peat to save P. Liming with a rate of 0.75 soil acidity was quite effective in improving peat soil fertility (Masganti 2003). On intensive cultivated peat soils, liming of 1–2 t/ha was sufficient (Agus and Subiksa 2008), where as degraded peat soils needed 2–5 t/ha of lime (Maftuah 2012).

Effect of Ash Farmers have implemented organic ash as an ameliorant material since opening of the peatland. This ash comes from agricultural waste (straw etc.), weeds, and crops (not peat soil) which are then burned at a selected safe place. Ash is rich in several nutrients, such as P, Ca, Mg, and K. The number of base cations in organic ash can be used as agents to absorb P, so that it may increase the capacity of soil to store P. The ash may come from several sources of organic matter (not peat soil) that are abundant in peatland. They include plant litter, crop stubble, a by product of the timber industry, agricultural waste etc. Ash's characteristics also vary depending on type of material, but it generally contains high cations, high pH, and high bases saturation. Ash from sawed wood contains exchangeable Ca 6.7 cmol/kg, Mg 1.23 cmol/kg, K 4.31 cmol/kg, Na 1.35 cmol/kg, with a base saturation of approximately 83.68 % (Najiyati et al. 2005).

Making ash requires caution to avoid fire and reduce CO_2 emissions. Sources of ash are not peat soil, but other organic materials that are burned at 2–5 cm thickness of mineral soil material, which covers up the peat soil surface. Nevertheless, use of continuous ash without control will result in too high a soil pH, which can reduce micro nutrient availability. Therefore, use of ash needs to be done carefully and soil pH should be monitored and maintained at appropriate levels (pH around 5.0). In addition, micronutrient availability also needs to be monitored to attain a nutrient balance in the soil. Excessive use of ash not only disturbs the nutrient balance in the soil, but it also increases the peat soil decomposition rate (Fig. 34.3).

Fig. 34.3 This is kind ash, which is a part of themineral soil material used to cover up the peat soil surface, a practice of the farmers in Central and West Kalimantan (Source: Noor 2011; Balittra 2013)

Fig. 34.4 Making biochar process (Source: IRRI 2013)

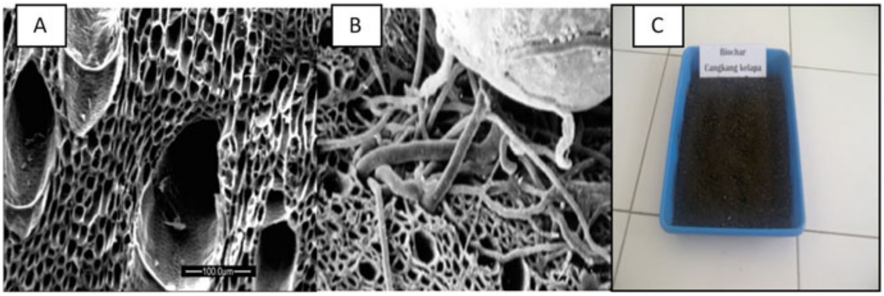

Fig. 34.5 Biochar pores (**a**), VAM in biochar pores (**b**), biochar fromi coconut shell (**c**) (Source: Lehmann and Joseph 2009; Balittra 2013)

Effect of Biochar Biochar is organic charcoal matter heated with an imperfect combustion process called pyrolysis (Fig. 34.4). In the soil, biochar provides a habitat for soil microorganisms, but it is not consumed and may remain for hundreds or even thousands of years. Over long periods, it does not interfere with the soil carbon-nitrogen balance, but it may save water and nutrients and make them more readily available to assist in plant growth (Fig. 34.5). Use of biochar together with both organic and inorganic fertilizers may increase soil productivity by improving nutrient availability and retention. Use of biochar can also increase availability of soil N, P and other macro cations, with a CEC up to 40 %, and pH up to one pH unit.

Effects of biochar on peat soil vary depending on quality of biochar as determined by biochar water content, surface area, pore size, and nutrient content (Lehmann and Joseph 2009). Biochar nutrient composition varies depending on raw materials used or the accompanying material present. The combination of biochar and manure provides a different chemical composition (Table 34.2).

Effect of Organic Matter Organic matter is a potential source of ameliorant and a major source of organic fertilizer. Farmers in West Kalimantan usually use organic matter, such as fish meal, shrimp head meal, cattle manure, and chicken manure. In one study, shrimp head flour contained N (3.08 %), P (0.75 %), K (0.82 %),

Table 34.2 Biochar and its combination with animal manure

Properties	Rice husk biochar + animal manure	Coconut shell biochar + animal manure	Rice husk biochar	Coconut shell biochar
pH	7.52	8.62	7.33	8.53
EC (mS/cm)	2.450	2.740	1.469	0.734
Organic-C (%)	27.55	25.21	26.26	24.94
Total N (%)	0.448	0.644	0.364	0.742
K_2O (%)	1.139	1.060	0.835	0.180
CaO (%)	0.164	1.165	0.083	1.065
MgO (%)	0.109	1.437	0.360	0.318
Total Fe (%)	0.126	1.684	0.139	0.796
Total P (%)	0.205	0.187	0.052	Trace
Water content (%)	87.71	47.01	40.04	10.77
CEC (cmol(+)/kg)	47.50	52.50	66.50	37.50

Source: Balittra (2013)

Table 34.3 Ameliorants that are recommended to be applied to peatlands

Ameliorant	Dose (t/ha)	Benefit	Reference
Lime	1–2 or dependsoil pH	Increasing soil basis and pH	Agus and Subiksa (2008)
Ash	10–20 t/ha	Increasing soil basis and pH	Agus and Subiksa (2008)
Biochar	5–10 t/ha	Increasing soil basis and pH, as habitat of soil microbes, and decreasing GHGs emission	Balittra (2013)
Animal manure	10–20 t/ha	Enriching macro and micro nutrients	Agus and Subikso (2008)
Mineral soil	10–20 t/ha	Decreasing toxicity of organic acid and GHGs emission	Agus and Subikso (2008)
Animal manure + dolomite	10–20 t/ha	Increasing soil pH and macro and micro nutrients	Maftu'ah. (2012)

Ca (2.41 %), Mg (0.18 %), while fish meal contained N (2.35 %), P (0.57 %), K (0.82 %), Ca (0.73 %), Mg (0.13 %) (Noorginayuwati et al. 2007). Rice husk contained a lot of K and other cations, thus it is used as a potential source of nutrients and soil ameliorants substituting ash for peat soil (Table 34.3).

Farmers in Kalampangan, Central Kalimantan are using animal manure to improve soil fertility and increase plant yield. Farmers usually combine an application of animal manure with ash for vegetable farming. Animal manure as ameliorant has some weaknesses, such as limited ability to raise soil pH and nutrient content. Consequently, it needs to be distributed in large amounts ranging from 2.5 to 10 tons/ha (Prastowo et al. 1993). Nutrient content in fresh cattle manure was N (1.53 %), P (0.67 %), K (0.70 %), while chicken manure contained N (1.50 %), P (1.97 %), K (0.68 %) (Hartatik and Widowati 2006). According to Pinus Lingga (1991), cattle manure contained N (0.30 %), P_2O_5 (0.20 %), K_2O (0.20 %) and C/N ratio 20–25 %, while chicken manure was N (1.50 %), P_2O_5 (1.30 %), K_2O (0.80 %) and the ratio of C/N 9–11.

Purun tikus compost *was* also effective in increasing the availability of P in peat soil, because it contained a total Fe content of 7.78 ppm (Damanik 2009). Fe might have increased the capacity of the soil to save P in the peat soil, so that P loss through leaching decreased (Masganti 2003). One month of composting resulted in a C/N ratio of 21, organic-C content of 42.66 %, and total N of 2.33 %. In addition, *purun tikus* compost was able to increase P holding capacity, absorption site, and binding energy constant so that it might increase capacity of soil to save P.

Good management practice of organic matter includes composting techniques, and fertilizer quality settings by manipulating or mixing organic matter of different quality so that the chemical composition and nutrient content of organic fertilizers can be adjusted and enhanced. Mechanical assembly of organic fertilizers should consider synchronization between the releases of nutrients with plant requirements in order for the plants to absorb nutrients effectively to increase fertilization efficiency.

Effect of Mineral Soil Matter Mineral soil matter is also effective as an ameliorant because it makes peat soil more stable and may reduce GHG emissions. In addition it may contain many sources of polyvalent cations (Fe, Mn, and Zn) that can suppress organic acid activity by binding it with forming chelate compounds. Use of mineral soil matter as an ameliorant reduced the concentration of siringate, kumarate, and vanilate acids (Hartatik and Suriadikarta 2006). Further the researchers explained that the use of high levels of Fe-bearing mineral soil reduced the concentration of phenolic acids that resulted from interaction between the ameliorants Fe cation as a cation bridge and phenolic acids through a polymerization process. The lower phenolic acid concentration was to reduce soil acidity. Besides that, use of mineral soil was able to strengthen cation and anion bonds; thereby, protecting fertilizers from nutrient loss. The bonds between colloidal minerals with organic acids might inhibit decomposition of peat soil, so that peat land could be used as a natural resource overlong-term periods (Fig. 34.6).

Other mineral ameliorants that have been widely investigated are polyvalent cations ameliorant containing Fe, Al, Cu, and Zn, such as steel slag, lateritic mineral soil, and mud river. The ameliorants were very effective in reducing the toxic effects of phenolic acids (Salampak 1999; Sabiham et al. 1997). Application of polyvalent cations, such as Fe and Al created an absorption site for phosphate ions so that it can reduce P nutrient loss through leaching (Rachim 1995). Use of mineral soil ameliorant bearing high Fe increased the rice growth and yield in the peat soil (Mario 2002; Salampak 1999; Subiksa et al. 1997). Combinations of the ameliorants with *Pugam* (peat fertilizer) developed by Balittanah also effectively increased productivity of the peat soil. *Pugam* also contained high concentrations of polyvalent cations, so that the application as ameliorant did not need high dose, which in this case was only 750 kg/ha (Subiksa et al. 2009).

Fig. 34.6 Ameliorant application in peatlands

Table 34.4 Effect of ameliorants on chemical properties of peat soils

	$NH_4 + NO_3$	Available P	Exc. K	Exc. Ca	Exc. Mg	pH
Ameliorants	mg kg^{-1}	mg kg^{-1}	cmol(+) kg^{-1}	cmol(+) kg^{-1}	cmol(+) kg^{-1}	H_2O
Chicken manure	108.84 a	43.31 a	2.35 a	4.09 a	3.97 a	3.84 a
Mineral soil (Spodosol)	16.61 d	4.36 e	0.18 d	1.24 b	0.93 e	3.51 b
Puruntikus compost	71.74 b	8.76 e	0.60 c	1.24 b	0.81 e	3.39 b
Agricultural weed compost	39.77 c	25.30 cd	0.54 c	1.57 b	1.81 d	3.32 b
Control	11.74 d	2.36 e	0.16 d	1.29 b	0.93 e	3.39 b

Source: Maftuah (2012)

The type of ameliorant significantly affected the chemical properties of the peat soil. The most effective ameliorant in improving soil properties was chicken manure. The chicken manure, in addition, did not only supply these nutrients, N, P, K, Ca, and Mg, but it also increased soil pH from 3.39 into 3.84 (Table 34.4). Furthermore, the combination of animal manure with other ameliorant materials (agricultural weeds and grass *purun tikus*) has also been known to improve peat soil fertility in Landasan Ulin, South Kalimantan (Balittra 2012).

34.4.3 Fertilization

Fertilization in peatlands is needed to meet plant nutrient requirements on both a macro and micro level. This is due to the inherent nature of peat soil having very poor nutrient content. Ameliorant materials that can contribute nutrients to the plants may also act as a fertilizer, but it is important to add both organic and inorganic fertilizers to peat soil.

Organic fertilizers are those that are largely or entirely composed of organic materials derived from the remains of plants and animals that have been treated, have a solid or liquid form which is used to supply organic matter and improve the soil's physical, chemical and biological properties (MoA Regulation No. 2/2006). Criteria of organic fertilizer was an organic material which has a total N > 6 %, total P > 2 % and total K contents >1 % (Suriadikarta and Setyorini 2006). Inorganic fertilizers can be either a single or compound fertilizer. Thus, organic fertilizer originates from organic materials, while inorganic fertilizer comes from inorganic materials.

Some research on fertilization in peatlands showed that without fertilizer, N, P, K, Cu, and Zn, rice growth in peat soil was stunted (very low number of tillers). Micro nutrient deficiencies in Cu and Zn were indicated by a high number of empty grains. N, P, and K fertilizers, with a dose of 90-60-60 kg/ha respectively, and micronutrients of Cu and Zn with a dose of 5.0 kg/ha, increased rice yield by 14 % compared to farmers fertilizing. Noor et al. (2006) reported that Cu and Zn contents in peat soil taken from Kanamit Village, Maliku Sub District, Pulang Pisau District, Central Kalimantan Province were 4.95 and 11.85 ppm, respectively (relatively low). Application of Cu fertilizer was more effective through plant leaves because it was very mobile in plants, while it was absorbed strongly in the soil. In addition, *pugam* was not only able to increase peat soil productivity, but it also reduced CO_2 emissions (Balittanah 2012).

A combination technology of proper amelioration, fertilization, and water management was effective in increasing peat soil productivity. Supriyo (2006) showed that the combination of water use at a single tide detained in rice fields until the day before the period of a single tide with a 5 ton ameliorant of animal manure, dolomite 1 ton/ha, inorganic fertilizer of urea 119, SP 36 119, KCl 79 kg/ha increased Martapura rice yield as well as reduced soil exchangeable Al. The combination of inorganic fertilizer (urea, SP 36, KCl) with animal manure and lime produced a better effect on water quality, soil and plant growth in tides peatlands (Supriyo et al. 2007).

In relation to GHG emissions, type of ameliorant significantly influenced the level of GHG emissions at rice plants in peatlands. Use of ameliorant was able to reduce GHGs emissions in peatlands in term of CO_2 flux (Fig. 34.7) and CH_4 flux (Fig. 34.8). Animal manure was more effective in reducing CO_2 emissions compared to mineral soil ameliorant (Table 34.5). Use of rice husk biochar on upland peat soil was more effective than mineral soil, animal manure and *pugam* (Figs. 34.7 and 34.8).

In relation to the environmental aspects, using organic matter as an ameliorant in peat soil requires one to consider the quality and type of materials and level of maturity of the organic matter. According to Wihardjaka (2005), methane emissions from paddy soil using mature compost and animal manure were lower than those using fresh organic fertilizer and rice straw. Kartikawati et al. (2012) reported that use of ameliorants on flooded peat soil in South Kalimantan was able to reduce CH_4 emissions by 40–50 % and CO_2 emissions by 5–30 %, whereas the most effective ameliorant in lowering GHG emissions was animal manure (Table 34.5).

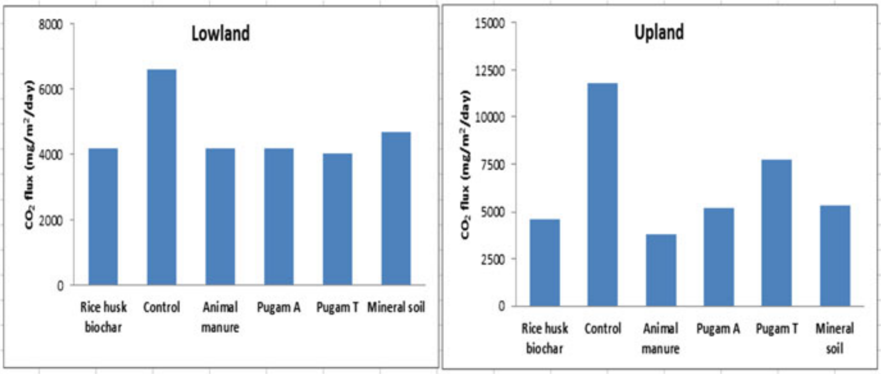

Fig. 34.7 Effect of ameliorants on CO_2 flux of lowland and upland peat soil of South Kalimantan (Kartikawati et al. 2012)

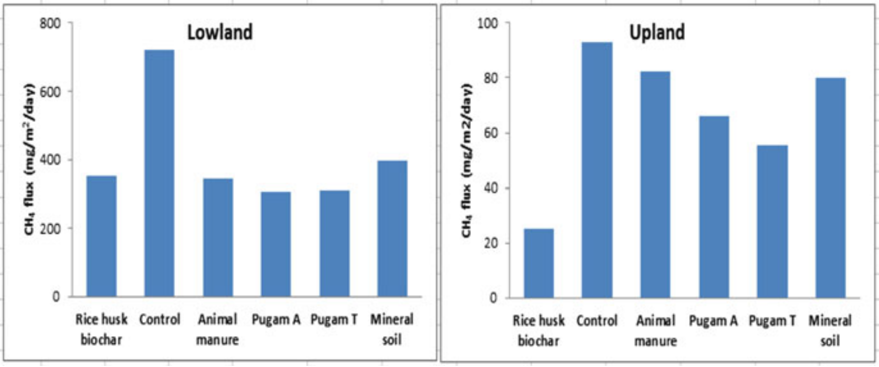

Fig. 34.8 Effect of ameliorants on CH_4 flux of lowland and upland peat soil of South Kalimantan (Kartikawati et al. 2012)

Table 34.5 Effect of ameliorant types on CO_2 and CH_4 emissions at flooded peat soil of Landasan Ulin, South Kalimantan

	CO_2		CH_4	
Perlakuan	Emission ($t\ ha^{-1}season^{-1}$)	Reduction (%)	Emission ($kg\ ha^{-1}season^{-1}$)	Reduction (%)
Control	20.6	–	620.9	–
Rize husk biochar	18.6	9.4	289.8	53.3
Animal manure	14.3	30.4	294.6	52.5
Pugam A	14.4	29.7	300.4	51.6
Pugam T	19.2	6.5	272.7	56.1
Mineral soil	15.8	23.2	373.1	39.9

Source: Kartikawati et al. (2012)

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Chapter 35
Tropical Peatland Forestry: Toward Forest Restoration and Sustainable Use of Wood Resources in Degraded Peatland

Hideyuki Saito, Akio Koizumi, Sampang Gaman, Prawira Yuda, Penyang, and Masato Shibuya

Abstract Forestry is an important land-use type in tropical peatlands that provides socio-economic and environmental services. Currently, tropical peatland forestry has contributed to the timber industry, but timber harvest has unfortunately caused degradation and deforestation in massive areas of tropical peat swamp forests. Consequently, serious reductions of wood resources and environmental services occurred in peatland forests, with land managers being caught in a forest management dilemma between the needs for timber production, conservation and restoration of environmental services. The woody materials produced from peatland forests have various and unique characteristics; these forests also provide commercially valuable timber. Given that degraded peatland can be restored to forest composed of indigenous trees of high ecological and commercial value, land managers feel confident that they can provide the benefits of both timber production and improved environmental services. First, during planting one must understand which tree species are best adapted to local site-conditions if successful reforestation techniques are to be developed. Cost-effectiveness must also be concerned, especially in degraded peatland, where considerable flooding may determine the survival and growth rates of seedlings and the operating cost. Second, as a management strategy, a reforestation program should be required to provide multiple benefits, not only timber production and environmental services, but these programs should also improve socio-economic conditions that ensure the ongoing livelihood of local people. In the future, tropical peatland forestry should play the roles of providing for both the restoration and sustainable use of wood resources in a way that benefits both the local community and the global market.

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35.1 Introduction

Forestry, a land-use type found in terrestrial ecosystems, not only results in the production of woody resources from harvested trees but also involves growing, managing, conserving and restoring forests. Wood resources mainly include pulpwood and timber (logs, timber, veneer sheet and plywood). Non-timber products, such as rattan and latex, also serve as important forest products. As a human activity, forestry also strongly affects the structure and function of forest ecosystems, leading to many environmental changes, especially changes related to heat balance, the water cycle, carbon storage, biodiversity and even global climate (Chapin et al. 2012). In general, forestry activities have often caused widespread areas of land degradation and deforestation worldwide (Curran et al. 2004; Margono et al. 2014). Simultaneously, forestry provides a promising approach for the effective restoration of degraded areas of forestland (Parrotta 1993; Lamb and Gilmour 2003; Lamb 2005). Therefore, forestry serves as an important land-use from both socio-economic and environmental perspectives.

Currently, various types of forests occur in tropical peatland (Figs. 35.1 and 35.2a). Selecting logging changes intact forest to thinned forest (Fig. 35.1a), while continuous and/or intensive logging leads to sparse forest that supports only a few small mature trees (Fig. 35.1b). If all the mature trees are harvested or are lost to intensive disturbances such as clear-cuts, windthrow and wildfire, trees can naturally regenerate, resulting in the recovery of secondary forests (Fig. 35.1c). However, frequent disturbance often leads to irreversible succession creating badly degraded peatland (Fig. 35.1d). After deforestation, the planting of commercially and/or environmentally restored forest may reach a land manager's goal of providing both commercial and non-commercial benefits. Non-commercial benefits include restoration of the environment and maintenance of biodiversity. As noted above, various types of forest and changes in patterns of ecological succession can be explained by the impacts of past forestry management, making it is possible to conceptually evaluate forest degradation and restoration from two view points, those of commercial and environmental benefit (Fig. 35.2). In this chapter, we establish a framework of reviewing the commercial and environmental benefits of peatland forest management to improve our understanding of the impact of the management of peatland forests.

In this chapter, we introduce various past, current and future aspects of forestry in tropical peatland. We focus on the three following topics; (1) history and the current situation as it relates to forest management in tropical peatlands, (2) the properties of wood, as lumber use, with special emphasis on the physical and mechanical properties of wood growing in tropical peat swamp forest, and (3) reforestation of degraded tropical peatland, with special emphasis on the strategies and methods

Fig. 35.1 Views of various tropical peatland forests and ruined peatland. (**a**) A thinned peat swamp forest, (**b**) a sparse secondary forest, (**c**) a secondary forest at 2–3 years old (foreground) and at about 15-years-old (background), (**d**) a degraded fern-covered peatland after logging and repeated wildfire

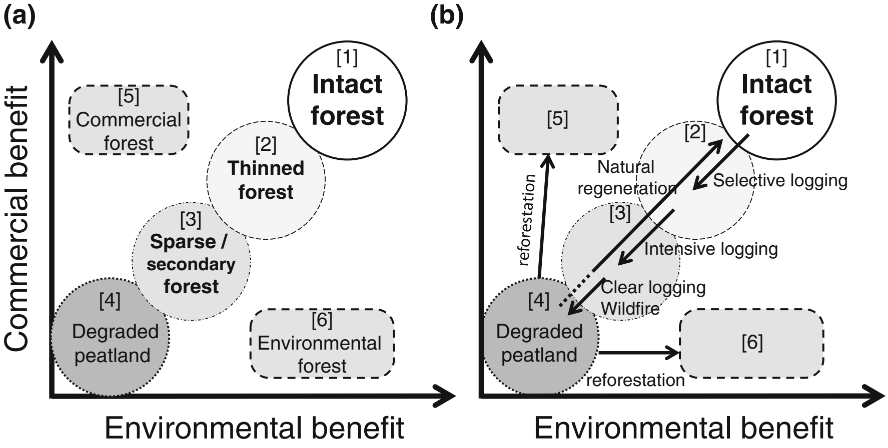

Fig. 35.2 Schematic diagrams of various peatland forests related to operation of forestry in the framework between commercial benefit and environmental benefit. (**a**) The relationship of each forest and two types of benefits. (**b**) The impact of a forestry-operation on forest succession. [*1*] intact forest, [*2*] thinned forest (selective logging changes intact forest to this forest type), [*3*] sparse and/or secondary forest (continuous and/or intensive logging changes thinned forest to this forest type), [*4*] degraded peatland (intensive logging or wildfire irreversibly shifts sparse and/or secondary forest to this forest type), [*5*] Commercial forest (plantation of monoculture crop trees), [*6*] Environmental forest (restored forest with the goal of improving the forest for environmental benefit without commercial benefit) (After Lamb et al. 2005)

used to manage degraded peatland. Finally, a perspective is provided regarding the roles of the multiple benefits provided by peatland forestry as it relates to the restoration and sustainable use of wood resources in tropical peatland forests.

35.2 Peatland Forestry in Southeast Asia

35.2.1 What Is Peatland Forestry?

Two styles of forestry can be defined based on the land/business owner, (1) industrial forestry, which is generally called "forestry" and (2) community or social forestry. Industrial forestry is managed by a private company or government agency with a large amount of capital, with the main goal of producing business income. Industrial forestry requires the use of large areas to constantly produce a large amount of timber wood or pulpwood every year. In contrast, community forestry is a type of forestry that involves participatory forest management. Small-scale forest management results in the production of a small amount of timber, firewood, and so on. Community forestry aims to improve rural socio-economic conditions in a way that increases the resources available to support the livelihood of local people.

Peatland forestry is defined as forestry conducted in peatlands. Peatland forestry centers on the world's peatlands that are distributed in boreal and tropical zones. In peatlands, excess soil water and poor nutrition lead to slow growing trees; consequently, peatland forests produce wood resources slowly. The excess water also results in difficulties during logging operations and log transportation; special techniques are required for field operations, such as draining to lower the water table and fertilizing to improve soil fertility (Paavilainen and Päivänen 1995).

Peatland forest management can be classified into three categories: (1) exploitation forestry, (2) managed silviculture forestry and (3) progressive management forestry, based on a study of boreal peatland forests (Paavilainen and Päivänen 1995).

Exploitation forestry: Exploitation forestry involves the harvest of trees with inadequate attention to regeneration (Figs. 35.3–(1) and 35.4). During exploitation forestry, trees are harvested without silviculture. Because no costs are involved in growing forest resources, exploitation forestry can supply inexpensive wood products to the marketplace. Logging techniques include both selective- and clear-cutting. Selective cutting often involves removal of the most commercially valuable trees and results in poor species composition in the residual forest, and may damage ecosystem functions. Additionally, selective cutting leaves some of the forest canopy intact making the impact less intense than that of clear-cutting. After clear-cutting, a secondary forest may be established by sprouting and natural regeneration, but ecological services appear to change drastically (Fig. 35.1). In any case, exploitative forestry leads to a reduction of forest resources, and an unsustainable use of peatland.

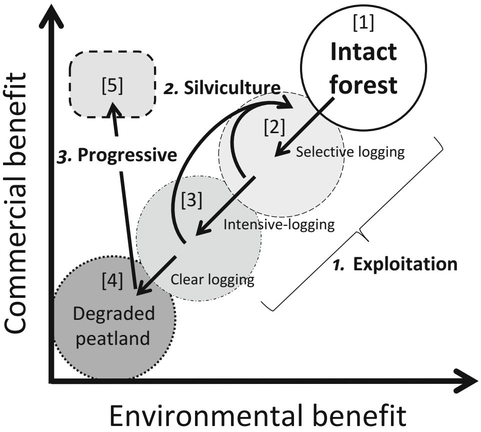

Fig. 35.3 Schematic diagram of impacts of three different types of forestry on forest succession in the framework between commercial benefit and environmental benefit; (*1*) exploitation forestry, (*2*) silvicultural management forestry and (*3*) progressive management forestry. Figure 35.2 describes the numbers [*1*–*5*]

Fig. 35.4 Photographs of logging (**a**) and transportation of logs (**b**, **c**) in peat swamp forests of Central Kalimantan, Indonesia

Silvicultural management forestry: Silviculture employs an organized and planned forest management method that includes logging, regeneration, and maintenance of forest stands to ensure the sustainability of timber and non-timber product production (Fig. 35.3–(2)). To guide Indonesian silviculture, the relationship between size limitations for logging and rotation intervals has been established and reported. However, from a practical standpoint, silvicultural operations have been unsuccessful in Indonesia because scientific insights into the forest dynamics of tropical peatlands are poorly understood, because foresters are not always well educated, and because governmental controls are either lacking or ineffective. Silvicultural forestry appears to not be suitable in peatland forests because forest operations have not been cost-effective; however, silvicultural management using natural regeneration is needed to realize sustainable forestry. Further study of forest dynamics in tropical peatland forest is needed to improve techniques of silvicultural management (Lee and Chai 1996b).

Progressive management forestry: Progressive management includes some of the above techniques and also involves activities such as draining, fertilization, and thinning (Fig. 35.3–(3)). Importantly, the control of water table levels is essential for the growth and performance of trees, transportation of logs, and soil quality management in peatland. The techniques used in peatland forestry were mainly developed in northern Europe. Since then, the technique has been applied to pulpwood plantations of acacia in tropical peatlands. In the past decade, tropical peatland forestry for pulpwood production has become an important industry in the peatland region of Southeast Asia.

35.2.2 History

Originally, wood-products had to be distributed on a community scale and volumes were low because little mechanical energy was available for logging and transportation. Since 1650 and the era of the kingdom in Java, exploitation forestry has been conducted in non-peatland forests in Indonesia. History records forestry concessions were introduced in Sumatra starting in 1870s, but most tropical forestry was conducted in non-peatland forests. Later, the Dutch government developed teak plantations. International trade of tropical timber trees has accelerated exploitation forestry in the tropics. However, in tropical peat swamp forest, the hard work required to harvest timber in wetland forest ecosystems prevented the use of exploitative forestry. Consequently, natural forest tropical peatlands remained relatively intact until the 1970s–1980s. With the decreasing availability of wood resources from non-wetland forests in the tropics, unfortunately, in the 1970s–1980s, peatland forests came under increasing pressure and more intense harvesting was initiated. Many natural peatland forests were converted to rice fields designed to benefit people who relocated into the area. The failure of sustainable agriculture in developed land encouraged illegal logging activities. Forests in Sumatra, Kalimantan and Sulawesi were subjected to selective cutting without silvicultural treatments for trees over 50–60 cm in DBH (diameter at breast height); however, subsequent regeneration appears to have been unsuccessful. Consequently, the abundance and quality of major tree species with high economic value declined in the forests (Istomo et al. 2010). Since the 1990s, governments and private companies initiated large-scale conversion of tropical peatlands for various reasons. These forests were not only converted to rice fields but were also converted for pulpwood, rubber, and oil palm plantations. Consequently, the reduction in the availability of forest resources in tropical peatlands has been given careful attention, e.g. the Mega Rice Project in Central Kalimantan by the Indonesian government in 1995.

Ramin (*Gonystylus bancanus*) and balau, which is known as lanan in Kalimantan or alan in Malaysia (*Shorea albida*) were the main targets of exploitative forestry in peatland in the 1970s–1990s because they produce high quality straight and large stems for use as timber (Lee and Chai 1996b). For example in Central Kalimantan Indonesia, at the beginning of the 1980s, processed ramin wood exports averaged 598,000 m^3 annually, including prime quality wood products. Later, ramin wood exports peaked at 900,000 m^3 during 1991 and 1992. However, exports declined continuously from 1994 to 1997 (Anonymous 1995). The high economic value of ramin wood production promoted intensive cutting, consequently leading to ramin becoming a Red-book Species (IUCN 2014). Meranti (*Shorea* spp.) and agathis (*Agathis* spp.) also supplied high quality timber wood in peatlands forests, but they were not the main targets of exploitation forestry in peatlands in the 1970s–1990s because of the relatively smaller size of these trees when grown in peatlands. After ramin stocks were depleted, meranti and agathis became major contributors to timber production in peatland forests (Anonymous 1995).

Starting in the 1990s, global climate change became a serious issue worldwide. Many studies pointed to the degradation and deforestation of peat swamp forests that had been a major source of carbon emissions to the atmosphere worldwide. This was caused by the loss of the photosynthetic uptake of carbon by trees lost to harvest, the decomposition of peat soils, and organic matter consumed by wildfire; these all caused the release of gaseous emissions into the atmosphere (Page et al. 2002; Hirano et al. 2012). The need for sustainable management of peatland forest was finally recognized. Furthermore, forest restoration and reforestation are now recognized as important tasks for not only researchers and government but also for forestry companies. Tropical peatland forestry must include new aspects of social responsibility in peatland forests in the tropics if they are to be managed sustainably under global climate change.

35.2.3 Wood Production

Several wood production systems have been developed in tropical peatland as follows.

Timber wood production: Plywood consists of manufactured wood panels. A strong international market exists for plywood; therefore, the demand for timber and wood production is strong in tropical forests, in part because of the high productivity of those forests. However, peatland forests have lower productivity in the tropics than in forests in other regions, so the plywood market seems to not expect tropical peatlands to produce raw wood for plywood.

Fig. 35.5 Sawing a log for local use in a lumber mill in Palangka Raya, Central Kalimantan, Indonesia. (**a**) Logs transported in the river. (**b**) Belt-saw at work

Solid (sawn) wood had dominated the market in Southeast Asia, but market share has diminished when compared with that of plywood in international trade because of a decrease in the availability of timber resources in tropical forests. Currently, the global market requires solid wood with excellent quality that can be used for specialized materials such as truck beds, decks of ships and in the housing industry. The production of most high quality solid wood, such as meranti, depends on the harvest of natural forests, not second growth or industrial forests that are managed for high rates of fiber production. The tropical peatland forests continue to contribute to solid wood production. Unlike the global market, the domestic market for timber actively supplies products for use in infrastructure and home construction (Fig. 35.5). In Palangka Raya the capital of Central Kalimantan, Indonesia, kahui (*Shorea balangeran*), a red meranti from peat swamp forests, is the most expensive solid wood in the local market. This market also consumes gerunggang (*Cratoxyllon arborescens*), tumih (*Combretocarpus rotundatus*) and other trees. Even today, natural peat swamp forests play an important role in solid wood production for the domestic market.

Pulpwood production: The market for peatland forestry products has demands from paper manufacturers to produce pulpwood in Southeast Asia. The regional market suffers from a lack of a pulpwood supply. Nevertheless, this market has resulted in production of about 12,400,000 m^3 of pulpwood needed to supply the demand in support of economic growth in developing Asian countries. To fill the demand for pulpwood, new pulpwood plantations need to be developed. However, preparing the ground of a highly productive pulpwood plantation in the tropics is not easy, because highly productive landscapes are still used for other industries by many local people such as agriculture and oil-palm plantations. With these conditions, the low price of pulpwood provides little motivation for land managers to change the land use toward pulpwood plantations. Tropical peatland was not very productive when compared with the other types of tropical forest. Nevertheless, large areas were available for forestry because few local

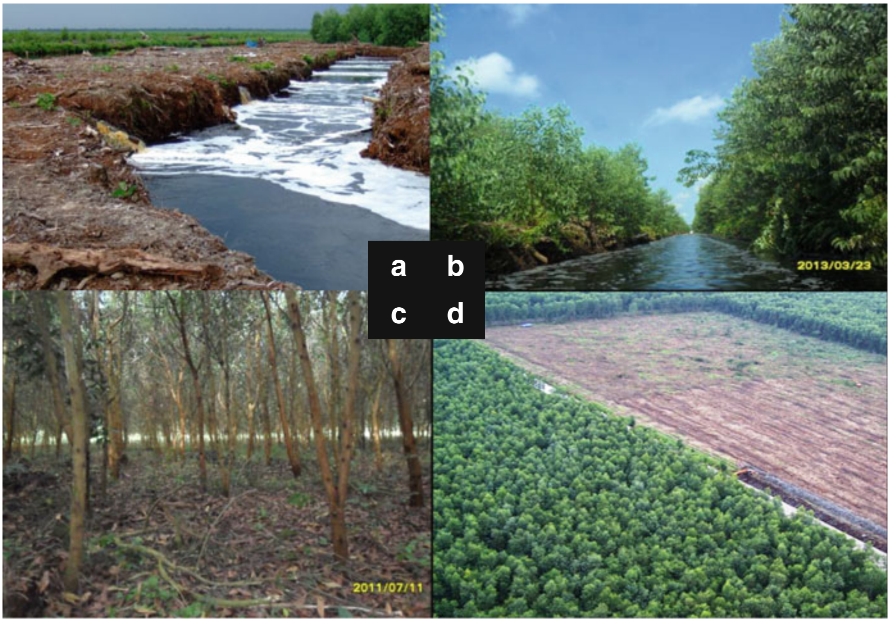

Fig. 35.6 *Acacia crassicarpa* plantation, a progressive managed forestry using drainage. (**a**) Drainage channel to lower the water table in peatlands in a plantation in Riau, Indonesia. (**b**) Drainage canal used to transport logs in a plantation. (**c**) Understory of a plantation. (**d**) Clear-cut area within a plantation

people live in the area. The accelerating demand for pulpwood plantations encourages the use of tropical peatland forests for pulpwood production.

Acacia crassicarpa is the only tree species available for pulpwood plantations in tropical peatland forestry (Fig. 35.6). *A. crassicarpa* is suitable for growing in drained peatlands with a depth to the water table of about 60–90 cm, despite the fact it is a non-native peatland species. Furthermore, the ease of seed collection, propagation, nursery operations, planting and the high survival rate of this species make its strong growth and performance suitable for drained peatlands (Fig. 35.7). With a 5 year rotation age, the wood is suitable for pulpwood. These properties allowed the use of *A. crassicarpa* for pulpwood production in peatlands. Despite these positive points, negative impacts in drained peatlands and mono-cultured *A. crassicarpa* plantations affect the local environment, e.g. land subsidence, greenhouse gas emissions and a reduction of biodiversity (Jauhiainen et al. 2012). Other *Acacia* and *Eucalyptus* species, which are major pulpwood plantation trees in the other tropical regions, are not suited for peatland conditions in Indonesia.

Non-timber wood production: Non-timber wood production such as latex production (Fig. 35.8), and the production of rattan, gemor (*Alseodaphne* sp.) and edibles serve as important cash crops that are harvested from natural peat swamp

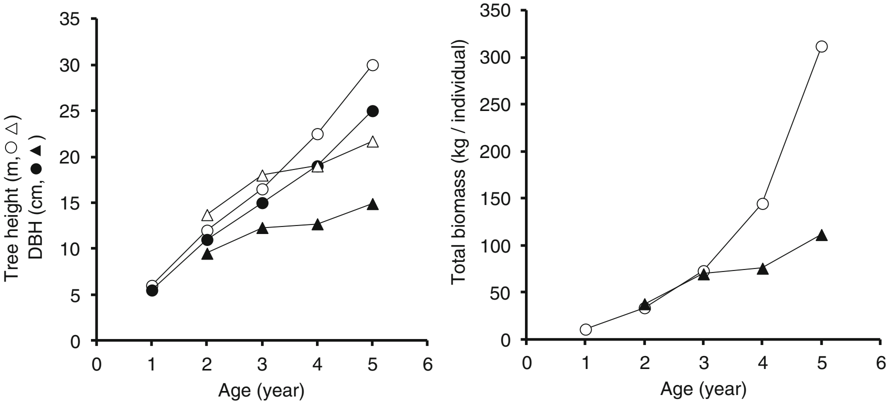

Fig. 35.7 Growth performance of an *Acacia crassicarpa* plantation during 5 years in peatlands of Riau Province, Indonesia. *Circles* and *triangles* denote data from different data sets (Swardi et al. 2011 at the Sinar Mas Plantation at Bukitbatu, Bengkalis Regency and Watanabe et al. 2012, respectively)

Fig. 35.8 Rubber tree with pineapple plantation managed by local people in a degraded peatland, Taruna Central Kalimantan, Indonesia (**a**). Tapping latex from injured stem of a rubber tree in Palangka Raya, Indonesia (**b**)

forests. This non-timber wood production can support the livelihood of local communities because it provides for income every year.

For example, latex is useful for natural rubber and chewing gum. Jelutung (*Dyera lowii*), a well-known tree used for latex production, is native to peat swamp forests. Within about 5–10 years from planting in peatland, *D. lowii* can produce latex for chewing-gum. Latex production stops in overmature forests of this species; nevertheless, the stem wood can still be used for timber. Therefore, *D. lowii* is a candidate tree for agroforestry in tropical peatlands.

Rattan is a woody climbing plant growing in sub-tropical and tropical forests. Rattan is used for furniture, cages, and baskets. Gemor (*Alseodaphne* sp.) is another tree species growing in peat swamp forests. The bark of gemor is useful for mosquito coils because of its high Pyrethrin content. *Gyrinops* spp., also called agarwood or locally jinkoh, emits a strong fragrance when burned, and is the highest price non-timber wood product of the tropics; however, only low quality jinkoh can be produced in tropical peat forest resulting in a low price (Tarjaman M., personal commun.). The market seems to not need agarwood production in peatland.

Various trees, shrubs, lianas and ferns produce edibles of fruits and nuts in peat swamp forests (Lee and Chai 1996a). In addition, traditionally used local, medicinal plants may also be harvested there (Lee and Chai 1996a), but they seem to have little value for international trade.

Fuel wood production: Great interest in energy crops has been generated for producing fuel for power generation as a renewable energy source to achieve the obligations of countries under the Kyoto Protocol to reduce greenhouse gas emissions. Furthermore, the Fukushima Daiichi nuclear power station disaster in Japan accelerated the need for fuel crops. Short rotation coppice (SRC) is a forestry method used to produce fuel wood. SRC trees are characterized by easy propagation, dense planting, early growth and high biomass production yield, high-energy yield of wood, and a 2–5 years rotation period. In tropical zones, although fuel wood production was expected to provide high performance biomass production, 6–25 ton ha^{-1} year^{-1} has been produced or an equivalent of about 300–8,000 GJ ha^{-1} (Onyekwelu 2011), a tropical SRC has not yet been established. In tropical peatland, the production yield is lower than in other tropical land, but SRC may provide a method of creating a new type of forestry in the near future because large areas of degraded peatland remain available. To achieve this, fast growing peatland trees with SRC characteristics must be identified. For example, tumih may be suitable for SRC as a native pioneer species that sprouts easily and has a relatively higher production yield, produces high density wood, and grows in peatlands. Future studies of SRC in tropical peatland are necessary to add commercial value to biomass production of pioneer trees in secondary forest regenerated after clear-cutting or wildfire disturbance.

35.3 Wood Properties for Lumber Use

35.3.1 Why Is Tropical Wood Production Expected?

Tropical forests are more suitable for timber production than forests in temperate regions because trees in those forests have an indefinite period of dormancy in the warm climate. For this reason fast-growing tree species such as *Acacia mangium*, *Eucalyptus globulus*, or *Paraserianthes falcataria* are planted widely in tropical regions. The logs of fast-growing species tend to split and warp during logging and milling because of the high levels of stress that accumulate during vigorous growth as the trunk diameter increases rapidly. Considering the disadvantages for their use as lumber, some fast-growing woody species are used for biomass or pulp production. Meanwhile, native tree species grown in peat-swamp forests grow relatively slowly and some of them show superior characteristics for lumber use in building construction and furniture production.

Many tree species grow in tropical forests and feature extreme variations in physical and mechanical properties when compared with those grown in temperate and boreal zones. For example, both balsa (*Ochroma lagopus*), the lightest wood in the world, and lignum-vitae (*Guaiacum officinale*), the heaviest, grow in tropical forests in the Americas. The various characteristics of the species lead to their use in a wide range of wood products and applications.

35.3.2 Range and Characteristics of Juvenile Wood

Cambium cells form juvenile wood, which shows unstable properties until those cells mature. Juvenile wood is formed near the pith and has characteristics that are different from mature wood formed in the outer part of the trunk cross-section. In general, wood fibers of juvenile wood are shorter and microfibril angles in the secondary walls of cells are larger than those of mature wood. Furthermore, the fluctuations of cell wall thickness and the percentage of areas used for vessels will affect the properties of juvenile wood. Consequently, the mechanical properties of juvenile wood are inferior to those of mature wood. Because fast-growing species may produce large volumes of juvenile wood problems arise in the structural properties of their wood. The properties of juvenile wood and the age of maturity have been studied for many species (Nugroho et al. 2012; Ishiguri et al. 2012a). Kojima et al. (2009) reported that maturation depends on the age of the cambium for *Eucalyptus* spp. and on the diameter of growth for *Acacia* spp. and *Paraserianthes* spp. Juvenile wood may not occupy a large area in a cross-section or may not affect the mechanical properties of rather slow-growing species. Ishiguri et al. (2012b) reported that the radial variations in basic density and compressive strength were small for 35-year-old *Shorea acuminatissima* planted in Indonesia. Koide et al. (2011) reported that the wood density within 25 mm from the pith was smaller than the outer wood for 9-year-old *Shorea balangeran* planted in peatland in Central Kalimantan; for this species, the mechanical properties remained almost constant in wood grown more than 25 mm from the pith. This characteristics could contribute high yield of timber production in plantation.

35.3.3 Physical and Mechanical Properties of Wood

Table 35.1 lists the wood density, shrinkage, and mechanical properties of small, clear specimens of 68 species native to peat-swamp forests (data extracted from

Table 35.1 Physical and mechanical properties of tree species grown in peat-swamp forests

Species	Distribution	Sampling site	Density	Shrinkage		Moisture content	Static bending		Compression parallel to gain		Janka hardness		Shear strength^{c}	Cleavage^{c}	Impact bending	Reference
			(g/cm^{3})^{a}	R	T		MOR	MOE	CS	MOE	RT	LR/LT^{c}			(J/cm^{2})^{d}	
			(kg/m^{3})^{b}	(%)		(%)	(MPa)	(GPa)	(MPa)	(GPa)	(kN)	(kN)	(MPa)	(N/mm)	(J)^{e}	
Alstonia angustiloba	M, S, J, B, P	In	290^{b}	3.0	4.5	53.0	27.2	6.1	14.7		1.22	0.90	1.7	30.9	2.2^{c,d}	Wardi and Soewarsono (1963)
		In	0.35^{a}			13.1	31.9	7.2	21.8		1.31	0.73	1.6	27.4	1.8^{c,d}	Wardi and Soewarsono (1963)
A. congensis	Af	In	0.27^{a}			14.0	22.6	5.2	18.2		1.11	0.60	1.8	31.4	0.8^{c,d}	Wardi and Soewarsono (1963)
A. macrophylla	M, T, P, V, B	P	640^{b}	6.3	8.5	green	84.1	11.4	35.9	13.8	5.79	5.57	17.6		4.4^{e}	Lamicio and Bollosillo (1962)
		NG	0.64^{a}	3.6	5.3											Gary (1962)
A. scholaris	I, Ma, A	P	380^{b}	3.8	5.8	green	39.9	6.6	21.5	8.6	2.22	2.01	6.2		2.1^{e}	Lamicio and Bollosillo (1962)
		NG	0.42^{a}	1.4	2.9											Lamicio and Bollosillo (1962)
		In	380^{b}			42.1	35.4		17.8		2.04	1.28	4.6	31.9	2.8^{c,d}	Wardi and Soewarsono (1963)
Anisoptera aurea	P	P	480^{b}	4.2	10.0	green	49.2	9.4	25.1	12.5	3.52	2.94	6.5		2.8^{e}	Lamicio and Bollosillo (1962)
		P	0.59^{a}			12.0	82.0	11.8	43.7	14.2	3.83	3.66	8.9		2.4^{e}	Lamicio and Bollosillo (1962)
A. brunnea	P	P	540^{b}	4.1	8.4	green	60.5	10.3	30.1	13.9	3.78	4.46	8.9		3.9^{e}	Lamicio and Bollosillo (1962)
		P	0.64^{a}			12.0	89.6	11.5	45.9	15.9	4.41	4.67	11.2		3.1^{e}	Lamicio and Bollosillo (1962)

(continued)

Table 35.1 (continued)

			Density	Shrinkage		Moisture	Static bending		Compression parallel to gain		Janka hardness		Shear		Impact bending	
		Sampling	(g/cm^3)^a	R	T	content	MOR	MOE	CS	MOE	RT	LR/LT^c	strength^c	Cleavage^c	(J/cm^2)^d	
Species	Distribution	site	(kg/m^3)^b	(%)		(%)	(MPa)	(GPa)	(MPa)	(GPa)	(kN)	(kN)	(MPa)	(N/mm)	(J)^e	Reference
A. cochinchinensis	Ma	C	0.70^a			12.0	117.6		60.2					15.7	5.5^{c,d}	Sallenave (1955)
		C	0.66^a			12.0	132.8		46.7					11.8	5.5^{c,d}	Sallenave (1955)
		IC	0.64^a	2.9	8.2	12.0	112.7	9.6	49.4				7.3	17.6	4.9^{c,d}	Sallenave (1955)
		IC	0.60^a	4.7	8.2	12.0	110.4	9.1	45.5				8.0	12.7	2.9^{c,d}	Sallenave (1955)
A. costata	Ma	In	540^b			85.0	75.2		33.3		3.60		7.2	62.2	5.6^{c,d}	Wardi and Soewarsono (1963)
		In	0.67^a			13.5	79.6		45.3		3.31	3.52	7.6	69.1	5.6^{c,d}	Wardi and Soewarsono (1963)
A. glabra	Ma	My	470^b	2.3	7.1											Kingston and Risdon (1961)
		My	480^b	2.3	7.1	green	53.3	8.5	28.9							Stewart and Kloot (1957)
		My				12.0	73.3	9.9	35.4							Stewart and Kloot (1957)
A. marginata	M, S, B	In	510^b	3.7	7.6	88.9	58.2	11.2	28.5		2.87	2.19	5.4	58.8	6.1^{c,d}	Wardi and Soewarsono (1963)
		In	0.59^a			13.1	66.2	9.6	36.3		2.45	2.21	6.0	58.3	4.3^{c,d}	Wardi and Soewarsono (1963)
A. polyandra	NG	NG	0.62^a	2.0	5.3				28.5							Gary (1962)
		NG	0.58^a	2.0	5.3				36.3							Chowdhury and Gosh (1958)
		NG	480^b			green	55.9	10.0	26.9	11.3	2.70	2.48	5.1			Kingston and Risdon (1961)
		NG	0.60^a			12.0	60.5	10.6	43.9	12.7		2.96				Kingston and Risdon (1961)

Anthocephalus cadamba	I, Ma	In	420^{b}	3.0	6.9	53.4	50.6		27.3		2.70	2.34	4.1	49.5	4.8^{c,d}	Wardi and Soewarsono (1963)
		In	0.52^{a}			13.7	67.7		36.7		4.01	2.63	5.2	44.6	5.6^{c,d}	Wardi and Soewarsono (1963)
Artocarpus cumingiana	P	P	530^{b}	5.5	2.9	green	57.6	6.8	30.3	8.2	5.53	5.34	7.7		2.4^{e}	Lamicio and Bollosillo (1962)
		P	0.60^{a}			12.0	85.5	8.8	45.3	9.6	7.53	5.57	11.2		2.3^{e}	Lamicio and Bollosillo (1962)
A. elasticus	Ma	In	400^{b}	3.4	6.5	58.2	38.5	7.7	21.4		2.31	3.86	4.7	35.8	3.6^{c,d}	Wardi and Soewarsono (1963)
		In	0.43^{a}			12.6	48.8	8.5	27.8		2.05	1.88	5.1	35.8	3.8^{c,d}	Wardi and Soewarsono (1963)
Calophyllum blancoi	P,B	P	510^{b}	6.7	10.6	green	49.9	8.9	21.5	11.3	3.03	2.59	6.5		3.8^{e}	Lamicio and Bollosillo (1962)
		P	0.68^{a}			12.0	115.1	14.7	53.4	17.6	5.25	4.72	12.4		3.6^{e}	Lamicio and Bollosillo (1962)
C. pulcherimum	M, S, B	In	600^{b}			52.6	76.7	13.6	40.3		4.36		6.4	39.7	7.3^{c,d}	Wardi and Soewarsono (1963)
Campnosperma auriculata	T, M, S, B	NG	0.42^{a}	1.6	3.0											Gary (1962)
		In	340^{b}			51.0	38.3	8.0	20.2		1.69		3.3	28.9	4.6^{c,d}	Wardi and Soewarsono (1963)
		In	0.42^{a}			12.8	58.1	8.6	32.5		2.42	1.55	5.1	36.3	2.7^{c,d}	Wardi and Soewarsono (1963)
C. macrophylla	T, M, S, B	NG	0.46^{a}	1.6	3.0											Gary (1962)
Camptostemon philippinese	P, B	P	570^{b}			green	55.0	8.9	29.6	11.4	3.66	4.01	5.9		2.3^{e}	Lamicio and Bollosillo (1962)
		P	0.67^{a}			12.0	103.4	11.9	48.7	13.3	5.79	4.64	7.9		2.1^{e}	Lamicio and Bollosillo (1962)
Canarium hirsutum	Ma	P	440^{b}	4.1	7.5	green	38.3	5.9	18.3	7.7	2.10	1.65	5.7		2.0^{e}	Lamicio and Bollosillo (1962)
		P	0.52^{a}			12.0	75.1	9.7	33.5	11.2	4.06	2.85	7.8		1.9^{e}	Lamicio and Bollosillo (1962)
C. vrieseanum	In	P	570^{b}	5.0	8.8	green	63.4	11.9	31.2	14.0	4.72	4.67	8.6		4.3^{e}	Lamicio and Bollosillo (1962)
C. vulgare	NG	In	420^{b}	4.5	6.6	49.4	46.6	10.0	23.7		2.32	1.56	4.2	36.8	4.3^{c,d}	Wardi and Soewarsono (1963)
		In	0.50^{a}			14.1	61.9	10.2	36.5		2.82	1.70	5.1	39.7	3.1^{c,d}	Wardi and Soewarsono (1963)
Castanopsis argentea	In, M	In	630^{b}			65.6	63.6	12.0	32.7		4.80	4.18	5.8	63.2	8.3^{c,d}	Wardi and Soewarsono (1963)
		In	0.75^{a}	3.7	9.6	14.2	95.8	16.9	53.4		5.50	4.65	7.6	71.1	8.0^{c,d}	Wardi and Soewarsono (1963)
C. javanica	In, M	In	520^{b}			80.0	56.9	11.1	27.4		3.68	4.14	5.8	47.5	7.0^{c,d}	Wardi and Soewarsono (1963)
		In	0.61^{a}	4.6	6.2	13.8	88.9	12.9	43.6		3.95	3.39	5.0	40.7	7.3^{c,d}	Wardi and Soewarsono (1963)
Combretocarpus rotundatus	In	In	570^{b}	3.9	10.4	78.0	56.3	12.7	32.6		3.37	3.33	6.7	49.0	5.7^{c,d}	Wardi and Soewarsono (1963)
Cratoxylon arborescens	In, M	In	490^{b}			66.0	47.0	8.9	20.4		1.91		2.9	38.7	5.9^{c,d}	Wardi and Soewarsono (1963)

(continued)

Table 35.1 (continued)

Species	Distribution	Sampling site	Density	Shrinkage		Moisture content	Static bending		Compression parallel to gain		Janka hardness		Shear strength^c	Cleavage^c	Impact bending	Reference
			(g/cm^3)^a	R	T		MOR	MOE	CS	MOE	RT	LR/LT^c			(J/cm^2)^d	
			(kg/m^3)^b	(%)		(%)	(MPa)	(GPa)	(MPa)	(GPa)	(kN)	(kN)	(MPa)	(N/mm)	(J)^e	
C. ligustrinum	V	In	800^b			33.0	85.3	15.4	35.2		3.68	5.10	5.8	47.0	9.5^{c,d}	Wardi and Soewarsono (1963)
Dacrydium elatum	Ma	NG	0.54^a	2.0	4.5											Gary (1962)
		NG	0.54^a,450^b	2.0	4.5											Chowdhury and Gosh (1958)
Dactylocladus stenostachys	In, M	B	0.54^a,450^b	2.1	4.1											Chowdhury and Gosh (1958)
Dillenia ovata	Ma	C	0.88^a			12.0	136.2							21.6	3.0^{c,d}	Sallenave (1955)
Diospyros celebica	Su	In	730^b			43.5	90.3	13.1	42.6		4.75		9.1	59.8	13.3^{c,d}	Wardi and Soewarsono (1963)
D. ferrea	Ma	NG	0.74^a	3.4	7.7											Gary (1962)
D. mindanaensis	P	P	690^b	3.8	9.1	green	88.5	13.8			6.32	6.91			3.1^e	Lamicio and Bollosillo (1962)
		P	0.83^a			12.0	124.9	14.7			10.78	9.31			3.8^e	Lamicio and Bollosillo (1962)
D. montana	I, Ma	P	570^b	5.1	8.1	green	62.5	8.4	25.6	12.8	3.29	3.78	5.7		5.0^e	Lamicio and Bollosillo (1962)
		P	0.72^a			12.0	116.4	13.8	50.5	17.1	8.02	6.37	12.3		3.4^e	Lamicio and Bollosillo (1962)

D. nitida	C	P	710[b]	4.9	9.3	green	88.2	13.4	40.3	17.6	6.60	6.91	11.0		4.6[e]	Lamicio and Bollosillo (1962)
		P	0.84[a]			12.0	150.1	18.0	70.3	20.5	11.41	9.49	15.9		4.3[e]	Lamicio and Bollosillo (1962)
D. philippensis	P	P	840[b]	5.2	8.7	green	70.3	9.6			7.49	8.59	10.0		5.2[e]	Lamicio and Bollosillo (1962)
		P	1.00[a]			12.0	126.0	18.5			18.13	17.95	18.7		5.4[e]	Lamicio and Bollosillo (1962)
D. pyrrhocarpa	Ma	P	630[b]	5.9	10.8	green	69.6	10.5	32.2	13.2	4.99	4.95	8.4		4.1[e]	Lamicio and Bollosillo (1962)
		P	0.77[a]			12.0	118.5	14.0	56.0	16.6	8.96	7.30	12.2		3.8[e]	Lamicio and Bollosillo (1962)
Dryobalanops aromatica	In, M	In	680[b]	4.4	8.9	47.8	81.7	15.1	44.9		4.10	4.02	6.8	54.9	7.4[c,d]	Wardi and Soewarsono (1963)
		In	0.78[a]			14.1	107.8	16.9	61.2		7.28	5.91	7.5	58.3	7.5[c,d]	Wardi and Soewarsono (1963)
D. oocarpa	In, M	In	470[b]	2.5	7.1	71.8	54.7	10.0	30.5		3.22	1.99	4.0	51.5	5.4[c,d]	Wardi and Soewarsono (1963)
		In	0.53[a]			13.4	62.2	10.9	38.0		2.26	2.36	4.2	45.1	4.9[c,d]	Wardi and Soewarsono (1963)
Dyera costulata	In	NG	0.48[a],380[b]	1.3	3.6											Chowdhury and Gosh (1958)
Elaeocarpus novoguineensis	NG	NG	0.48[a]	1.2	3.9											
E. oxypyrens	In	In	350[b]			102.9	32.4	8.8	19.4		1.74	0.94	1.9	38.7	2.9[c,d]	Wardi and Soewarsono (1963)
		In	0.43[a]			13.8	52.0	9.5	31.9		2.06	1.52	5.9	41.7	3.0[c,d]	Wardi and Soewarsono (1963)
E. sphaericus	In, NG	NG	0.48[a]	1.2	3.9											Gary (1962)
Elateriospermum tapos	In, M	In	680[b]			43.2	86.2	15.7	47.8		5.31		8.6	78.4	9.7[c,d]	Wardi and Soewarsono (1963)
		In	0.83[a]			13.7	116.7	17.5	69.9		6.89	6.30	8.5	84.8	7.1[c,d]	Wardi and Soewarsono (1963)
Ganophyllum falcatum	Ma	NG	0.62[a],490[b]	3.4	7.1											Chowdhury and Gosh (1958)
		In	670[b]	4.3	8.1	65.7	68.7	11.5	31.4		4.66	4.54	9.0	71.5	12.9[c,d]	Wardi and Soewarsono (1963)
		In	0.81[a]			12.6	88.4	12.5	57.8		8.24	7.89	12.2	91.1	6.1[c,d]	Wardi and Soewarsono (1963)
Garcinia salakensis	In	In	650[b]			60.7	78.2		38.7		4.45		6.8	70.1	7.4[c,d]	Wardi and Soewarsono (1963)
		In	0.70[a]			14.3	100.5		50.1		5.07	4.20	7.4	75.0	6.7[c,d]	Wardi and Soewarsono (1963)
Gonystylus bancanus	Ma	SA	580[b]			green	67.4	10.8	37.2			2.85	6.2			Kukachka (1961)
		SA				12.0	127.0	15.0	69.5			5.79	9.5			Kukachka (1961)
G. hackenbergii		In	600[b]			32.5	50.0	13.1	25.2		2.62	2.35	3.5	29.4	3.5[c,d]	Wardi and Soewarsono (1963)
		In	0.61[a]			13.9	84.1	13.6	46.6		3.72	2.97	5.9	53.9	4.3[c,d]	Wardi and Soewarsono (1963)

(continued)

Table 35.1 (continued)

			Density	Shrinkage		Moisture	Static bending		Compression parallel to gain		Janka hardness		Shear		Impact bending	
		Sampling	(g/cm^3)^{a}	R	T	content	MOR	MOE	CS	MOE	RT	LR/LT^{c}	strength^{c}	Cleavage^{c}	(J/cm^2)^{d}	
Species	Distribution	site	(kg/m^3)^{b}	(%)		(%)	(MPa)	(GPa)	(MPa)	(GPa)	(kN)	(kN)	(MPa)	(N/mm)	(J)^{e}	Reference
G. macrophyllus	In, NG	P	520^{b}	3.7	8.0	green	53.9	9.8	26.5	12.9	3.29	3.08			4.0^{e}	Lamicio and Bollosillo (1962)
		P	0.56^{a}			12.0	95.7	13.3	46.4	16.2		5.62			2.8^{e}	Lamicio and Bollosillo (1962)
Hopea sangal	In	In	640^{b}	3.4	7.5	50.1	83.4		41.9		4.36	4.54	5.8	61.7	7.8^{c,d}	Wardi and Soewarsono (1963)
		In	0.62^{a}			13.2	93.9		50.4		4.17	3.57	6.8	46.1	5.6^{c,d}	Wardi and Soewarsono (1963)
Palaquium burckii	Ma	In	0.60^{a}			13.4	79.0	12.8	44.3		3.78	2.96	4.9	43.1	4.6^{c,d}	Wardi and Soewarsono (1963)
P. gutta	Ma	In	550^{b}			67.6	61.7	8.9	32.9		4.09		7.4	63.7	5.2^{c,d}	Wardi and Soewarsono (1963)
P. lanceolatum	P	P	520^{b}	4.0	6.6	green	71.0	11.1	34.5	14.0	4.23	3.97	7.7		4.1^{e}	Lamicio and Bollosillo (1962)
		NG	0.54^{a}	1.2	5.1											Gary (1962)
P. obovatum	T	In	650^{b}			55.6	80.8	13.6	42.2		4.63	3.19	3.6	58.8	7.7^{c,d}	Wardi and Soewarsono (1963)
P. ridleyi	Ma	In	850^{b}			35.0	94.3	17.8	49.0		7.04	6.61	7.0	54.9	11.9^{c,d}	Wardi and Soewarsono (1963)

Podocarpus amara	I	NG	0.46[a]	1.7	3.8											Gary (1962)
P. blumei	In	In	470[b]			42.5	51.7	10.7	29.4		2.67	2.16	3.2	38.2	5.2[c,d]	Wardi and Soewarsono (1963)
P. imbricatus	In, M, NG	In	0.59[a]	3.4	7.0	13.9	76.0	12.3	45.0		5.42	3.65	3.9	49.5	4.9[c,d]	Wardi and Soewarsono (1963)
		IC	0.56[a]	5.0	10.5	12.0	99.5	9.4	36.6					17.6	3.9[c,d]	Sallenave (1955)
Shorea balangeran	In	In	760[b]			63.0	77.2	14.1	36.6		4.88	5.00	4.7	58.3	7.6[c,d]	Wardi and Soewarsono (1963)
		In	0.89[a]			15.2	94.2	16.0	52.6		5.58	5.20	5.9	54.4	5.4[c,d]	Wardi and Soewarsono (1963)
Syzygium buettnerianum	In, NG, A	NG	0.69[a]													Gary (1962)
Tristania conferta	A	In	690[b]	5.5	10.9	67.6	72.1	12.2	35.5		4.44	5.03	6.5	73.0	13.6[c,d]	Wardi and Soewarsono (1963)
T. decorticata	P	P	930[b]	9.2	10.3	green	122.6	17.2	57.9	21.5	8.73	10.29	14.1		7.7[e]	Lamicio and Bollosillo (1962)
		P	1.24[a]			12.0	190.1	20.6	101.9	27.0	21.47	20.32	14.7		6.6[e]	Lamicio and Bollosillo (1962)
T. maingayi	In	In	910[b]			33.9	108.4	20.3	58.8		9.85		10.0	76.9	13.4[c,d]	Wardi and Soewarsono (1963)
T. suaveolens	A	NG	0.85[a]	5.2	10.0											Gary (1962)
Vatica mangachapoi	T	P	620[b]	4.0	9.3	green	75.1	13.2	38.4	16.2	5.04	5.04	9.3		3.1[e]	Lamicio and Bollosillo (1962)
		P	0.77[a]			12.0	136.4	17.6	61.8	19.8	9.00	6.95	13.1		3.9[e]	Lamicio and Bollosillo (1962)
V. pachyphylla	P	P	780[b]			green	88.2	15.6	47.7	18.7	7.40	8.51	10.7		4.7[e]	Lamicio and Bollosillo (1962)
		P	1.02[a]			12.0	160.5	18.7	77.8	21.3	15.14	14.07	17.6			
V. teysmaniana	In	In	900[b]			36.9	113.6	16.7	53.9		7.62	5.29	7.4	60.8	9.2[c,d]	Wardi and Soewarsono (1963)
		In	1.04[a]			13.3	156.1	18.9	85.8		12.62	11.86	11.2	83.3	12.9[c,d]	Wardi and Soewarsono (1963)
Xylocarpus granatum	Ma, Af	NG	0.64[a]	2.1	2.2											Gary (1962)

Excerpted from FFPRI (1965)

Notes: Latin names of coniferous species are shown in boldface. Shrinkage are total shrinkage from green to oven-dry. Abbreviations for nations or district: *A* Australia, *Af* Africa, *B* Borneo, *C* China, *I* India, *IC* l'Indochine française, *In* Indonesia, *J* Java, *M* Malaysia, *Ma* Malesia, *My* Myanmar, *NG* New Guinea, *P* Philippines, *S* Sumatra, *SA* Southeast Asia, *Su* Sulawesi, *T* Thailand, *V* Vietnam

Legend: *MOR* modulus of rupture, *MOE* modulus of elasticity, *R* radial direction, *T* tangential direction

[a] air-dry density

[b] basic density

[c] Values are averaged or mixed of those tested for longitudinal-radial surface and longitudinal- tangential surface

[d] absorbed energy in the impact bending test

[e] toughness

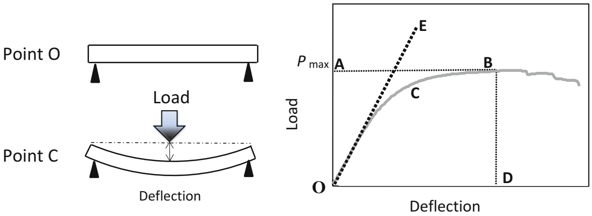

Fig. 35.9 Method for evaluating bending properties of wood; modulus of elasticity (*MOE*), modulus of rupture (*MOR*), absorbed energy (U_b) and Tetmajer's modulus (*TM*). The illustration shows wood-sample deflecting by a loading at mid-span position. In the schematic graph, a curve of O-C-B shows the relation between the load and the mid-span deflection. MOE is calculated from the slope of OE, which means the stiffness in elastic range. MOR is calculated from the maximum load ($P_{\max}$). U_b is the area of OCBD. TM is the ratio of the area of OCBD (U_b) to that of OABD

FFPRI 1965). The small clear specimens were tested according to several standards and were modified to be consistent with ASTM D143-52 (1973). The data for small clear specimens can be applied to discuss the performance of furniture members, because the members used in furniture making are rather short and have small cross-sections. However, the reduction of strength caused by defects such as knots or grain slope must be considered in the grading systems for structural members to be used for building construction. Many countries use mechanical grading to analyze lumber for potential structural use; grading uses the modulus of elasticity (MOE, Fig. 35.9) as an indicator of strength properties while visual grading focuses on various defects.

Wood density or specific gravity is one of the most important characteristics of wood. Density is not only important during the quantitative evaluation of wood for use in biomass production, but also serves as a good indicator of shrinkage and the status of several mechanical properties. Although the same regression equations are estimated for both non-peatland and peatland species, the wood of peatland forests seems to have less variation in bending strength (MOR, modulus of rupture, Fig. 35.9) when compared with that of non-peatland forests (Fig. 35.10). Note that the correlation between wood density and strength properties may be weak for some tropical species that feature distinctive interlocked grains or have a large amount of extracts in their heartwood. Some peatland species that have extremely heavy xylem, such as ulin (*Eusideroxylon zwageri*) or balau (*Shorea* spp.), show high levels of resistance to fungi making these species valuable in building houses. Wood density can be obtained by measuring the weight and the volume of wood samples or by soft X-ray densitometry methods. The detailed density distribution within a growth ring can be evaluated by the latter methods.

Wood shrinkage can be demonstrated by the high level of anisotropy seen in the wood; the shrinkage ratio for the tangential and radial directions is about 2:1. Longitudinal shrinkage is negligible and may generally be disregarded. Large amounts of shrinkage along the transverse direction may cause problems when joining edges of boards during the assembly of case furniture. Because shrinkage properties are also correlated with wood density, relatively light-weight wood is

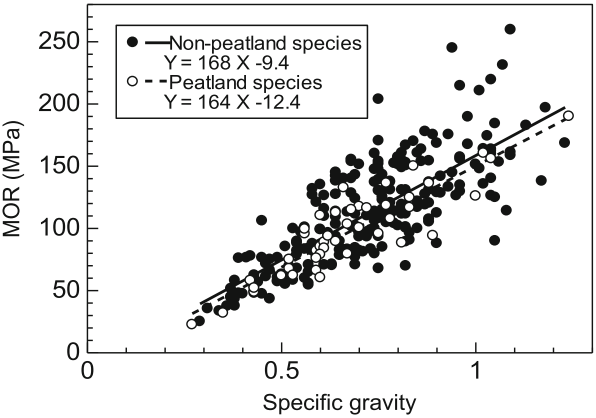

Fig. 35.10 The correlation between specific gravity and modulus of rupture (*MOR*). Regression lines were calculated for non-peatland and peatland species (Data are extracted from FFPRI (1965))

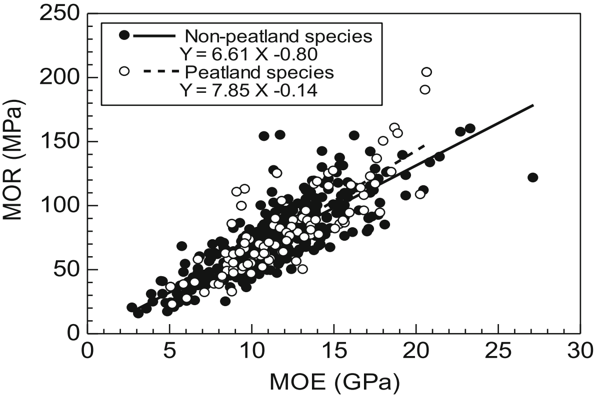

Fig. 35.11 The correlation between modulus of elasticity (*MOE*) and MOR. Regression lines were calculated for non-peatland and peatland species (Data are extracted from FFPRI 1965)

suitable for such applications. Concerning the use of wide boards, during seasoning, flat sawn boards may exhibit significant amount of cupping if the material exhibits a large anisotropic ratio (radial/tangential) of shrinkage.

Mechanical properties also show high anisotropy. When using wood as axial members such as posts or beams, strength properties in the longitudinal direction are the prime consideration. Bending properties such as the modulus of elasticity (MOE), modulus of rupture (MOR), and absorbed energy (U_b) or a work-to-failure as well as the maximum crushing strength (CS) are the most important properties. The MOE is useful because it is used as a nondestructive indicator of MOR as mentioned previously. No significant difference in regression lines between peatland wood and non-peatland wood was observed (Fig. 35.11). MOE for small clear specimens can be evaluated by the longitudinal vibration method, as well as by usual bending tests (Teranishi et al. 2008). The CS is important during the evaluation of allowable stress for structural lumber. The U_b calculated from load-deflection curves in static bending tests shows good correlation to the absorbed energy observed in the impact bending tests (Teranishi et al. 2008). Shear strength, cleavage, and hardness or partial bearing strength are also important.

35.3.4 Desirable Characteristics for Lumber Used in Buildings and Furniture

Lumber for structural members such as posts, beams, and braces should be straight and as long as needed. Coniferous species, which have excurrent crown shape, are used as structural members in the temperate and boreal zones where most hardwood trees have decurrent shapes (rounded crown shape). Structural lumber which includes defects, such as knots, can be graded visually and/or mechanically. Piles and sills which are exposed to water or moisture need to be very resistant to attacks from fungi. Additionally, resistance against termites is essential in tropical regions for structural members in buildings.

Heartwood color and decorative patterns mainly caused by the tissue orientation may add aesthetic value to interior boards and furniture. Several species of *Diospyros*, *Pterocarpus*, *Dalbergia*, and *Cassia* spp., grown in tropical forest of Southeast Asia, show distinctive dark colors in their heartwood. Strength properties are required for chairs and beds that have to support loads including humans. Among strength properties, toughness is one of the most important. If toughness of furniture member is larger, fracture can be expected to avoid injury caused by the failure of brittle members. One indicator of toughness is the Tetmajer's modulus (TM, Fig. 35.9). The TM generally has values from 0.5 (elastic fracture) to 1.0 (rigid-plastic fracture) and higher may be observed in tougher kinds of wood. Hardness or partial bearing strength is necessary for desktop boards.

Although those desirable characteristics is variable, it seems no relationships between those desirable characteristics and habitat of trees, peatland or non-peatland conditions.

35.4 Reforestation in Degraded Peatland in Southeast Asia

35.4.1 Why Is Reforestation Needed?

In tropical peatland, degradation and deforestation have continued over the past few decades, and huge areas of degraded peatland have been created. Southeast Asia was estimated to have 12.9 Mha (approximately 50 % of area) of deforested peatland from 1985 to 2006 (Hooijer et al. 2010). Once peatland forests have been degraded by clear-cutting of trees or wildfire, the peat swamp forest does not succeed to barren ground, but regenerates to secondary forest. However, if deforested peatland is turned into barren ground pteridophytes may become the dominant vegetation. This occurs because excavation for drainages allows the soil to dry out and because forest trees have been removed by logging and repeated wildfires. This results in the formation of degraded peatlands where the functioning of ecological services has become degraded so that timber production, carbon storage, the protection of water reserves and the preservation of biodiversity no longer occur (Page et al. 2002; Hooijer 2005; Hooijer et al. 2010). It is almost impossible for degraded peatlands to recover even over extended periods of time because mother trees have been removed and environmental changes create stressful conditions that severely limit seed germination and seedling recruitment (Fig. 35.1a–d). Therefore, assisting the recovery of degraded peatlands requires human intervention at the earliest possible stage to restore the ecological services and revitalize the forest ecosystem.

35.4.2 Strategy and Problems in Reforestation

The basic principle of the restoration of degraded peatland is the same as other degraded land in the tropics. Additionally cost-effectiveness and sustainability are key points for success (Mansourian 2005). Reforestation has both biological aspects related to silvicultural technique and socio-economic aspects related to management. Appropriate techniques, such as choosing appropriate tree species that are highly resistant to environmental stress factors and that are unique to degraded peatlands, are required to restore the forest to its original condition. Sustainable management of the forests also requires a long-term outlook because it will take the forests decades to become revitalized. Such intervention includes controlling environmental change by regulating groundwater levels, fire risks, and use of the forest by the local population. In almost all other degraded lands, problems that inhibit restoration are largely caused by the inability of managers to address socio-economic rather than silvicultural issues (Lamb 2012); however, in tropical peatlands the required biological knowledge of appropriate silvicultural techniques is also lacking.

Two alternative methods are available for the restoration of degraded tropical forest land; commercial and environmental reforestation (Fig. 35.12a; Lamb et al. 2005). Commercial reforestation aims to establish a plantation with a monoculture of crop tree species that is designed to produce commercial benefit in the form of pulpwood or timber such as an acacia plantation (Fig. 35.12a [5]). Given the plantation will be profitable, commercial reforestation using large amounts of capital is a promising way to restore forest in degraded peatland as well as in other degraded lands (Parrotta 1993; Lamb 1998). In degraded tropical peatlands, the most threatened event is wildfire during growing of stand, nevertheless intensive management of plantation can give local people a preventive consciousness of

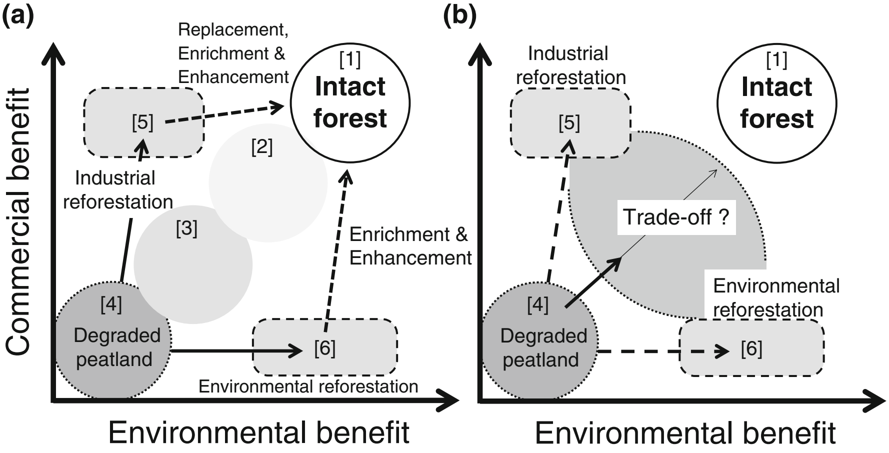

Fig. 35.12 Schematic pathway of reforestation in the frameworks of commercial and environmental benefit. (**a**) Two alternative pathways are conceptually recognized for restoration, via commercial plantation forests using crop trees ([*4, 5, 1*]) and via environmental forest by advanced planting of indigenous pioneer trees and then enrichment planting of indigenous late successional trees ([*4, 6, 1*]). (**b**) A third conceptual pathway is for practical restoration via cobenefits forest providing finances and environmental service, but this idea is uncertain because a trade-off relationship of tree's characteristics may exist between two benefits

wildfire, leading to decrease of the wildfire-risk. After the establishment a plantation, replacement of commercial crop trees with native trees will enrich species diversity while initially providing trees of high commercial value. This will enhance stand structure and function in a way that is designed to rehabilitate the secondary forest. At a minimum, it seems that extensive areas of degraded peatland can attract those interested in creating plantations as a result of the increasing demand of pulpwood production in international trade. However, whether the motivation exists to shift the degraded land from plantation to rehabilitated secondary forest is questionable. The question remains as to whether commercial reforestation can be accompanied by a reduction of the environmental load that is often involved in progressive forest management such as controlling the water table. A threat exists that peatlands may be damaged in a post-plantation scenario.

Environmental reforestation aims to restore native forest with environmental benefits, but the goal is not to provide commercial benefit (Fig. 35.12a [6]). First, to create suitable conditions for seedlings, planting should be conducted quickly to ease the establishment of light demanding pioneer species to create groundcover in degraded peatlands. That is, excessive light and high soil temperatures need to be mitigated. Then, planting of late successional species can be conducted in a way that enhances the restoration of secondary forests; consequently, these forests can develop a similar stand structure to that of intact forests. Environmental reforestation is very costly and requires a long period of time with a high risk of wildfire and land-use change by local people. While environmental reforestation seems to be the best way to restore natural forests, it may be difficult for environmental reforestation efforts to succeed without land managers implementing a robust and long-term management. Performing effective environmental reforestation requires adequate long-term financing; however, land managers have a difficult time developing a good method of ensuring that environmental reforestation is successful because environmental services have a limited market value (ITTO 2014). Therefore environmental reforestation seems to be impracticable in tropical peatland.

Focusing on only the good points of two above ways, i.e. providing financial and environmental benefits, a third way has been proposed in degraded tropical lands, seeking an appropriate balance between woody goods production and environmental service by using indigenous tree (Fig. 35.12b, Lamb et al. 2005). This idea has been recognized as only a concept due to few appreciate tree species for this management strategy in degraded peatland. Trees may have a trade-off relation of the characteristics between commercial and environmental benefits, implying the limitation of the win-win method. Nevertheless, we believe that this idea should be an ambitious goal realizing the cobenefits of commercial and environmental services, as documented in Sect. 35.5.

35.4.3 Development of Reforestation Procedure

Two procedures are available for reforestation in degraded peatland as follows.

Planting seedlings: Plans for planting need to be consider the most appropriate method of seedling establishment during reforestation in tropical regions (Fig. 35.13a). However, planting requires numerous costly steps such as seed collection, seedling preparation in pots at a nursery, and transplanting in the field (Ǻdjers and Otsamo 1996). Successful planting requires knowledge of tree ecology and physiology such as flowering and fruiting phenology, seed dispersal type (wind or animal), knowledge of seed dormancy and germination, environmental conditions needed for raising seedlings in a nursery and for

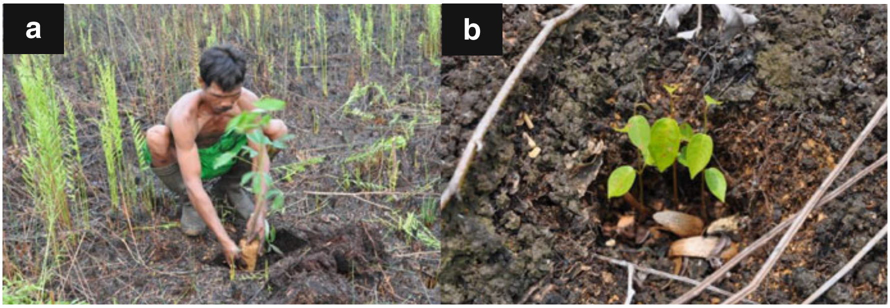

Fig. 35.13 Photographs of a seedling being planted (**a**) and direct sowing (**b**) in a burnt and degraded peatland, Central Kalimantan Indonesia

planting seedling in the field. If collecting seeds proves to be difficult, cutting shoot propagation and wilding are useful methods. Furthermore, stamp planting is an additional option that can be used to save planting costs. Site-preparation takes considerable effort as has been noted for other degraded lands. For peatland, mound construction is available for tree species that are intolerant to flooding despite the high cost of construction. However, soil moisture conditions on the mound may change to extreme drought conditions during the dry season as a result of the physical properties of peat soil. Therefore, care should be taken to address the effects of drought on survival and growth performance of seedlings planted on mounds.

Direct sowing: Direct sowing is an alternative forest restoration method to planting in tropical silviculture (Fig. 35.13a, Weinland 1998). Direct sowing is less costly and labor intensive than planting; however, it is generally thought to result in unreliable germination and survival rates (Weinland 1998). Little research has been conducted related to direct sowing techniques for tropical peatland tree species. Therefore, given the need for a better scientific understanding of the effectiveness of the direct sowing method, whether it may become a useful method in tropical peatland restoration remains unknown. For example, site-preparation, including weeding, sowing-hole size, and depth of soil cover are points that need to be considered. In fact, *Shorea balangeran* is a promising tree that can be used for direct sowing using a sowing hole without weeding as site-preparation (Saito et al. 2011a).

35.4.4 Species Selection

For successful reforestation in degraded peatlands, special care of species selection should be taken on the following three points.

Cost-effectiveness: Although reforestation requires significant costs, financial mechanisms to support reforestation activity are poorly developed; thus, saving the cost of preparing seedling stock and field operation required for planting are important. To select cost-effective tree species, several ecological properties should be considered: frequent fruiting and easy collection of seed, easy handling and germination of seed, limited maintenance-cost for raising seedlings, insensitivity of seedlings to transportation and planting in an open site. Furthermore, the risk of pests and diseases for seedlings should be considered (Nair 2007; Penyang et al. 2010).

Right species to the right condition: Attention must be paid to determine which of the available tree species perform well with high rates of efficient establishment from planting or direct sowing in a degraded tropical peatland. After wildfire, degraded peatlands have morphed into a harsh environment where almost all tree species fail to recruit and grow because the bare land has created harsh sun light and high temperature conditions and because the land becomes easily flooded; after fires, the ground shrinks resulting from the destruction of organic

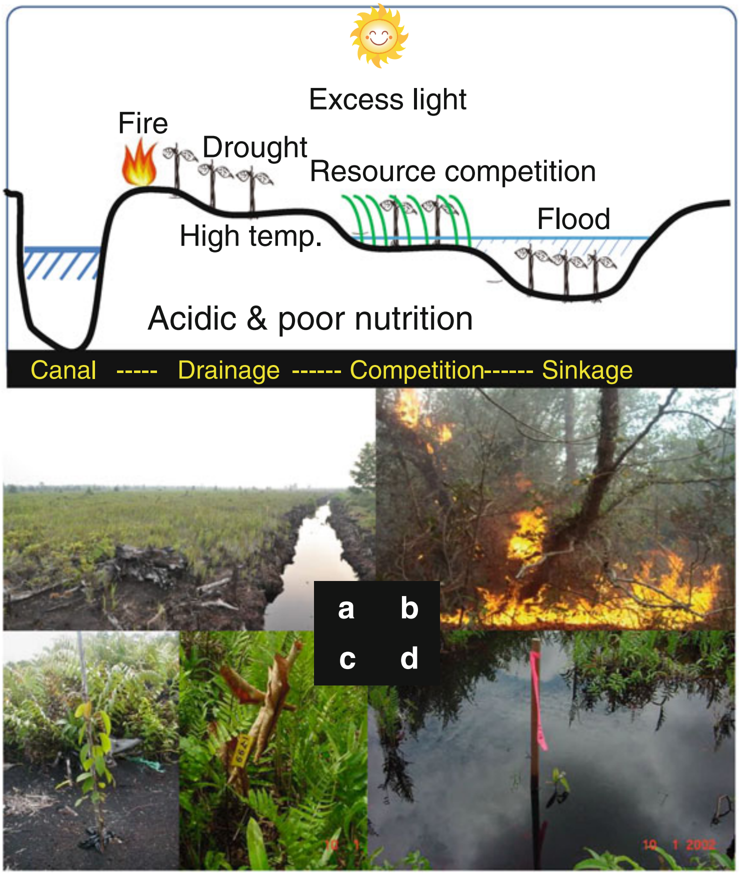

Fig. 35.14 Changes of site-conditions after degradation and deforestation in peatland. *Upper* illustration shows a cross-section of topography with a description of various site-conditions in degraded peatland. (**a**) Canal drainage results lowers the water table level and dries out soil at the surface. (**b**) Wildfire is very destructive and will burn planted seedlings. (**c**) Solar radiation causes soil temperature of bare ground to exceed 50 °C, and planted seedlings are intolerant of open-site conditions. (**d**) The ground sinks after a wildfire; subsequent decomposition caused frequent, prolonged and deep flooding, causing seedlings to become submerged

matter by the fire (Fig. 35.14). After several years without wildfire, ferns can recruit in the bare land, and the ground surface often changes to extremely shaded. This doesn’t allow for regeneration of light demanding pioneer trees at the ground level. Therefore, understanding environmental conditions required for site reforestation is important. Compared with other degraded lands, a special point to consider in degraded peatland is the flooded conditions (Giesen 2004; Wösten et al. 2008).

Flood depth and duration influence the survival and growth of seedlings. Almost all trees that grow in peat swamps can tolerate water-logged soils and submergence up to half the height of a seedling. However, the survival of seedling under full-submergence is species-dependent, i.e. from 0 to >90 % survival after 1 month (Saito et al. 2011b, Gaman S. unpublished data). Thus it is critical to screen out full-submergence-tolerant tree species as a special emphasis of degraded peatland reforestation. Unlike excess water from flooding, a lack of soil water also causes unfavorable conditions in degraded peatland. Canal construction lowered the groundwater table, leading to frequent soil drought in the dry season. However, little is known about the ability of peatland trees to tolerate drought conditions. Lighting is also a critical factor because direct solar radiation causes excess light and increased temperatures and worsens conditions on degraded tropical land. In general, pioneer trees can tolerate bright light conditions; therefore pioneer tree species should be selected for reforestation. Poor nutrition with acid conditions is a special feature of peat soils in degraded peatland forests (Kyuma 2003), limiting growth performance of trees, nevertheless it seems not to be critical factor of survival of planted seedlings for indigenous tree species.

Several years after the planting and establishment of seedlings, wildfire presents the most serious threat that can kill the trees in a degraded peatland. The resistance of trees to fire is species-dependent (Delmy 2001). For example, trees with thick bark on the trunk may resist fire quite well. The sprouting ability of a species is also an important characteristic and may allow the regeneration of an individual after aboveground material is killed. Thus, selecting fire-resistant tree species is a good method that can reduce the risk from wildfire to planted trees during a reforestation program.

In coastal and near coastal area of peatland, acid sulphate soils ($pH < 3.5$) are serious factor limiting regeneration of trees. The acidic soil formation is caused by oxidation of pyrite, iron sulphide underlying peat soils, triggered by drainage and disappearance of peat soils due to reclamation, decomposition and wildfire (Kyuma 2003). In the location of this sort, planting trees with tolerance to acid sulphate soil must be chosen.

Indigenous species: Undoubtedly, certain exotic species, such as *Acacia* sp., have an important role to play in the restoration of severely degraded sites with infertile soils. They can also act as facilitators and assist the establishment of indigenous species that are not tolerant of open-planting or infertile soils (Lamb 2012). However, little is known about the positive effects of non-native species in degraded tropical peatland. Nuyim (2003) pointed out that *Acacia mangium* may grow well in initial stage, but the plants eventually died in peatland. A planting trial case study showed that lower survival rates of non-peatland trees, *Shorea pinanga* and *S. selanica*, were found compared with peatland trees such as *S. balangeran*, in a degraded peatland in Central Kalimantan, Indonesia (Takahashi et al. 2003). A planting trial using tumih, an indigenous pioneer tree, resulted in better growth and performance with a greater coverage of tree-crowns providing shaded conditions at the surface when compared with *A. mangium* in a degraded peatlands of Central Kalimantan, Indonesia (Saito et al. 2005, Saito, Gaman, and Yuda, unpublished data). Because indigenous pioneer trees can grow well in degraded peatland, the planting of nurse trees should be considered using indigenous pioneer trees rather than exotic species to allow the conservation of biodiversity.

Case studies for each species: Giesen W (2004) reported a comprehensive review of a planting trial in degraded peatland of Kalimantan, Indonesia. This report documented that *Shorea balangeran* had the best survival rate in open-planting (approximately 80 %; Takahashi et al. 2003). *S. balangeran* seems to have suitable properties such as ease of seed-collection, seed handling, seedlings cultivation, a high resistance of seedlings to open and flooded conditions (Takahashi et al. 2006; Saito et al. 2011a), and stronger growth performance (Shibuya et al. 2007), so that *S. balangeran* may be an appropriate tree species for reforestation in degraded peatland.

Tumih is a pioneer tree species that can regenerate in post-burn open area (Saito et al. 2005; Page et al. 2009). Seeds of this species are easy to collect because even juvenile trees flower and fruit frequently. Direct sowing appears to be a reasonable method for artificial regeneration in degraded peatland (Saito, Gaman, and Yuda, unpublished data). Additionally, it seems to be suitable for planting because of rapid early-growth rates with a larger projection area of the tree crown (Saito, Gaman, and Yuda, unpublished data). Resistance to full-submergence of seedlings is lower for tumih when compared with *S. balangeran*.

Gerunggang is another pioneer and commercially variable timber tree. Seeds of this species are easy to collect because even juvenile trees flower and fruit at every year (Saito, Gaman, and Yuda, unpublished data). However, seed germination techniques and methods needed to break see dormancy remain unclear. Resistance to full-submergence of seedlings is lower for gerunggang when compared with tumih and *S. balangeran*.

Jelutung serves both as gum production tree and a timber tree, and is widely used in reforestation programs in degraded peatland in Central Kalimantan. However, the survival rate of planted Jelutung seedlings was approximately 40–50 % in an open area, and the plants grew slowly in degraded peatland; for example, trees in a 4-years-old plantation were only about 1.5 m tall in a degraded peatland of Central Kalimantan, Indonesia (Saito, Gaman, Yuda, unpublished data). The availability of shade or the presence of water-logged soil conditions seems to improve the survival rate of seedling in planting trials (Saito, Gaman, Yuda unpublished data). Currently, a loss of mother trees for seedling collection has become a serious issue because of the intensive logging for seed-collection and timber production around Palangka Raya, Central Kalimantan.

Pulai (*Alstonia* sp.) is variable tree used to produce traditional medicine and timber. It thrived when planted in an open site of a degraded peatland, with a survival rate of about 100 % for this light demanding tree. Resistance of seedlings to full-submergence is lower when compared with *S. balangeran*.

Ramin is a commercially and ecologically important tree species that should be restored since it is now listed as a Red-book Tree species in peatland forest (ITTO 2006; IUCN 2014). Because the fruiting phenology is uncertain, cutting propagation is an available method for preparing planting stock despite the high cost (Gaman et al. 2012). Young plants need shaded conditions, and the growth rate is extremely slow. Thus, it may take many years to restore ramin to enrichment biodiversity during reforestation.

Nuyim (2003) provided insight into several species and summarized the ecological characteristics and uses of 27 tree species used in the reforestation of degraded peatlands in Thailand. *Eugenia oblata*, *Melareuca cajuputi*, *Alstonia spathulata*, and *Calophyllum sclerophyllum* were characterized as having rapid growth rates for commercial trees (growth in height of more than 60 cm per year at 9-years-old). *M. cajuputi* produces essential oil in its leaves giving it added value. Other useful trees were identified.

35.4.5 Lesson from a Governmental Reforestation Project

In general, government projects related to environmental reforestation can result in successful planting, but unfortunately, these projects often fail to result in the establishment of secondary forest in degraded tropical forest landscape. This occurs not only because wildfire burns and kills the planted trees. Land-use patterns of local people can also change to agriculture or palm-plantations because of the poor understanding of the significance of environmental reforestation (Kobayashi S., personal communication). Relying solely on environmental benefits failed to provide the local people with adequate incentives to grow and conserve the planted trees. Therefore, successful reforestation may require governments to provide multiple benefits to local people including more than environmental services. Financial incentives should be provided to improve the rural socio-economic conditions, and consequently ensure the livelihood of local people (Brown 2005). Minimized disturbance of land management with appropriate use of agricultural land is also required for landholder (Schirmer and Bull 2014).

In Central Kalimantan, Indonesia, the Ministry of Forestry has promoted a reforestation program for improving degraded peatlands in the past decade. To test the general ideas provided above, we investigated how the various forest management procedures influence the success of forest restoration because the success of afforestation after planting varies depending on the location. In this study, we chose two sites each from a total of four successful and failed experimental sites, and looked at the determinants of success or failure by interviewing the local people and visiting the actual forest planting sites. The tree species planted was indigenous gum trees (*Dyera lowii*) because it produces latex as commercial trees with conservation of biodiversity, suggesting a candidate of cobenefit tree (Fig. 35.12b). In the successful cases, the forest restoration project was regarded as a community forest planting, and the activities were conducted to yield profits for the local people. In the cases of failure, local people ignored the forest restoration project after the initial planting activities, and no subsequent effort was made to maintain the trees. The gum trees with growing slowly after planting might not be

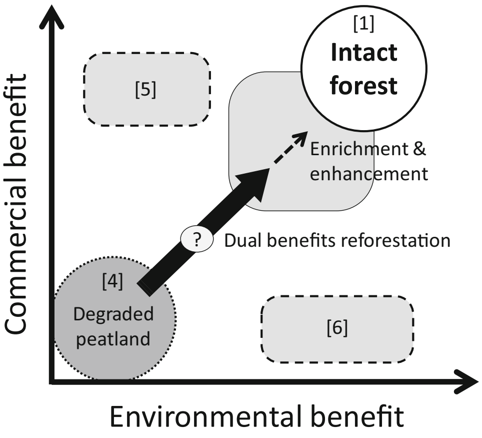

Fig. 35.15 Schematic scenario illustrating the dual benefits reforestation combined with the sustainable use of wood resources in a degraded peatland. Figure 35.2 describes the numbers [*1*–*6*]

able to give an impression of commercial benefit to local people. Therefore, projects should be designed in which local people view the management of the plantation as a great profit-making venture (Fig. 35.15).

35.5 A Perspective: New Aspects of Peatland Forestry Related to the Restoration and Sustainable Use of Wood Materials in Peatland Forest

In the past few decades, tropical peatland forestry has contributed to the timber and fiber production industries, but has unfortunately caused degradation and deforestation in a massive area of tropical peat swamp forests, consequently reducing the availability of timber resources and environmental services (Sect. 35.2). The restoration of peatland forest has become an important task (Sect. 35.4). However, timber production is still in demand in the marketplace for products from tropical peatland forests (Kato T. Personal commun.). Thus, we have the forest management dilemma with two contrary demands, timber production along with the conservation and restoration of environmental services (Fig. 35.16). We must develop a win-win method to satisfy these two demands in the future.

The degraded peatland may ironically have a potential for a new use for peatland forestry. Tropical peatland forest has the potential to produce various and unique wood materials of indigenous trees including high value commercial lumber (Sect. 35.3). The flat and massive area of degraded peatland has satisfied past needs for the industrial management of forests, and the drained condition of the land makes field-operations for forestry possible (Sect. 35.4). Given that degraded peatland can be restored to forests composed of commercially and ecologically valuable indigenous trees, and the restored forest can be sustainably managed for timber production, we feel confident that we will create a win-win method of

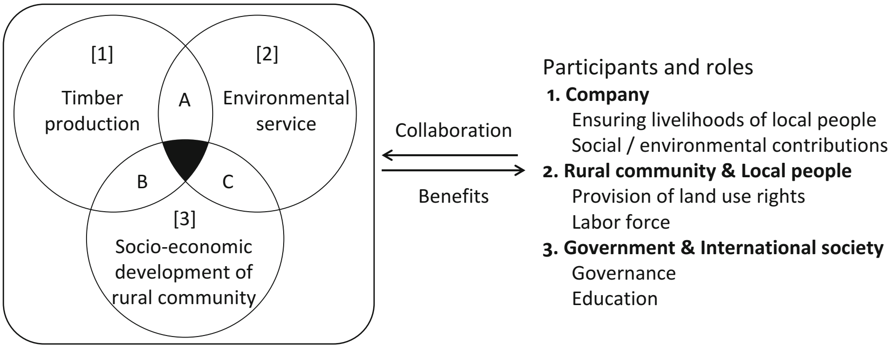

Fig. 35.16 Schematic diagram of three applicable aspects of new peatland forestry; [*1*] timber production, [*2*] conservation and restoration of environmental services, and [*3*] improvement of socio-economic conditions in a rural community to ensure the livelihood of people living in the degraded peatland. The three aspects need to be considered to have successful restoration and sustainable use of wood resources in peatland forests compatibly. The requirements of three aspects are as follows; (**A**) indigenous timber trees with high market value, suitable species for the specific site conditions, cost-effectiveness management, rapid growth and high productivity, (**B**) collaborative forest management between an industrial company and the local community, (**C**) understanding of the significance of environmental services as a part of local and global infrastructure. The center of Benn-diagram (Black) indicates the objective to realize new peatland forestry. Participants of new peatland forestry are company, rural community and local people, and government and international society

peatland forest management to obtain the dual benefits of timber production and environmental services (Fig. 35.16A). Furthermore, to successfully restore degraded peatland, suitable reforestation techniques that provide for the dual benefits as described above need to be developed (Sects. 35.4.3 and 35.4.4). Nevertheless, appropriate socio-economic mechanisms that are acceptable in rural communities need to be implemented (Sect. 35.4.5) to ensure the livelihood of local people including the landowners during peatland forest management (Fig. 35.16B). Only community forestry in rural region is insufficient for large-scale reforestation and efficient operation of forestry, so that collaborative forest management between an industrial company and the local community may be in place (Fig. 35.16B). The local people also need to understand the significance of environmental services including prevention of wildfire that are needed to improve the infrastructure in the rural region, as well as for global climates (Fig. 35.16C). To realize the harmony of those three aspects, governance and education by government and/or international society are also needed.

We believe, for example, *Shorea balangeran* may be a promising tree for timber production with multiple benefits for both the socio-economic and environmental services in degraded peatland of Central Kalimantan, Indonesia (Fig. 35.15). *S. balangeran*, indigenous timber tree in peat swamp forest, may be planted cost-effectively, and is a light tolerant and relatively early growth tree (Takahashi et al. 2003; Saito et al. 2011b) with high wood quality (Soerianegara and Lemmens 1994; Choong and Achmadi 1996; Koide et al. 2011, 2012); it belongs to the highest class of commercial valuable domestic timber and is in the middle class in the international market for export to India (ITTO 2014). Direct sowing methods may be available (Saito et al. 2011a), which can lower the cost of planting. Knowing that *S. balangeran*-based forestry can be established, one can easily realize this tree can be used for both timber production and for the restoration of environmental services. Furthermore, the planting of *S. balangeran* may help discontinue the use of exploitation forestry in natural peatland forests, by suppressing illegal logging, degradation and deforestation of tropical forests. Although scientific evidence of this idea is poor, *S. balangeran*-based forestry may provide great multiple benefits of timber production, environmental services and of improving socio-economic conditions in rural communities, and even contribute to the international timber market and help improve global climatic conditions.

To perform above tasks, a basic knowledge of ecological and use properties is crucially lacking. A number of research reports have been published on the mechanical properties of the wood species in tropical forests (Bhat et al. 2001; Bosman et al. 1994; Choudhury et al. 2009; Montes et al. 2007; Moya and Munoz 2010; Trockenbrodt et al. 1999); nevertheless, we should continue to accumulate reliable data related to the characteristics mentioned in Sect. 35.3 for various species, whose sources are specified. The distance from the pith to juvenile wood should also be recorded for the specimens so that the effects of juvenile wood can be discussed, especially for wood produced in plantation forests. Then new applications could be proposed for species grown in peat-swamp forests that are currently not being used. Furthermore, although numerous and divergent tree species exists in tropical peatland forests, little is known about ecological properties needed for developing reforestation techniques and forest management. For example, reproduction and growth of seedlings, the ability of seedlings to thrive in degraded peatland conditions and the production yield of timber needs to be documented, even for commercially viable trees (Sect. 35.4). However, the above ideas and the possible scenario regarding the use of *S. balangeran*-forestry encourages us to study new aspects of peatland forestry in an attempt to obtain the multiple benefits of timber production, resource conservation, the restoration of ecological services and the improvement of socio-economic conditions for rural communities living in areas of degraded peatland. Peatland forestry should challenge us to advance to a new position of simultaneously realizing both restoration and sustainable use of wood resources for local and global benefits from both socio-economic and environmental perspectives.

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Chapter 36
Ethnic Plant Resources in Central Kalimantan

Yutaka Tamai, Penyang Sandan, Sampang Gaman, and Yuda Prawira

Abstract Ethnic plant resource diversity and the forms of use were studied for Central Kalimantan. A total of 69 species representing 45 families of ethnic plants (including mushrooms) were recorded. Moraceae and Zingiberaceae are the most species rich families. The habits were categorized as follows: trees (27), shrubs (8), palm (1), bamboo (1), rattan (3), lianas (1), vines (4), grass (15), epiphyte (1), and ferns (3). Usages of the plant resources were categorized as follows: food (vegetables, fruit, mushrooms, spices, additives, and others), medicine, materials for working (craft, wood), and others (poisons, repellants, charcoal, ornaments, and others). Ten species belonged to two categories.

Keywords Food plant • Medicine plant • Woody material • Mushroom

36.1 Introduction

Central Kalimantan (Kalimantan Tengah) is one of the five provinces of the Indonesian part of Borneo island. The Dayak who live there belong to the largest ethnic group of the island. Central Kalimantan has about 1.5 million inhabitants and a total area of about 153,800 km^2 mostly consisting of peatlands and jungle. The province is bordered by the river basins of the Katingan, Kahayan, Kapuas, and Barito rivers. Major towns are located around the rivers and flow through the whole area from the coastal areas (lowlands) to the headwaters (highlands) where they have their sources. The province is divided into 13 regencies, but vast areas of the northern part of the province are sparsely populated and comprises only two regencies. The coastal area around the estuaries is also sparsely populated and consists of peat swamps, which reach up to 100 km inland.

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The vast tropical forests produce large quantities of wood, and offer much other potential as a producer of non-timber forest products. Although there are many potential non-timber forest products in Central Kalimantan, we have mainly explored particulars of plant species that have traditionally been used by the local population.

36.2 Field Site and Data Collection

The study site was around Palangkaraya city, Central Kalimantan. Data was collected through interviews with people randomly selected in the markets of the city. The background of the respondents varied and included housewives, greengrocers, traditional medicine merchants, students, and elderly people. Besides this, efforts were made to collect data from a variety of literature available in the library. Collected data was classified based on the habits of ethnic plants and the usages these are put to. Plants in this paper were shown at Table 36.1.

36.3 Ethnic Plants List

Ethnic plant resource diversity and the forms of use were studied in the community of Central Kalimantan. A total of 69 species representing 45 families of ethnic plants (including 5 mushrooms) were recorded. The most species rich families are Moraceae and Zingiberaceae, which included five and four species, respectively. The habits were categorized as follows; trees (27), shrubs (8), palm (1), bamboo (1), rattan (3), vines (4), liana (1), grasses (15), epiphyte (1), and ferns (3).

Usage of the plant resources was categorized as follows: food (37 species: vegetables, fruit, mushrooms, spices, additives, and others), medicine (29 species), materials for various uses (5 species: crafts, wood) and others (8 species: poisons, repellants, charcoal, ornaments and others). Eleven species belonged to two categories.

36.3.1 Food Plants

Thirty eight species (34 plant and 4 mushroom species) belonging to 27 families (23 plant and 4 mushroom families) were recorded as food resources. Most of these are wild, non cultivated species. Edible parts of the plants are the fruits, seeds, leaves, stems, tubers, and roots. Suna (*Allium chinense*: leaf, bulb), Rotan Irit (*Calamus trachycoleus*: shoot) (Picture 36.1, (1)), Kalakai (*Stenochlaena palustris*: leaf, stem) (Picture 36.1, (2)), Baluh (*Cucurbita moschata*: fruit), Uwi (*Dioscorea alata*: tuber), Bajei (*Diplazium esculentum*: leaf) (Picture 36.1, (3)), Bakung (*Hanguana*

Table 36.1 Ethnic plant species in Central Kalimantan

Scientific name	Family (habit)	Vernacular name (language)	Usage	Category	Picture 36.1
Allium chinense	Alliaceae (grass)	Suna (Dayak Ngaju/Indonesia)	Vegetable, medicine	F/Me	
Eleutherina palmifolia	Alliaceae (grass)	Bawan Dayak (Indonesia)	Medicine	Me	(15)
Mangifera foetida	Anacardiaceae (tree)	Tuwe (Dayak Ngaju)	Poison fishing	O	(13)
Mangifera casturi	Anacardiaceae (tree)	Kasturi (Dayak Ngaju/Banjar/Indonesia)	Fruit	F	
Dyera lowii	Apocynaceae (tree)	Jelutung (Indonesia)	Gum base	F	
Calamus caesius	Arecaceae (rattan)	Rotan Taman (Indonesia)	Craft	M	
Calamus manan	Arecaceae (rattan)	Rotan Manau (Indonesia)	Craft, fruit	M/F	
Calamus trachycoleus	Arecaceae (rattan)	Rotan Irit (Indonesia)	Craft, vegetable	M/F	(1)
Auricularia sp	Auricularaceae (mushroom)	Kulat Bitak (Dayak Ngaju)	Mushroom	F	(8)
Stenochlaena palustris	Blechnaceae (fern)	Kalakai (Dayak Ngaju/Banjar)	Vegetable	F	(2)
Durio kutejensis	Bombaceae (tree)	Paken (Dayak Ngaju)	Fruit	F	(6)
Cordia sp.	Boraginaceae (tree)	Suji (Indonesia)	Food color	F	
Garcinia mangostana	Clusiaceae (tree)	Manggis (Indonesia)	Fruit	F	
Costus speciosus	Costaceae (grass)	Sawangkak (Dayak Ngaju)	Medicine	Me	(10)
Cucurbita moschata	Cucurbitaceae (vine)	Baluh/Labu Kuning (Dayak Ngaju/Indonesia)	Vegetable	F	
Eleocharis dulcis	Cyperaceae (grass)	Purun (Dayak Ngaju/Banjar/Indonesia)	Craft	M	(11)
Dioscorea alata	Dioscoreaceae (vine)	Uwi (Dayak Ngaju/Indonesia)	Vegetable	F	
Diplazium esculentum	Dryopteridaceae (fern)	Bajei (Dayak Ngaju)	Vegetable	F	(3)
Phyllanthus niruri	Euphorbiaceae (shrub)	Ambing buah (Banjar)	Medicine	Me	
Flagellaria indica	Flagellariaceae (shrub)	Uwei Manyamei (Dayak Ngaju)	Medicine	Me	
Fagraea crenulata	Gentianaceae (tree)	Kayu bulan (Dayak Ngaju/Banjar)	Medicine	Me	
Hanguana malayana	Hanguanaceae (grass)	Bakung (Dayak Ngaju/Banjar)	Vegetable	F	
Hygrocybe chlorophana	Hygrophoraceae (mushroom)	Kulat Siau (Dayak Ngaju/Banjar)	Mushroom	F	
Curculigo villosa	Hypoxidaceae (grass)	Lemba (Dayak Ngaju)	Spice	F	
Alseodaphne coriacea	Lauraceae (tree)	Gemor (Dayak Ngaju/Banjar/Indonesia)	Mosquito coil	O	(14)

(continued)

Table 36.1 (continued)

Scientific name	Family (habit)	Vernacular name (language)	Usage	Category	Picture 36.1
Cinnamomum burmannii	Lauraceae (tree)	Kayu Manis (Indonesia)	Spice, medicine	F/Me	
Cinnamomum sintok	Lauraceae (tree)	Sintuk (Dayak Ngaju)	Medicine	Me	
Leea indica	Leaceae (shrub)	Kayu Mali-mali (Dayak Ngaju/Banjar)	Medicine	Me	
Termitomyces sp.	Lyophyllaceae (mushroom)	Kulat Bantilung (Dayak Ngaju)	Mushroom	F	
Melastoma malabathricum	Melastomaceae (shrub)	Karamunting (Dayak Ngaju/Banjar)	Medicine	Me	
Aglaia sp.	Meliaceae (tree)	Kaja laki (Banjar)	Medicine	Me	
Fibraurea chloroleuca	Menispermaceae (shrub)	Akar Kuning (Banjar)	Medicine	Me	
Tinospora crispa	Menispermaceae (vine)	Akar gantung (Banjar)	Medicine	Me	
Albertisia papuana	Menispermaceae (liana)	Sasungkai (Dayak Ngaju)	Spice	F	
Antiaris toxicaria	Moraceae (tree)	Ipu (Dayak Ngaju)	Arrow poison	O	
Artocarpus sp.	Moraceae (tree)	Pilang (Indonesia)	Fruit	F	
Artocarpus champeden	Moraceae (tree)	Mangkahai (Dayak Ngaju)	Fruit	F	
Artocarpus odoratissimus	Moraceae (tree)	Tarap (Dayak Ngaju/Banjar)	Fruit	F	
Ficus microcarpa	Moraceae (tree)	Uhat jajangkit (Dayak Ngaju)	Medicine	Me	
Ardisia sp.	Myrsiniaceae (shrub)	Butu tupai (Dayak Ngaju)	Medicine	Me	
Melaleuca leucadendra	Myrtaceae (tree)	Galam (Dayak Ngaju/Banjar/Indonesia)	Building material, charcoal	M/O	(12)
Tristaniopsis sp.	Myrtaceae (tree)	Palawan (Dayak Ngaju/Indonesia)	Medicine	Me	
Nepenthes sp.	Nepenthaceae (grass)	Katupat Napu (Dayak Ngaju)	Ornamental plant	O	
Grammatophyllum speciosum	Orchidaceae (grass)	Anggrek Tebu (Indonesia)	Ornamental plant	O	
Areca catechu	Palmaceae (palm)	Pinang (Indonesia)	Betel nut	O	
Baccaurea lanceolata	Phyllanthaceae (tree)	Kapul (Dayak Ngaju/Banjar)	Fruit	F	
Piper betle	Piperaceae (vine)	Sirih (Indonesia)	Betel leaf	O	
Dendrocalamus asper	Poaceae (bamboo)	Betung (Indonesia)	Vegetable	F	(4)
Cymbopogon citratus	Poaceae (grass)	Sarai/Serai (Dayak Ngaju, Banjar/Indonesia)	Spice, medicine	F/Me	

Pycnoporus coccineus	Polyporaceae (mushroom)	Kulat Merah (Dayak Ngaju)	Medicine	Me	
Nauclea orientalis	Rubiaceae (tree)	Taya (Dayak Ngaju)	Vegetable	F	(5)
Myrmecodia pendans	Rubiaceae (epiphyte)	Sarang Semut (Dayak Ngaju)	Medicine	Me	(9)
Lavanga sarmentosa	Rutaceae (tree)	Saluang Belum (Dayak Ngaju)	Tonic, medicine	F/Me	
Viscum orientale	Santalaceae (tree)	Kayu Tungkun (Dayak Ngaju)	Medicine	Me	
Dimocarpus malesianus	Sapindaceae (tree)	Tangkuhis (Dayak Ngaju)	Fruit	F	
Nephelium maingayi	Sapindaceae (tree)	Katiau (Dayak Ngaju/Banjar)	Fruit	F	
Nephelium sp.	Sapindaceae (tree)	Tanggaring (Dayak Ngaju)	Fruit	F	
Schizophyllum commune	Schizophyllaceae (mushroom)	Kulat Karitip (Dayak Ngaju)	Mushroom	F	
Eurycoma longifolia	Simaroubaceae (shrub)	Pasak Bumi (Indonesia)	Tonic, medicine	F/Me	
Solanum ferox	Solanaceae (grass)	Rimbang (Dayak Ngaju)	Vegetable	F	
Solanum torvum	Solanaceae (grass)	Segau (Dayak Ngaju)	Vegetable	F	
Callicarpa longifolia	Verbenaceae (shrub)	Kitat Pusa/Sangkareho (Dayak Ngaju/Bakumpai)	Medicine	Me	
Vitex pubescens	Verbenaceae (tree)	Kalapapa (Dayak Ngaju)	Medicine	Me	
Alpinia galanga	Zingiberaceae (grass)	Langkuas/Laos (Dayak Ngaju/Indonesia)	Spice, medicine	F/Me	
Curcuma longa	Zingiberaceae (grass)	Henda/Kunyit (Dayak/Indonesia)	Spice, medicine	F/Me	(7)
Etlingera hemisphaerica	Zingiberaceae (grass)	Potok (Dayak Ngaju)	Vegetable	F	
Zingiber officinale	Zingiberaceae (grass)	Lai/Jahe (Dayak Ngaju/Indonesia)	Spice, medicine	F/Me	
?	? (tree)	Tadangkak (Dayak Ngaju)	Medicine	Me	
?	? (fern)	Tagentu (Dayak Ngaju)	Medicine	Me	

Category: *F* Food, *Me* Medicine, *M* Material, *O* Others

(1) Rotan Irit (*Calamus trachycoleus*) Shoot

(2) Kalakai (*Stenochlaena palustris*)

(3) Bajei (*Diplazium esculentum*)

(4) Betung (*Dendrocalamus asper*)

(5) Taya (*Nauclea orientalis*)

(6) Paken (*Durio* kutejensis)

(7) Henda (*Curcuma longa*) Flowers

(8) Kulat Bitak **(*Auricularia sp*)**

(9) Sarang Semut (*Myrmecodia pendans*)

Picture 36.1 Picture of plants

(10) Sawang Kak (*Costus Speciosus*)

(11) Purun (*Eleocharis dulcis*)

(12) Galam (*Melaleuca leucadendra*)

(13) Tuwe (*Mangifera foetida*)

(14) Gemor (*Alseodaphne coriacea*)

(15) Bawan Dayak (*Eleutherina palmifolia* L)

Picture 36.1 (continued)

malayana: inside of stem), Betung (*Dendrocalamus asper*: shoot) (Picture 36.1, (4)), Taya (*Nauclea orientalis*: leaf) (Picture 36.1, (5)), Rimbang (*Solanum ferox*: fruit), Sanggu (*Solanum torvum*: fruit), Potok (*Etlingera hemisphaerica*: stem, bulb) were used as vegetables in daily food.

Fruits of Kasturi (*Mangifera casturi*: mango), Rotan Manau (*Calamus manan*: rattan), Paken (*Durio kutejensis*: durian) (Picture 36.1, (6)), Manggis (*Garcinia mangostana*: mangosteen), Kapul (*Baccaurea lanceolata*), Pilang and Mangkahai (*Artocarpus* spp.: jackfruits), Tangkuhis (*Dimocarpus malesianus*: longan), and Katiau and Tanggaring (*Nephelium* spp.: rambutan) are all edible.

Lemba (*Curculigo villosa*: leaf), Kayu Manis (*Cinnamomum burmannii*: bark), Sasungkai (*Albertisia papuana*: leaf), Sarai (*Cymbopogon citratus*: stem, leaf), Langkuas (*Alpinia galanga*: rhizome), Henda (*Curcuma longa*: flower) (Picture 36.1, (7)), Lai (*Zingiber officinale*: rhizome) are used as spices.

Saluang Belum (*Lavanga sarmentosa*: root, xylem) and Pasak Bumi (*Eurycoma longifolia*: root) are used for tonics as well as medicine. Latex from Jelutung (*Dyera lowii*) is a substitute of chicle (chewing gum base). Edible mushrooms, Kulat Bitak

(*Auricularia* sp.: tree ear) (Picture 36.1, (8)), Kulat Siau (*Hygrocybe conica*: conical wax cap), Kulat Bantilung (*Termitomyces* spp.: termite mushroom), and Kulat Karitip (*Shizophyllum commune*: common split gill) were commonly collected from the forest, but recently the ear mushroom is mainly cultivated in the villages.

36.3.2 Medicine Plants

A total of 29 species (28 plant and 1 mushroom species) belonging to 20 families (19 plant and 1 mushroom families) were recorded as medicinal resources. Most of these were used as traditional folk medicine to treat ailments such as headache, stomachache, wounds, fever, cough, viral diseases, and others.

Extracts from the bark of Sintuk (*Cinnamomum sintok*) is believed to have anti-malarial properties. Mixed extracts from Akar Kuning (*Fibraerea chloroleuca*: root) and Kulat Merah (*Pycnoporus coccineus*: hole) are also used for malaria. Root of Pasak bumi (*Eurycoma longifolia*) contains an analeptic stimulant, the products mentioned here are still popular folk medicines. Sarang Semut (*Myrmecodia pendans*: tuber) (Picture 36.1, (9)) is an epiphytic myrmecophyte (ant plant), used for all kinds of disease treatment. Rhizomes of Sawangkak (*Costus speciosus*) (Picture 36.1, (10)) have been used to treat fevers, rashes, asthma, bronchitis and intestinal worms.

36.3.3 Material Plants for Working

Calamus spp. are well known as rattan. Rattan is used as a craft material, but is also occasionally as structural components. The fruit of Rotan Manau (*C. manan*) and young shoots of Rotan Taman (*C. caesius*) are edible, and both species are also categorized as food.

The stems of Purun (*Eleocharis dulcis*) (Picture 36.1, (11)) may be used for mulch, fodder, fruit and vegetable packaging, and craft products. *Melaleuca leucadendra* is well known as ‘Galam’ (Picture 36.1, (12)), a kind of wood traditionally used in building construction and as a fuel wood.

36.3.4 Other Plants

Sap from Tuwe (*Mangifera foetida*: horse mango) (Picture 36.1, (13)) is highly toxic and used for traditional poison fishing. Ipu (*Antiaris toxicaria*) is a fast growing tree and source of lightweight wood. Because of the latex containing intense toxin, the tree is notorious as a poison for arrows and blow darts.

Gemor tree (*Alseodaphne coriacea*) (Picture 36.1, (14)) bark contains insect repellant and is still commonly used for the production of mosquito coils. Katupat Napu (*Nepenthes* spp.: Pitcher plant) and Anggrek Tebu (*Grammatophyllum *speciosum*: epiphytic orchid) are collected from the forest and grown in the village, then sold in the market as ornamental plants.

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Part IX
Ecological Services in Peatland

Shigeo Kobayashi and Hendric Segah

Chapter 37
Local Community Safeguard by REDD+ and Payment for Ecosystem Services (PES) in Peatland

Shigeo Kobayashi, Hendrik Segah, and Eriko Momota

Abstract The Ramsar Convention on wetland conservation was concluded as treaty in 1971. Peatland forests in the tropics have, however, been experiencing drastic land-use changes for easy access and utilization, which, together with tropical peatland/forest decline, has also been a focal point of global environmental issues. Rehabilitation of degraded peatland has, nevertheless, hardly been attempted. LULUCF (Land-Use, Land-Use Change and Forestry) has been discussed as an agenda of IPCC since 2001. It is, therefore, urgently necessary to conduct research on land resource management option and local society empowerment for global-warming prevention in peatland of Southeast Asian. COP15 of Copenhagen Agreement was proposed REDD+ (Reducing Emissions from Deforestation and Forest Degradation) in Developing Countries (2009) and COP16 of Cancun proposal REDD+ with Safeguard (2010). Therefore, the local community safeguard was discussed in relationship with REDD+ and PES (Payment for Ecosystem Services). The following safeguards, especially in peatland, should be promoted and supported such as (1) Action complement or are consistent with the objectives of national peatland/forest programme and relevant international conventions and agreements, (2) Transparent and effective national peatland/forest governance structure, taking into account national legislation and sovereignty, (3) Respect for the knowledge and rights of indigenous peoples and members of local communities, by taking into account relevant international obligations, national circumstances and laws, and noting that the United Nations General Assembly has adopted the United Nations Declaration on the Rights of Indigenous Peoples, (4) The full and effective participation of relevant stakeholders, in particular, indigenous peoples and

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local communities, in actions referred to in paragraph 70 and 72 of this decision, (5) Actions are consistent with the conservation of natural peatland/forest and biological diversity, incentivizing the protection and conservation of natural peatland/forest and their ecosystem services, and enhance other social and environmental benefits, (6) Actions to address the risks of reversals, and (7) Actions to reduce displacement of emissions from peatland/forest.

Keywords REDD+ • Safeguard • PES (Payment for Ecosystem Services) • Tropical peatland/forest • Rehabilitation

37.1 Introduction

In light of the increasing reclamation and development of lowland swamps, the Ramsar Convention was concluded in 1971 as an international treaty for wetland conservation. Changes in land use, however, are rapidly taking place in peatland/forest in tropical areas because of their easy access from rivers and seas, which, along with a decrease in tropical forests, have been discussed as a global environmental problem. In particular, tropical peatland/forest ecosystems are characterized by singular ecosystems based on mangrove ligneous peat which sedimented during the age of Holocene glacial retreat. The area of tropical peatland/forest in Indonesia is the largest in Southeast Asia at 22,500,000 ha. People have traditionally lived in the periphery of peatland/forest. Due to immigration policy and development, however, people have come to live even inside the peatland/forest.

Many parts of those peatland/forest were formed historically and affected by the ocean. As pyrite is thus contained in their mud layer, their soils easily become sulfuric acidic, hindering plant growth. Its mineral content, especially calcium content, etc., is extremely small. Development of peatland/forest accelerates dehydration and decomposition of organic matter, and peatland/forest fire (Chap. 5). Thus, converted area of peatland/forest into oil palm gardens, fast growing tree plantations, farmland, and shrimp/fish cultivation ponds are subsequently abandoned because of a decline of productivity.

Therefore, conservation and rehabilitation of peatland/forest is necessary using new mechanisms such as REDD+ and PES.

37.2 REDD+ Mechanisms of Peatland/Forest of Central Kalimantan as Pilot Province in Indonesia

There have been a number of efforts to design policies to curb global warming, including REDD+. Specifically after the United Nations Framework Convention on Climate Change (UNFCCC) was adopted at the Earth Summit (United Nations Conference on Environment and Development) held in Brazil in 1992, international discussion to address global warming issues have been actively conducted. One of the important points of the UNFCCC is that the convention recognized the fact that developed countries had been responsible for most greenhouse gas emissions, and adopted the principle which states that developed and developing countries should make efforts to protect the climate system "on the basis of equity and in accordance with common but differentiated responsibilities and respective capabilities". After the UNFCCC, the Third Conference of the Parties (COP3) was held in Kyoto in 1997, where the Kyoto Protocol was adopted and the following commitments were agreed upon: (1) developed nations as a whole must reduce their greenhouse gas emissions by at least 5 % compared to the 1990 levels, (2) each Party must set legally binding targets (with no reduction targets for developing countries), and (3) a so-called Kyoto mechanism was included to increase flexibility.

At COP11 held in Montreal, Canada in 2005, Papua New Guinea and Costa Rica jointly proposed the innovative idea of reducing greenhouse gas emissions through curbing deforestation and forest degradation. This is the origin of the Reducing Emissions from Deforestation and Degradation (REDD), and since then REDD has attracted international attention as the first measure to reduce emissions through a focus on forests. At COP13, held in 2007 in Bali (Indonesia) it was decided to (1) urge the Parties to conduct activities to examine the feasibility of REDD to reduce emissions through deforestation and forest degradation in developing countries and to promote and assist capacity-building in developing countries, and (2) provide guidelines for the activities. Further, (3) it was also decided that a Subsidiary Body for Scientific and Technological Advice (SBSTA) would work on methodological issues in preparation for COP14. In the discussions at COP13 about the framework for the next conference, it was also decided to (4) examine related policy measures and incentives, and (2) investigate the roles of maintaining or increasing forest carbon stocks. It was from COP13 that international negotiations about REDD+ moved to center stage.

At COP15 held in Copenhagen in 2009 the agenda included the mention of mid- and long-term targets developed from scientifically-based measures, stating that "it is necessary to prevent the temperature of the entire world from rising more than 2 degrees Celsius," as stated in the Fourth Assessment Report of Intergovernmental Panel on Climate Change (IPCC). Concrete mechanisms for Measuring, Reporting, and Verification (MRV) of carbon assessments and financial assistance were agreed on. Further, this MRV was adopted for the REDD mechanism, and each country started discussions about creating a standard manual for curbing greenhouse gas emissions from forests. In response to the Copenhagen Accord, COP16 held in Cancun, Mexico in 2010 clarified the scope of REDD+ activities as follows:

1. Reducing Emissions from deforestation
2. Reducing Emissions from degradation
3. Conservation of forest carbon stocks
4. Sustainable management of forest
5. Enhancement of forest carbon stocks

At COP16 the Parties were encouraged (1) design national strategies or action plans, (2) establish national forest reference emission levels and forest reference levels, (3) design robust and transparent national forest monitoring systems for the monitoring and reporting of activities of the REDD+, and (4) develop institutions for providing information on how the agreed social and environmental safeguards are being addressed and respected. Further, the Cancun Agreement recognized the importance of a phased approach for REDD+ based on the specific circumstances of developing countries and urged developed countries to address issues involved in the deforestation and forest degradation, land tenure issues, forest governance issues, gender considerations, and safeguards.

At COP17 held at Durban in South Africa in 2011, the main agendas were on the issue of MRV, national forest reference emission levels and forest reference levels, and financing.

Further, at COP19 held in Warsaw, Poland in 2013, four agreements were reached: (1) documents about five technologies and methodologies related to REDD+, (2) documents about funds (conditions of result-base payment and information disclosure), (3) arrangements and organizations for providing assistance (each country to designate a focal point, and a forum will be held), and (4) establishment of rules for implementing result based payments.

In this way, the issues of REDD+ have been discussed at the COP every year, and efforts to design an international framework to curb greenhouse gas emission have advanced gradually.

37.2.1 REDD+ Mechanisms

At present, the international mechanism known as REDD+ is being discussed in international negotiations as a candidate for an international framework for reducing CO2 emissions from deforestation and degradation of forests in parallel to the Clean Development Mechanism (CDM).

The roles of REDD+ are conservation, sustainable management of forests, and increasing forest carbon stocks in developing countries as well as reductions in CO2 emissions from deforestation and degradation of forests. The basic idea underlying this mechanism is conducting activities to curb deforestation and forest degradation in developing countries, and obtaining economic incentives (carbon credits, funds) through achieved reductions in greenhouse gas emissions or increases in the amounts of carbon in carbon sinks. The main activities are as follows:

1. Reducing Emissions from deforestation
2. Reducing Emissions from degradation
3. Conservation of forest carbon stocks
4. Sustainable management of forest
5. Enhancement of forest carbon stocks

The Fourth Assessment Report of IPCC has already recognized the benefits of the roles played by forests in protecting against global warming. It has also estimated that forests will bring the greatest benefits in sustainable reductions in

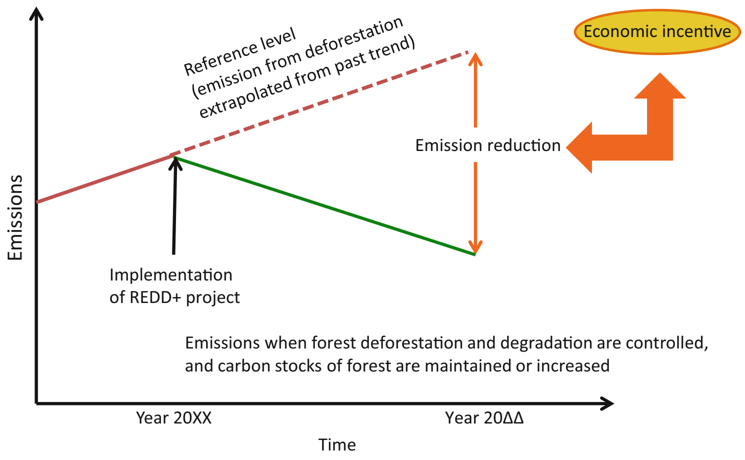

Fig. 37.1 Reductions of the greenhouse gas emissions by REDD+, curbs of deforestation and degradation – forest conservation in developing countries

global warming by implementing a strategy for sustainable management of forests to maintain or increase carbon stocks in forests. Further, it describes that curbing deforestation and forest degradation will lead to reductions in greenhouse gas emissions, contributing to measures against global warming.

The following is the basic structure of REDD+ (Fig. 37.1). First, the reference emission level (reference level) (A) is established. The reference level (A) is the emissions estimated based on past records without considering measures curbing deforestation and degradation or forest conservation. The amount (B) is the emissions resulting with the activities of REDD+ and the measures curbing deforestation and degradation and maintaining or increasing carbon stocks in forests. Economic incentives are given to the reduced emissions, the difference between the reference emission level (A) and the amount (B).

Under REDD+, the methods of returning the benefits gained by the economic incentives to the local community are another important consideration. Types of financial mechanisms for these incentives include a market type (Raising funds by converting the emission reductions achieved through REDD+ projects and the maintained or increased carbon stocks into credits, and trading these credits at a carbon market) and a basic type of incentives (providing funds directly to developing countries without passing through the carbon market).

37.2.2 Economic Analysis of the REDD+ System

The climate change issue has been recognized as one of the most important policy issues for the region's development. Integrated Regional Assessment (IRA) promotes a better understanding of how regions contribute to global environmental

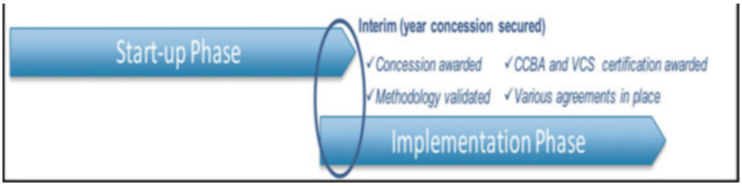

Fig. 37.2 REDD+ project framework phases

change. Then the methodological challenges of IRA are required as illustrating the practice of such assessments at the regional scale. In this pilot project, it should develop a Provincial/Local Economic Analysis model for REDD+, the effect on climate change, human impact, and fossil fuels.

Economic feasibility: ***operational and financial analysis***: As in any business, the design and implementation of a REDD+ project has to be supported by robust operational and financial economic feasibility analysis. In order to understand the long-term financial implications among various carbon credit pricing scenarios, a meaningful economic analysis needs to reflect real costs and revenues associated with every step of REDD+ through start-up and implementation phases at large (Fig. 37.2).

We will assess the economic feasibility of REDD+ projects by categorizing the transaction costs into main functions (e.g., MRV, community development, biodiversity and protection and enforcement) and capturing "bottom-up" activity costs (e.g., personnel, travel, supplies, fuel, consultants and capital assets). Such information will be used to understand the short and long-term cost requirements for implementing a REDD+ project in Indonesia, and to identify options for revenue streams and cost reduction opportunities. This will be translated into a user-friendly excel-based interface, with which REDD+ project proponents may estimate and assess different costs associated with different project types and conditions (e.g., forest types and locations). Figure 37.3 provides an overview of the REDD+ cost model structure.

The economic analysis will also inform the current dialogue on REDD+ benefit sharing when the flow of revenue through REDD+ carbon financing is realized through various mechanisms. There is a need to examine how national and global funds are managed and distributed and how "benefits" are to be shared, as this is of primary interest to stakeholders at all levels including the government, project developers, communities and civil society. In order to effectively halt deforestation and forest degradation under the REDD+ scheme, REDD+ benefits must be determined and shared according to rights and responsibilities attached to specific activities. Such approach will likely to justify the allocation of benefits and motivate responsible parties to make necessary behavioral changes and/or livelihood adjustment.

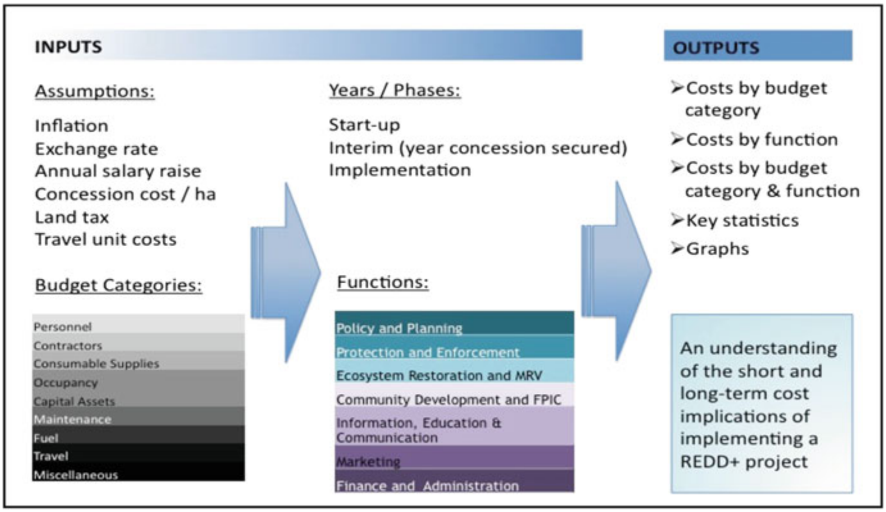

Fig. 37.3 REDD+ cost model structure

37.2.3 Challenges in REDD+

However, there are many problems in REDD+ that still have to be dealt with. Specifically with the following three issues there are difficulties to find solutions with the big differences that there are between developed and developing countries.

1. Establishment of reference levels;

   To establish the reference levels (emissions in the case where no measures have been taken to curb deforestation and forest degradation), past forestry data including forest coverage, forest soils, branch coverage, foliage, dead-wood, and underground carbon stock biomass are necessary. However, these data are not adequately established in many developing countries. For this reason, we must consider how it is possible to set reliable reference levels. Also, how the baseline years are set for the calculation affects the reference levels.
2. Establishment of monitoring methods;

   To calculate actual emissions requires regular monitoring of deforestation and degradation (changes in forest area and forest carbon stocks). To this end we need to establish a “Monitoring”, “Reporting”, and “Verification” (MRV) system, but it needs improvements to become an absolute and fully accepted technique.
3. Safeguards;

   To promote REDD+, it is necessary for every citizen to recognize that conserving forests through sustainable management brings more benefits than deforestation, by providing economic incentives for conservation of forests. Securing the rights and lives of indigenous peoples will lead to the conservation of forests, and at the same time it will contribute to the conservation of environments in terms of biodiversity. For this purpose, it is necessary to promote REDD+ by improving the governance of the countries involved, while giving sufficient consideration to balancing the validity, efficiency, and fairness of the measures that are put into effect.

The seven items listed below are described in Annex I of the Draft Decision [-1 CP.16], which stipulates safeguards for the political approach and governance of REDD+, adopted in COP16 held in Cancun, Mexico. It is necessary to observe and follow these items to carry out proper governance:

(i) Action to complement and conform to national forest programs and related international treaties and agreements;
(ii) Establishment of Forest Governance;
(iii) Respect for the knowledge and rights of indigenous people and local communities;
(iv) Participation of indigenous people and local communities;
(v) Conformity with conservation of natural standing forests and biodiversity;
(vi) Action to enable coping with the risks of reversal;
(vii) Action to reduce the reassignment of emissions.

37.2.4 REDD+ Program in Kalimantan and Indonesia

Considering the huge impact of peatland forest management on climate change, peatland forests in general have been a priority or target area for the REDD-Indonesia scheme as described in the IFCA Consolidation Report 2008, and the National Action Plan for Climate Change (Rencana Aksi Nasional Perubahan Iklim, RANPI), especially related to the implementation of options for strategic intervention and restoration-rehabilitation of peatland forest ecosystems. In this strategy, awareness raising, improving capacity, and resolving disharmony among government authorities in peatland administration are addressed as part of the provisions of the enabling conditions.

Further, the restoration-rehabilitation of deforested-degraded ecosystems is also carried out in selected areas as demonstration activities involving related stakeholders. The plantation of indigenous and valuable species will provide direct benefits (income) to local communities and environment management, and has therefore been included in national policies related to the conservation of biological diversity. Indigenous and valuable species have been identified and tested for planting in the restoration-rehabilitation areas of degraded peatlands and have shown very promising results, both to improve forest conditions as well as to improve incomes of local communities.

Referring to the above policies and considering international commitments regarding REDD+, the Government of Indonesia has recently made significant progress in developing REDDES by issuing:

(i) UU No 6/1994: Ratification of United Nations Framework Convention on Climate Change
(ii) UU No 41/1999: Forestry
(iii) UU No 5/2997: Biodiversity
(iv) UU No 17/2003: State Finances
(v) UU No 17 of 2004: Ratification of Kyoto Protocol on the UN Framework Convention on Climate Change
(vi) UU No 25/2004: National Development Planning System
(vii) UU No 18/2004: Plantation
(viii) UU No 17/2005: RPJP 2005–2025
(ix) UU No 31/2009: Meteorology, Climatology and Geophysics
(x) UU No 32/ 009: Environment Protection and Management
(xi) UU No 41/2009: Sustainable Food Land Protection
(xii) PP No 26/2008: National Spatial Plan
(xiii) PP No 10/2010: Method of Change of Forest Area Allocation and Function
(xiv) PP No 15/2010: Implementation of Spatial Structuring
(xv) PP No 24/2010: Forest Area Use;
(xvi) KEPPRES No 5 of 2010, RPJMN of 2010–2014;
(xvii) Ministerial of Forestry Regulation No. 68/2009; Organizing Demonstration Activities for Reducing Emissions from Deforestation and Degradation.
(xviii) Ministerial of Forestry Regulation No. 30/2009; concerning Mechanisms for Reducing Emissions from Deforestation and Degradation. This regulation provides information on the mechanisms in implementing REDD in Indonesia.
(xix) Ministerial of Forestry Regulation No. 36/2009; related to mechanisms for service utilization for carbon storage and sequestration in commercial forests.

The National Council on Climate Change of Indonesia (DNPI) reported to UNFCCC that the total CO_2 emission of Indonesia including the emissions from ecosystems such as forests and peatlands is the third largest in the world after China and the United States of America (Fig. 37.3). About 80 % of the emissions are from two sectors: 41 % from Land Use, Land Use Change and Forestry (LULUCF), and 37 % from peatland development (right graph on Fig. 37.4). This clearly shows that the amount of emissions from ecosystems, such as forest and peatlands, is much larger than that from energy, transportation, and agriculture. It can be inferred that deforestation and forest degradation are in a serious situation, and that decomposition of peat has progressed very much. If this situation continues unabated, the precarious ecosystems of Indonesia will be destroyed, and animals and plants may go extinct. Further, the destruction of ecosystems will powerfully influence the livelihoods of residents, such as through degradation of soil and moisture retention functions and water pollution. Governments need to formulate policies to protect the livelihood of residents.

At the G20 Pittsburgh Summit in September, 2009 President Yudhoyono of Indonesia announced CO_2 emission reduction targets, and declared that Indonesia

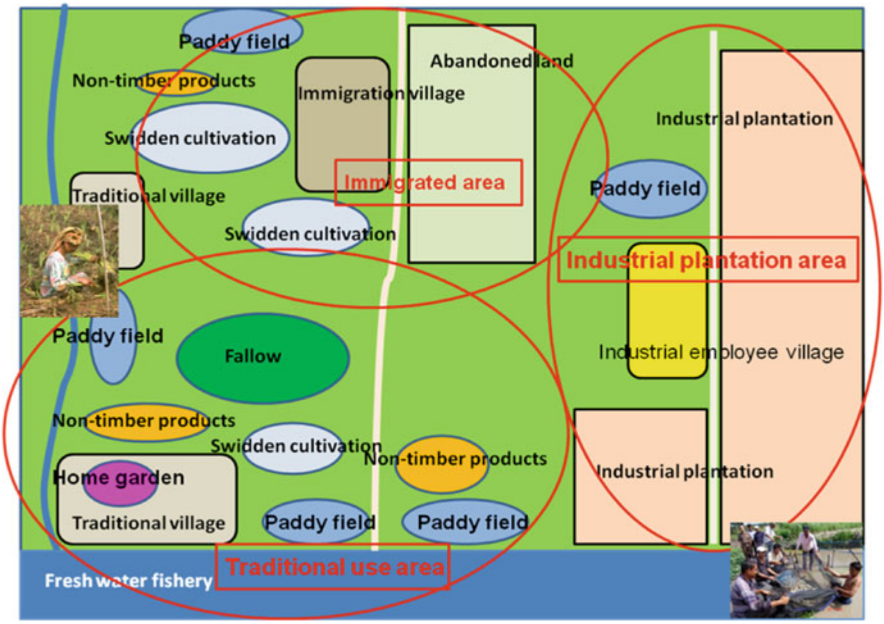

Fig. 37.4 Different background history of each village which must be taken into account for consideration of PES and the safeguard in peatland/forest

pledged an emissions reduction target of 26 % under domestic efforts by 2020 or 41 % with international assistance. In November, 2011, President Susilo Bambang Yuhdoyono has signed a presidential decree creating a National Action Plan to Reduce Greenhouse Gas Emissions, known as RAN-GRK, and there is the creation of the RAD-GRK covering 33 Indonesian provinces, and the whole country by the end of 2012 became obligated to join (the low of National Action Plan for Green House Gas Reduction 2011).

Also President Yudhoyono announced the selection of Central Kalimantan as a pilot province to carry out pilot testing of the initial stage of Reducing Emissions from Deforestation and Forest Degradation (REDD+) in Indonesia. The selection by the President was conducted during the Cabinet meeting on 23 December 2010, where the President selected Central Kalimantan out of nine forested provinces, upon receiving a report by Dr. Kuntoro Mangkusubroto, Head of the President's Delivery Unit for Development Monitoring and Oversight (UKP4), who was also assigned by the President as the Chairman of the Task Force for the Preparation of REDD+ Institutional Establishment (REDD+ Task Force). The Central Kalimantan Province was selected after evaluating the other proposals from the following 8 (*eight*) provinces: Aceh, Jambi, West Kalimantan, East Kalimantan, Papua, West Papua, Riau and South Sumatra.

The REDD+ Task Force was established on 20 September 2010, based on Presidential Decree No. 19/2010, as part of the Partnership program between the governments of Indonesia and Norway. The Task Force will work with local governments to improve the institutions, systems and capacities that are at the front lines of forest protection. Dr. Kuntoro stated that the President selected Central Kalimantan based on a combination of quantitative and qualitative evaluation. “The assessment showed that Central Kalimantan is a province with large forest cover and peat land and faces a real threat of deforestation. The level of readiness and commitment of the Governor to implement REDD+ was also considered promising for Central Kalimantan to be a successful partner,” said Dr. Kuntoro. Central Kalimantan has the third largest forest cover and the third largest amount of peat land in Indonesia.

Indonesia and Norway signed a Letter of Intent in Oslo on 26 May 2010 outlining the framework for a USD one billion partnership to combat deforestation and forest degradation. The implementation of Phase 2 of the partnership, beginning next year, will include the establishment of a national REDD+ agency, continuation of the development of a comprehensive national REDD+ strategy, the creation of a financing instrument, the development of a monitoring, reporting and verification (MRV) framework, and the implementation of a pilot province and a 2–year suspension for new concessions on forests and peatlands. Furthermore, on 19 May 2011, Indonesia’s President signed a presidential instruction bringing into force a 2-year moratorium on the granting of new forestry concessions and logging in primary forests, and dredging in peatlands to unlock up to $1 billion in seed funding from the government of Norway that could help the country earn billions more by saving tropical rainforests and capturing carbon in trees.

Central Kalimantan is the best place for a REDD+ Pilot Project, because (1) large forest and peat area still remain, (2) lots of studies for rehabilitation and management in the Mega Rice Project Area have been and are being done, (3) A high level of International Collaboration Research has been and is being done by Hokkaido University, Japan, KFCP, WWF, etc., (4) A high level of Domestic Research has been and is being done by LIPI, FORDA, etc.

In another point of view, as the REDD+ Pilot Project should be extended or applied to other areas, Kalimantan itself has benefits to be the model area in Indonesia, because (1) A large area of Kalimantan is covered in Forest (second in Indonesia) and Peatland (third in Indonesia), (2) There is a good network for research and education among the Universities in Kalimantan: The University of Mulawarman (UNMUL), The University of Lambung Mangkurat (UNLAM), The University of Palangka Raya (UNPAR), The University of Tanjung Pura (UNTAN), (3) Various key-ecosystems such as Peatlands, Wetlands, Drylands, Mangroves, Mountainous areas, and (4) Various Forest Types such as production forests, limited production forests, protection forests (national parks), and nature conservation areas.

Furthermore, in national level based on the Indonesian President Decree No. 62/2013, about establishment of the REDD+ Agency. The REDD+ Agency is tasked with reforming Indonesia’s forestry sector, which has been beset with mismanagement and corruption for decades. On that front, it will be expected to prepare and develop a national REDD+ strategy that includes safeguards to protect against corruption, ensure equitable benefits distribution, and mitigate the risk of social and environmental damage. The body will also be charged with integrating REDD+ into the broader economy, managing REDD+ funds, and coordinating law enforcement related to the program, all in the face of likely opposition from the country's powerful forestry interests.

37.3 PES (Payment for Ecosystem Services) Mechanisms

An extreme decline in ecosystem services has been occurring in degraded peatlands, such as frequent fires, rapid peat decomposition, and the extinction and decrease of wetland plants. Consequently, various programs for restoring devastated peatlands have been implemented. However, just protecting a peat swamp which has become grassland or carrying out forest rehabilitation by afforestation is not effective because reforestation is impeded by repeated wildfires. In order for a rehabilitation program to have effectiveness, it is necessary for the program itself to be connected to some economic production activity and to provide a high incentive to local community and administrative organizations for applying adequate control, including a proactive fire prevention scheme.

Under this subtopic, based on the reflection of such a history of peatland restoration, we will undertake the following (Fig. 37.4). (1) We will clarify the ecological requirements for ensuring a sustainable rehabilitation program for each type of rehabilitation programs which have been implemented in the target area and each mode of various peatland uses and, at the same time, create a decision making tool for selecting an optimal option from among alternative options for peat swamp rehabilitation by assessing the quality and quantity of ecosystem services that the rehabilitation program can provide. (2) We will develop technology for using biomass resources obtained from those various rehabilitation options effectively and in a manner catered to the actual local situation to enhance an incentive for introducing rehabilitation options. (3) By integrating the results of efforts specified in (1) and (2), it is intended to create an integrated rehabilitation plan combining individual rehabilitation options and biomass resources.

37.3.1 Assessment and Development of Rehabilitation Options on Payment for Ecosystem Services in Degraded Peatland/Forest

The severe decline in ecosystem services in general has been occurring in tropical peatland/forest, such as a decline in carbon storage, the extinction and decrease of the highly endemic wetland biota, and a sudden change in the ecosystem due to a fluctuation in water quality and moisture environment. Regarding the sustainable management of tropical forests, the United Nations Forum on Forests (UNFF) established its criteria and indicators, and the policy is under examination to enforce monitoring, assessment, and reporting for these criteria and indicators. Nonetheless, even though discussion is going on for preventing an enormous impact which deforestation and degradation of tropical peat swamp forest give to the global environment and the further loss of peatland/forest, there are few cases where the rehabilitation of ecosystem services of a degraded peatland/forest itself was systematically examined.

In order to rehabilitate degraded peat swamps, it is necessary to develop a project for rehabilitation those degraded ecosystems at landscape level. For this purpose, it is indispensable to combine various rehabilitation options appropriately. As to rehabilitation options, various attempts have so far been made to rehabilitate degraded peatlands, including the development of secondary forests through natural transition, the conversion to farmland by introducing tree crops such as rubber and oil palm, the conversion to industrial plantation with fast growing tree species such as acacia, the conversion to afforestation areas with various types of useful indigenous tree species in region and the conversion to farmland with herb crops. For example, at the Riau research site, an area of degraded peatland is zoned into an agricultural district (oil palm plantation), an afforestation district (acacia plantation), and a reserve (natural forest and secondary forest). While the first two districts have been under development with large-scale drainage, the preservation of biological diversity in a natural forest and restoration through natural transition are expected in the reserve. Applicability conditions exist for each of these restoration options. For example, *Acacia crassicarpa*, a main candidate plant species for a peatland, shows good growth in suitably moist soil, but its growth declines so significantly as to preclude the viability of its industrial planting if submergence frequency is too high. It is necessary to indicate clearly the applicable range of various existing restoration options by systematically examining and assessing them and to assess the quality and the quantity of ecosystem services which are enabled by adopting them.

Rehabilitation experiments using various indigenous tree species constituting peat swamp forests (lamin, macaranga, and melaleuca) are also conducted although the use of these species has not been put into practice yet. Under this research topic, we intend to create a comprehensive list of restoration options which have already been implemented or used experimentally and clarify ecological and social conditions required for introducing each option. At the same time, ecosystem service functions which can be offered are intended to be assessed from two viewpoints of the material cycle and biological diversity. In addition, impacts on local communities are also intended to be clarified. On the basis of these results, it is intended to develop a tool for appropriately selecting restoration options in accordance with the present state and environmental conditions of a peatland. It is especially important to restore a devastated area by using native species. It is also important to use tree species indigenous to these three districts for producing non-timber forest products including bintangor (*Calophyllum lowii*:edible oil) and jelutung (*Dyera lowii*:chewing gum ingredient), etc. in addition to dipterocarp species (*Dipterocarpacea*) and lamin (*Gonistylus* sp.).

37.3.2 Development of Appropriate New Technology for Using Biomass in Peatland/Forest

In order to restore a peatland, it is also indispensable for a restoration program to offer a sufficient economic incentive. For this purpose, it is necessary to develop technology for effectively using resources produced under the restoration program, especially biomass resources, in the target area. At the same time, it is also necessary to develop technology for improving the plant species used in restoration by developing effective breeding technology. Following three technology development efforts will be made under this sub-subtopic.

1. The screening of biofuel materials and the development of biofuel material technology. It is intended to screen raw materials for bioethanol and biodiesel production and to conduct technology development for their practical use. There are three processes necessary for bioethanol production: pretreatment for separating cellulose, the saccharification of cellulose by cellulase, and the conversion to ethanol by yeast fermentation or other means. It is intended to develop biomass pretreatment technology under the mild conditions utilizing resources peculiar to peat swamp forests especially in order to establish the procedures of screening peat swamp forest species suitable to pretreatment and biorefinery technology which can be implemented by local residents. Specifically, we will consider (1) biomass upgrading by torrefaction and (2) saccharification pretreatment by using white-rot fungus peculiar to peatland. For biodiesel production, it is intended to screen peat swamp forest species such as bintangor (*Calophyllum lowii*) which have been used as oils and fats indigenous resources, improve the yield of oils and fats plants such as oil palm which are widely used, and to develop oil expression technology which is catered to the local situation to explore the possibility of using biodiesel as regional energy resources.
2. The screening of timber resources and the development of technology for using them A tropical forest has extremely high biological diversity, and ligneous resources obtained under the restoration programs include a variety of tree species. From diverse ligneous resources, tree species for building construction use are intended to be screened by measuring and evaluating fundamental data such as flexural, tensile, and compressive performance. Based on the results obtained, it is intended to determine the suitability of each species for various wood-based materials such as lumber, laminated wood, plywood, and particle board to construct a mass flow of ligneous resources. At the same time, an attempt is to be made at timber utilization suitable to shipped timber and the development of wood-based materials. In addition, we will aim at creating high value-added products by promoting the use of natural adhesive whose commercialization is now in view. Furthermore, it is intended to make proposals for easily constructable housing or housing parts using various tropical timbers and wood-based materials as structural materials and face bars. It is intended to develop unique low-cost housing adapted to local conditions by supporting

the timber industry based on local communities on the basis of such advanced technology. Concurrently with this effort, an attempt will be made for the screening of tree species from which cellulose nanofiber is extractable and for the effective utilization of wood-based materials which have so far been abandoned, such as bark and chip of wood discharged in felling and lumbering processes, for instance, the development of new wood-based materials from the barks of acacia timbers which are highly anti-bacterial. The feasibility of the conversion process will then be evaluated.

3. Tropical tree breeding technology (molecular breeding, cutting, and tissue culture) What has emerged as an agenda in production of wood-based biomass resources is how to select fast growing forest trees from which biomass is produced at a fast rate, forest trees with a high utilization efficiency suitable for bioethanol or pulp conversion, or new varieties which have tolerance to an extreme habitat, etc. Under this sub-subtopic, it is intended to construct the technological foundation indispensable to molecular breeding of tropical biomass plants by utilizing technology such as molecular breeding of fast growing trees, cutting, and tissue culture, etc. This research attempts at molecular breeding of tropical acacia with high biomass productivity incorporating useful genes by constructing highly efficient transformation and redifferentiation systems and the gene expression database of tropical acacia for the purpose of establishing foundational technology for the second-generation biofuel production and industrial raw materials production from non-edible resources.

37.3.3 Creation of an Integrated Rehabilitation Plan

Although international conferences concerning the great influence of devastated and degraded tropical forests upon the global environment have been progressed, there are not many researches for restoration of these forests. Rehabilitation of the devastation tropical forest leads to recovery of cultural, ecological functional, and social economic value. A primary factor of decrease and deterioration of the tropical forest differs depending upon each area condition. A characteristic factor of that is slash-and-burn cultivation in south-east Asian region, fuel material collection at the African region, and large-scale field and abandoned pastures in south America. In addition, recently, human-induced forest fire and large-scale commercial illegal lumbering are serious factors of deforestation and degradation in not only tropical region but the world. Therefore, because each local people's incentive for the rehabilitation of the devastation tropical forest differs in the three areas, we study on four topics; (1) investigation of the actual condition of degraded tropical forests and development of a restoration technology, (2) traditional knowledge and regional life in a tropical forest, (3) empowerment to a local community in the tropical forest which is restored, and (4) establishment of a rehabilitation strategy which accompanies a land resource management option which contributes to life of the local resident. Additionally, each characteristics of the area is clarified. The study is conducted as an international collaborative research together with Center for International Forestry Research (CIFOR), at which the applicant had worked for three and a half years.

The expected results are revealing the devastation factor in tropical forests, evaluating actual condition of devastation in terms of cultural, ecological functional, and social economic value, and evaluating degree of dependence of the local people's life to the tropical forest. International networking is conducted with the analytical results relating to restoration. After integration of restoration technology is done, a book of restoration technical options adjusted to a condition of each area is published. Local residents' participation is promoted by adding incentive to the restoration of the degraded tropical forest. It offers fundamental data to restoration business of the degraded tropical forest, and then reforestation management of planting gets a meaning in perspective of CDM or carbon credit operated by companies and NGOs.

As global environmental concerns, social economy and the research relating to a decrease and deterioration in tropical forests have international necessity for global warming prevention, sustainable forest management, biodiversity preservation, desertification preservation, and timber legality assurance system. It is conferred by COP6 (Kyoto Protocol), the Montreal process (benchmark index), and ITTO2000 (sustainable forest management), etc., and it is closely related to a series of international agreement etc. It is said that fully demonstrating various functions of the tropical forest including the global warming mitigation and biodiversity preservation is important. For sustainable management of tropical forests, United Nations Forum on Forests (UNFF) sets a benchmark index, and considers making a policy of monitoring, assessment and reporting (MAR) to it. Moreover, IPCC reported on the LULUCF guideline (land use and forestry) in 2003. However, the research of the restoration of tropical forests that go to ruin and are deteriorated is scarce, though the conference the great influence of devastated and degraded tropical forests upon the global environment have been progressed.

1. The study is directly connected with "Land use, land use change and forestry guideline" of IPCC and topics examined in the "sustainable management of tropical forests" study in United Nations Forum on Forests (UNFF).
2. Although UNFF and ITTO set the criteria and indicators for sustainable management of tropical forests, and considers a policy of monitoring, assessment and reporting (MAR), development of a technology, which have not been considered there, is needed for rehabilitation of degraded forests.
3. We make a data base containing recovery including of forest resources, environmental preservation function, and biodiversity, and the contents are opened to the public.
4. A rehabilitation methods are integrated to establish a rehabilitation technology option adjusted to each region.
5. The comparative study result of biodiversity and environmental preservation function in restored degraded land is applied to environmental education.
6. An international network is constructed with an analytical result of the restoration.

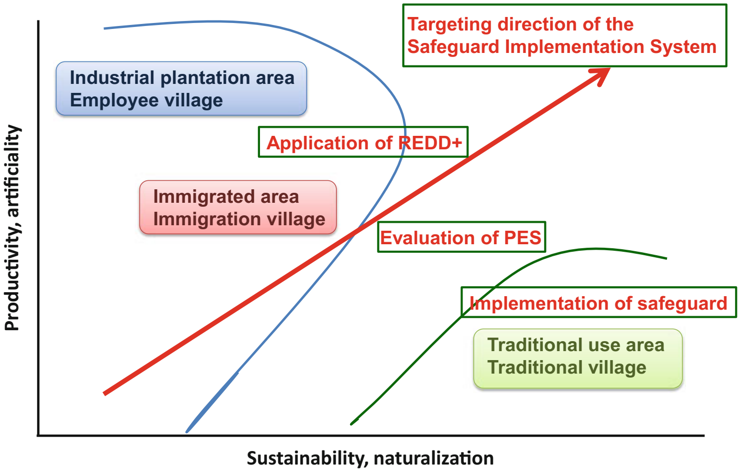

Fig. 37.5 Diagram of different historical villages position between productivity and sustainability

It is intended to create a plan for rehabilitating degraded peat swamps at landscape level by combining the rehabilitation options selection tool of the sub-subtopic, (1) and technology for using biomass resources developed under the sub sub-topic, (2) at this stage, the combination of the new water management method and the rehabilitation options under the sub topic as well as the effective penetration of the rehabilitation programs into local communities examined under the subtopic, will be subject to discussion. A small-scale rehabilitation experiment is to be carried out by creating multiple rehabilitation plans and scenarios. At the same time, while evaluating its results, an effort will be made for submitting governance recommendations specified in Fig. 37.5. We have emphasized on the relationship between the productivity (artificiality) and the sustainability (naturalization). Forest plantations in the tropics will play a very important role on the world wood supply in the future. Moreover, they can relieve the pressure to exploit natural forests if rates of reforestation substantially increase (Evans 1992). Plantation forestry has recently started in many tropical areas but the knowledge of nursery and planting techniques is limited to the fast-growing trees, such as *Eucalyptus*, *and Acacia* species, and a few other commercial species. However, there are many native tree species, some of which may possess characteristics making them suitable as plantation species. Development of research on seedling production and planting methods of these lesser-known species is a priority in many tropical countries (Kobayashi 2007).

Another problem is how to improve and maintain productivity of forest plantations. Many plantations are established on soils that are very low in nutrients and/or susceptible to degradation. Although the plantation has a potential of high productivity, it may have low yields and degrade the site if managed poorly. Information is urgently required on the factors that control the productivity of plantations under a wide range of soil and environmental conditions, and on ways of managing the site to maintain the productivity of successive tree crops (sustained productivity) (Kobayashi 2007).

Rehabilitated secondary forest can be defined as forests regenerating largely through natural processes an degraded lands, often aided by rehabilitation efforts, or the facilitation of natural regeneration through measures such as protection from chronic disturbance, site stabilitation, water management, and planting.

Finally, we propose the balancing and specification of the productivity (artificiality) and the sustainability (naturalization) accordancing in the region for REDD+ safeguard with purposes and targets of rehabilitations on Safeguard Implementation System (SIS).

37.4 Safeguard

The Kyoto Protocol, however, does not have a mechanism for reducing deforestation and degradation in developing countries. The framework is required for stopping deforestation and degradation in developing countries. Furthermore, there is a proposal made at the Cancun conference of COP16 in 2010 for the agreements and the safeguards as preventive measures against the negative impact of REDD+ implementation. The agreements, reached on December 11 in Cancun, Mexico, at the 2010 United Nations Climate Change Conference represent key steps forward in capturing plans to reduce greenhouse gas emissions and to help developing nations protect themselves from climate impacts and build their own sustainable future. The agreements consisted of nine issues such as (1) Establish clear objectives for reducing human-generated greenhouse gas emissions over time to keep the global average temperature rise below 2°, (2) Encourage the participation of all countries in reducing these emissions, in accordance with each country's different responsibilities and capabilities to do so, (3) Ensure the international transparency of the actions which are taken by countries and ensure that global progress toward the long-term goal is reviewed in a timely way, (4) Mobilize the development and transfer of clean technology to boost efforts to address climate change, getting it to the right place at the right time and for the best effect, (5) Mobilize and provide scaled-up funds in the short and long term to enable developing countries to take greater and effective action, (6) Assist the particularly vulnerable people in the world to adapt to the inevitable impacts of climate change, (7) Protect the world's forests, which are a major repository of carbon, (8) Build up global capacity, especially in developing countries, to meet the overall challenge, (9) Establish effective institutions and systems which will ensure these objectives are implemented successfully on REDD+.

Moreover, we pay attention on another discussion of the Safeguards when undertaking activities referred to in paragraph 70 of this decision, the following safeguards should be promoted and supported, and which including these agreements. The safeguards consist of seven issues which are (1) Action complement or are consistent with the objectives of national forest programs and relevant international conventions and agreements, (2) Transparent and **effective national forest governance structure**, taking into account national legislation and sovereignty, (3) Respect for **the knowledge and rights of indigenous peoples and members of local communities**, by taking into account relevant international obligations, national circumstances and laws, and noting that the United Nations General Assembly has adopted the United Nations Declaration on the Rights of Indigenous Peoples, (4) The full and **effective participation of relevant stakeholders**, **in particular**, **indigenous peoples and local communities**, in actions referred to in paragraph 70 and 72 of this decision, (5) Actions are consistent with **the conservation of natural forests and biological diversity**, ensuring that actions referred to paragraph 70 of and this decision are not used for the conversion of natural forests, but are instead used incentivize the protection and conservation of natural forests and their ecosystem services, and enhance other social and environmental benefits, (6) Actions to address the risks of reversals, (7) Actions to reduce displacement of emissions. We have to pay attention on the possibility of the implementation of these safeguards which must be emphasized on local communities and indigenous peoples (ex. Bold sentences).

Those safeguards clarify the purpose of national forest programs and complement or are consistent with relevant conventions and agreements. They construct transparent and effective national forest governance structures. They respect the knowledge and rights of indigenous peoples and members of local communities. They promote the full and effective resident participation of relevant stakeholders. They avoid the conversion of land use in natural forests and promote the conservation of ecosystem services.

In addition, they contribute to the conservation of natural forests and biological diversity that incentivize enhancing other social and environmental benefits to members of local communities. They take into account actions to address the risks of reversals and incorporate actions to reduce displacement of emissions. For the purpose of this study, its primary topic is these safeguards for REDD+, and its target areas are tropical peat swamp forest ecosystems, which are optimal for the study and working on which is the most efficient (Fig. 37.6). Therefore, we need to clarify the four subjects such as (1) The assessment and development of the rehabilitation options for ecosystem services in a degraded peat swamp and the development of advanced technology for biomass will be clarified with biodiversity conservation by rehabilitation of degraded peat swamp forest, and development of new biomass utilization including non-timber forest products, (2) Construction of systems for water management and optimal peat swamp land use for decreasing emissions will be also the target of research which mainly be focused on the water management system based on the map of underground water flow, Adaptive peat land use system, Evaluation of control of carbon emission, (3) PES (Payment for Ecosystem Services) in a peat swamp forest ecosystem, residents' participation in the commercialization of greenhouse gas emissions reduction, and the creation of regional employment for what the incentive of local community for REDD+, local community participation for the rehabilitation of degraded tropical peat swamp forests, local employment chances by development of new biomass utilization

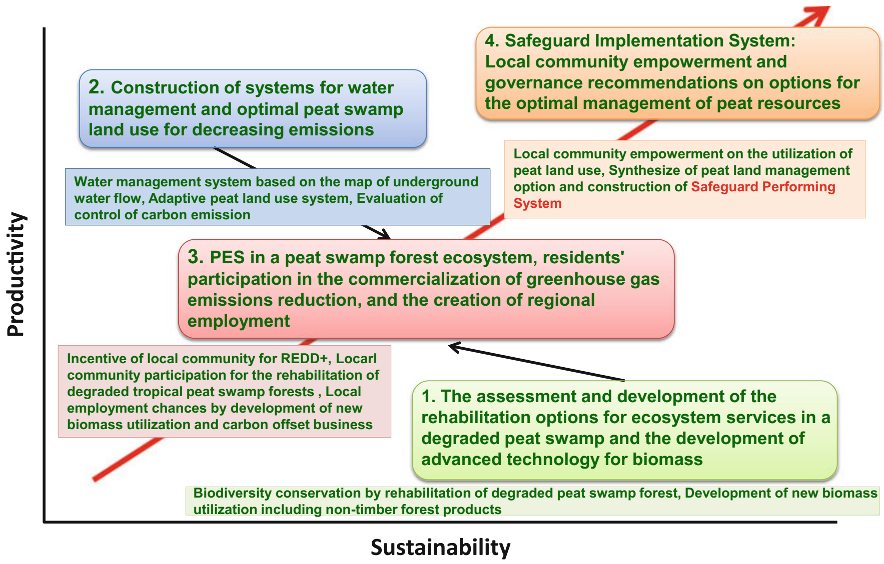

Fig. 37.6 Safegurd performing system on REDD+ at peatland/forest ecosystem

and carbon offset business, (4) Local community empowerment and governance recommendations on options for the optimal management of peat resources by the local community empowerment on the utilization of peat land use, synthesize of peat land management option and construction of Safeguard Implementation System (SIS). This SIS will be final target of the sustainable use/development of peatland/forest.

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Chapter 38
Carbon Credit Current Trend and REDD+ Projects

Noriyuki Kobayashi

Abstract Possibility of carbon credit introduction to tropical peatland is studied by referring several system on carbon credit. The goal of this chapter is to describe the present international and Japanese carbon credit current trend and REDD+ projects. Firstly, I would like to clarify the important role of forest for climate change from the report of IPCC and describe the historical outlook of REDD+. Secondly, the market-based approach is analyzed from the Kyoto Protocol, international market, and carbon-offset. Thirdly, Japanese policy and legal countermeasures on climate change are described, in focusing on a market-based credit system such as the J-Credit system as a domestic scheme and JCM as an international scheme.

Keywords REDD+ • Carbon-offset • J-VER • J-Credit • JCM

38.1 Introduction

With the importance of global environmental issue new concepts of forest function have been recognized since the early 1990s.

The United Nations Statement of Forest Principles (The Principles) defined the concept of Sustainable Forest management as the principle of forest management in 1992. The Principles stated that forest resources and forest lands should be sustainably managed to meet the social, economic, ecological, cultural, and spiritual needs of the present and future generations. The definition of the Principles advocates that appropriate measures be taken to protect and use forests to preserve the multiple value of forests, including, as carbon sinks and reservoirs.

Forest plays an important role in the prevention of global warming by acting as a sink for the removal and storage of carbon dioxide (CO_2). Therefore avoiding deforestation, forest degradation, and enhancement of forest carbon stock are the most important solutions to the problem of global warming.

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The Intergovernmental panel on Climate Change (IPCC) has reported that forest plays an important role in the prevention of climate change.

The IPCC Fourth assessment Report Working Group III (AR4 WGIII) regarding the prevention of global warming with forests reported the most important section as follows. The most effective measure for global warming prevention is appropriate sustainable forest management: “In the long term, a sustainable forest management strategy aimed at maintaining or increasing forest carbon stocks, while producing an annual yield of timber, fiber, or energy from the forest, will generate the largest sustained benefit.”

Mitigation measures in the area of forests have been evaluated as follows: “Forestry can make a very significant contribution to a low cost global mitigation portfolio that provides synergies with adaptation and sustainable development.” Although forests play important roles, the IPCC AR4 WGIII reported that emissions from the forestry sector account for 17.4 % of total world emissions (Barker et al. 2007, 29, 69, 70).

38.2 The Historical Outlook of REDD+

The full name of REDD+ is “Reducing Emissions from Deforestation and forest Degradation and the role of conservation, sustainable management of forest and enhancement of forest carbon stock in Developing countries”.

The rule and modality of REDD+ is considered one of the most important topic to be discussed for the new framework of post Kyoto Protocol starting from 2020.

As in the previous section, deforestation and forest degradation in developing countries account for a large part of global greenhouse gas emissions and are recognized as an important challenge in combating global warming.

In December 2005, at COP11 Papua New Guinea and Costa Rica placed REDD (Reducing Emissions and forest Degradation in Developing countries) on the formal agenda as a proposal. Considerations of measures and positive incentives regarding REDD were included in the “Bali road Map” of COP13 (Kobayashi 2011).

In December 2009, at the Copenhagen COP15 the following three additional activities were agreed to be included in REDD and became REDD+.

- Conservation of forest carbon stock
- Sustainable management of forest
- Enhancement of forest carbon stock

COP16, 2010 in Cancun, safeguards for REDD+ were agreed upon.

The definition of safeguards is not clarified in the COP documents, however the concept is considered as “Important points to be guaranteed for reducing environmental and social impacts in the implementation of REDD+ projects”.

The positive incentives, in other words, economic incentives for REDD+ are very important issues. Various approaches are being discussed at COP including the market-based approach, however no conclusion has been yet made for an appropriate approach.

38.3 Market-Based Mechanisms and Climate Change Policy Approach

38.3.1 International Current Trend of Market-Based Approach

The market based approach is an effective approach to environmental issues and considered more effective than the "command and control" approach.

The Rio Declaration's principle 16 states "National authorities should endeavor to promote the internalization of environmental costs and the use of economic instruments, taking into account the approach that the polluter should, in principle, bear the cost of pollution. National authorities should endeavor to promote the internalization of environmental costs and the use of economic instruments, taking into account the approach that the polluter should, in principle, bear the cost of pollution, with due regard to the public interest and without distorting international trade and investment". This principle indicates, that the market-based approach was recommended as an effective approach for environmental issues.

In Japan, the Basic Environment Act's article 22 stated the importance of economic instruments for environmental protection approaches.

The Kyoto mechanisms of the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) are considered as a typical international market-based approach, so called "flexibility mechanisms". The Kyoto mechanisms include Emissions Trading (ET, Article 17), Joint Implementation (JI, Article 6) and Clean Development Mechanism (CDM, Article 17), and these three mechanisms shall be supplemental to domestic action.

Markets for trading carbon (Carbon dioxide) are called carbon markets and can be categorized in two, as Compliance markets and Voluntary markets (Kobayashi 2008). Credits for compliance markets are used for compliance purposes in order to reach emission reduction targets, and the following are the compliance markets around the world. As an international market, Kyoto protocol Emission Trading is being implemented among industrialized (Annex I) countries. As a regional market, EU-ETS is promoted among EU countries. As a domestic market, New Zealand ET, Australian ET, and US domestic market schemes are in place, an example of this is the Regional Greenhouse Gas Initiative (RGGI). The Tokyo metropolitan government ET scheme is also considered as a compliance market.

Voluntary markets are expanding worldwide, as international markets, the Verified Carbon Standard (VCS) is well known. In Japan, the Japan Verified Emission Reduction scheme (J-VER) was established in 2008 (Kobayashi 2012).

38.3.2 COP17 Agreement on Market-Based Mechanism

Despite problems of carbon markets as lessons learnt from EUETS such as drastic drops of carbon price caused by gaps between demand and supply of carbon credits, a market-based approach will be playing an important role for climate change policy. At COP17, "new market mechanisms" were agreed for the target at 2020 and the next framework from 2020, as well as the appropriate market-based approach, it was agreed that it could be developed by the COP for REDD+.

Two different types of "new market mechanisms" were agreed at COP17 and carbon credit was expected to be used for the target in 2020 and for the new framework from 2020.

The following four paragraphs of COP17 Draft decision [−/CP.17] are considered to be important from the view point of a market-based mechanism, and the essentials of each paragraph are indicated as follows (Kobayashi 2012).

- Parties may, individually or jointly, develop and implement such approach in accordance with their national circumstance. (Preface of Chapter E)
- Various approaches must meet standards that deliver real, permanent, additional and verified mitigation outcomes (para79)
- A new market based mechanism, operating under the guidance and authority of the COP to promote mitigation action, may assist developed countries to meet part of their mitigation target or commitments under UNFCCC (para83).

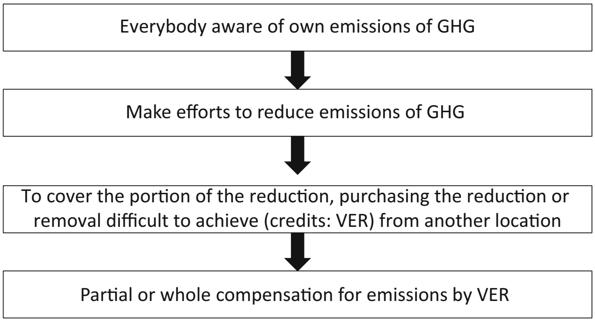
Regarding REDD+ market-based mechanism

- Consider that, in the light of the experience gained from current and future demonstration activity, an appropriate market-based approach could be developed by COP to support result-based action by developing country Parties (para66).

38.4 About the Carbon-Offset

38.4.1 Outline of Carbon-Offset

The prevention of global warming will require wide ranging efforts, voluntarily in daily life both by governments as well as by other organization and carbon-offset is one of the measures that are to be taken. The effort of carbon-offset which Future Forests Co. in Britain made in 1997 is known as the first of this kind of project. Since then, efforts involving this have multiplied in the market and the size of the transactions in the carbon market has expanded. The credit used for carbon-offset is referred to as VER (Verified Emission Reduction), differentiating it from the credit of the Clean Development Mechanism (CDM) of the Kyoto Protocol. Although the idea of carbon-offset is historically common in projects related to forests, it has penetrated into a wide range of fields such as clean energy including biomass energy.



VER: Verified Emission Reduction

Fig. 38.1 Concept of carbon-offset

Particularly, the purchase of carbon-offset credits of projects related to forests is an effort to prevent global warming which is familiar with citizens and companies in many countries. For examples, in Japan, private companies utilize the carbon-offset credit for CSR purpose and sales promotion of so called "carbon-offset goods".

38.4.2 The Definition and Concept of Carbon-Offsets

Following is a representative definition of carbon-offset, and Fig. 38.1 is a simple illustration of this definition.

> A system whereby all of society: citizens, businesses, NPOs/ NGOs, local government, national government, etc., are aware of their own emissions of greenhouse gases and make an effort to reduce them autonomously by purchasing the reduction credit or capture of emissions credit occurring in another location to cover the portion which is difficult to reduce (known as credits) or, partially or wholly compensating for emissions by establishing activities or projects to reduce or absorb emissions in another location. (Ministry of the Environment of Japan 2008)

38.5 Japanese Policy on Climate Change and the Market-Based Mechanism

38.5.1 Japanese Policy on Climate Change and Legal Measures on Climate Change

The Japanese government promotes the policy for climate change by executing. "The Act on Promotion of Global Warming Countermeasure" (1998, revised 2002, 2005, 2006, 2008 and 2013).

The main object of this act is for attaining the "Kyoto Target" of the first commitment period of the Kyoto Protocol.

Japan has submitted to UNFCCC on Jan. 2010, 25 % as an emission reduction target of Green House Gasses (GHGs) by 2020. However this target is currently reviewed due to the Great East Japan Earthquake and nuclear disaster, and a new target was not decided as of Aug. 2013.

For the new target achievements in 2020, “the Bill for the Basic Act on Global Warming Countermeasures” (Bill) was decided by the Cabinet in 2010, however this bill was not approved by the Diet. This Bill included domestic emission trading schemes (ETS) as one of the key policy measures.

The Liberal Democratic Party of Japan took over the government in Nov, 2012. Since then, Japanese policy on climate change has changed, and the important points are as follows;

- Not participating in the second commitment period of Kyoto Protocol (decided at COP18 Nov. 2012)
- “The Bill for the basic Act on Global Warming Countermeasure” was rejected
- Emission reduction target in 2020 shall be revised starting from scratch

The Act on Promotion of Global Warming Countermeasure was revised in May. 2013. The main object of this act was changed from attaining the “Kyoto Target” to promotion of a “Plan for countermeasure of global warming”.

38.5.2 Current Market-Based Credit System in Japan

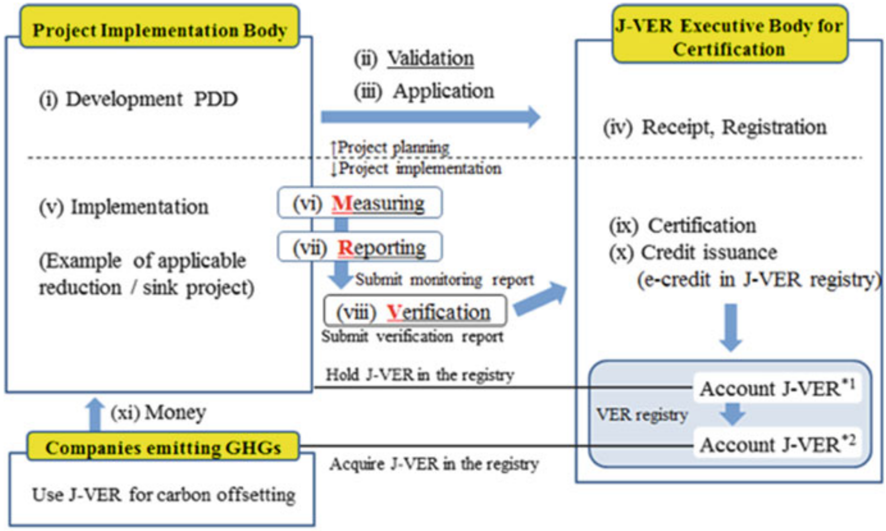
In Japan, two market-based credit systems have been promoted namely “the J-VER system” and “Japan’s domestic CDM system” since 2008.

Outline of J-VER system: The Japan-Verified Emission Reduction (J-VER) is managed under the ministry of Environment (MOE) as a carbon-offset system in Japan. Initiatives by MOE are the following.

The credits under the J-VER systems include credits for carbon sink capture volume credit and emissions reduction credit through biomass energy. In order to promote the expansion of carbon offsetting, the Ministry of Environment released “the Guideline” in February 2008 as general guidance, “The Implementation Rules for offsetting and Carbon Credit” in November 2008 and The Forest J-VER Guideline in March 2009.

In order to promote J-VER activities by prefectural governments, “The prefectural J-VER program” scheme was started in February 2010. The credits needed for carbon offsetting are called “Japan Verified Emission Reductions (J-VER)”. As of September 2011, the following types of forest projects are on the “J-VER” methodologies list:

- R001: Forest management (promotion of thinning),
- R002: Forest management (promotion of sustainable forest management),
- R003: Forestation (Aforestation and Reforestation activities).



*This scheme is based on ISO14064-2, ISO14064-3
*Validation and verification are by validator and verifier accredited based on ISO14065
(source : Adopted from MOEJ materials)

Abbreviations:
*1: Account of Project Implementation Body
*2: Account of Companies Emitting GHGs

Fig. 38.2 J-VER system and procedure

The Japanese Government has chosen "Forest Management" Article 3 paragraph 4 as an activity to fulfill forest carbon capture commitments of the Kyoto Protocol. Japan has selected the stock change method in accordance with the IPCC Good Practice Guidance (GPG), and the J-VER forest project this method as a model. The stock change method is a method whereby the annual capture volume is calculated from variations in the total stock volume of forests each year during the first commitment period of the Kyoto protocol.

The scheme and Procedure of J-VER: The scheme and flow of J-VER are shown in Fig. 38.2 and the procedures are described from (1) to (8) below;

(1) The project Implementing Body (Implementer) develops the Project Design Document (PDD) and (2) being validated by a third party, (3) will apply to EB. Then, (4) PDD and Validation reports are examined and judged by the Executive Body (EB) for receipt and registration. (5) The implementer carries out the project, and (6) the emissions and captured volume are monitored, (7) the results are reported and verified by a third party organization, (8) the results of the verification are submitted to the EB, then the reduction or capture of emissions are certified. In terms of the Kyoto Protocol CDM, (2) is equivalent to validation, (7) is equivalent to verification and (8) is certification.

Record of J-VER and lessons learnt from the experience with J-VER: The credits under J-VER system include credits for carbon sinks by forest projects and emission reduction credits by energy projects. As of February 2013, 233 J-VER projects have been registered and certified about 630,000 CO_2 tons.

Forest projects constitute 55 % of the 233 J-VER registered projects and 94 % of the certified CO_2 volume. This figure shows that forest projects are one of the important characteristics of J-VER (Ministry of Environment of Japan, 2014).

The lessons learnt from carbon-offset in Japan are as follows:

- Firstly, the scheme should be based on an international recognized scheme such as the CDM scheme and international standards such as ISO (ISO 14064(1), 14064(2), 14065).
- Secondly, the establishment of a scientifically reliable and economically feasible MRV system is essential for accountability and evaluation of forest carbon-offset.
- Thirdly, the issuance and registry of credit systems are very important for transparency of credit (income in money) flows for project participants.
- Fourthly, the participation of local people and municipality offices in the MR process are important for a better understanding of carbon-offset and to maintain the project in good order.

Outline of Japan's domestic Clean Development Mechanism (CDM) system: The domestic CDM system is managed mainly by the Ministry of Economy Trade and Industry (METI) together with MOE and the Ministry Agriculture, Forestry and Fisheries (MAFF). An outline of the workings of this system is as follows;

- Large companies and small and medium scale enterprises (SMEs) conduct joint projects on GHG reduction.
- Targets of this system are energy saving projects and civilian activities for emission reduction. Forestry projects (carbon sink projects) are excluded, but forest biomass energy projects are included.
- Large companies provide the necessary capital in exchange for domestic credits which are utilized to achieve voluntary action plan goals by the industries' federation for the Kyoto protocol, CSR and offsets.

The scheme and flow of the domestic CDM system is shown in Fig. 38.3.

As of February 2013, 1186 projects 650,000 CO_2 tons were certified.

38.6 New System for Domestic and Overseas by Japanese Governments

Japanese governments are implementing new scheme for domestic and overseas.

38.6.1 Outline of the Japan Credit System (J-Credit System)

Background of establishment of J-Credit System: As described above, two market-based credit systems co-exist, and yet there is some confusion about the

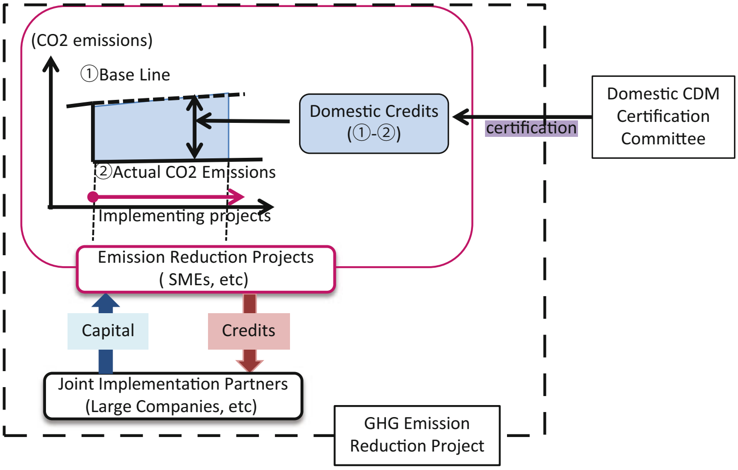


Fig. 38.3 The domestic CDM scheme and procedure (Sources: METI)

existing two systems. "The study group on the state of the new credit system" was established on April 2012 by MOE, METI and MAFF and the conclusions are as follows:

- Integration of the J-VER system and the domestic CDM system in order to avoid confusion of the two coexisting systems and to enhance the credit system.
- The new system should be established based on the four concepts below;
  - Adopt the merit of the two current systems
  - Viable environment but also convenient, applicable to a broad range of cases
  - Support regional effort towards reduction of GHGs and local revitalization
  - Highly evaluated internationally and used as a reference by international efforts to establish similar systems

Essential point of J-Credit System: The J-Credit system was launched in April 2013. The system was designed with many similarities with J-VER system and the essential points are as follows.

The project is defined as activities for reduction of emission or increasing removal of Green House Gases (GHGs). The types of projects are emission reduction projects and forest projects such as J-VER forest project.

Methodological and additional projects are defined by methodology list. As of July 2013, out of 56 methodologies, there are 37 energy use reduction projects, 9 renewable energy projects, 3 manufactures process project, 1 waste management project and 1 forest project.

Validation and verification are made by validators and verifiers of the authorized third party. MRV is based on international standards of ISO 14064-2, 14064-3 and ISO 14065.

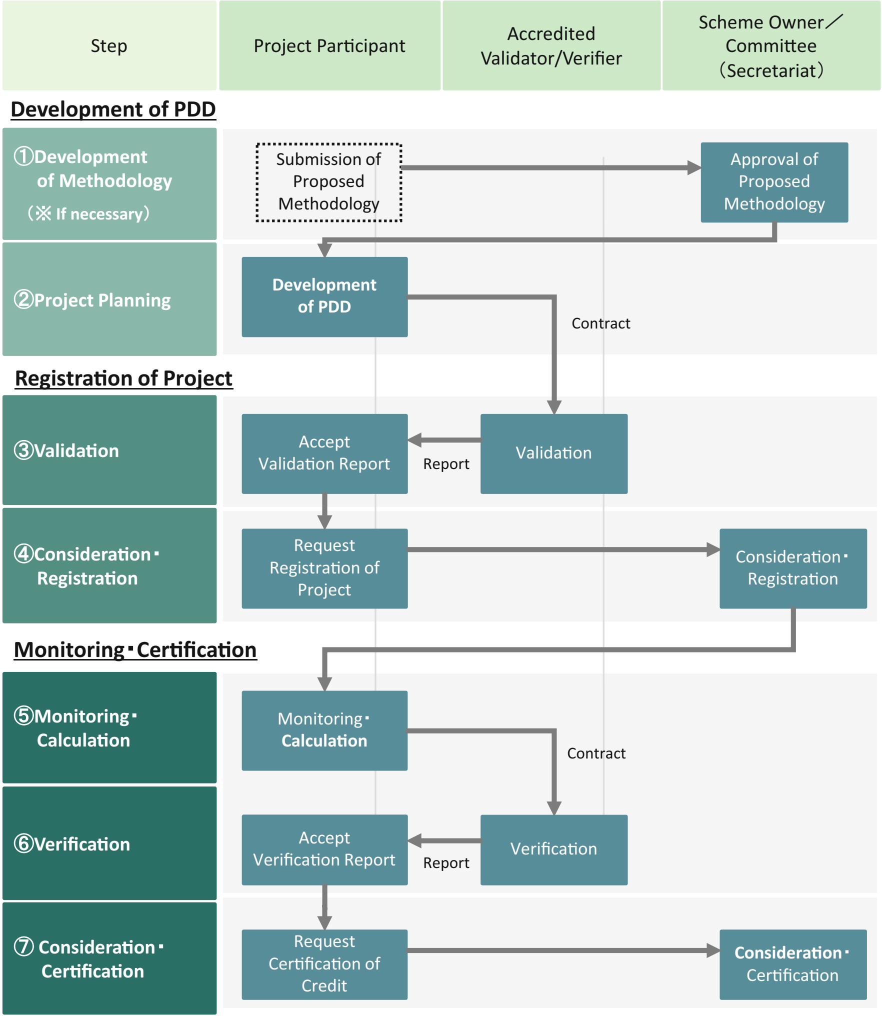


Fig. 38.4 J-Credit system scheme and procedure (Sources: MOE)

The purpose of using credit are for “commitment to a low carbon society”, carbon-offset and Act on promotion of Global Warming Countermeasure, etc.

J-Credit system scheme and procedure: The scheme and procedure are developed based on J-VER and the domestic CDM scheme is however very similar to J-VER scheme as shown in Fig. 38.4.

38.6.2 *Outline of the Joint Crediting Mechanism (JCM)*

Aim of JCM: The aim of JCM is the establishment of "win -win" relations between JAPAN and developing counties through promotion of technology transfer and emission credits.

The Japanese government will make agreement with partner countries for promotion of JCM. JCM projects include emission reduction projects such as power sector, transportation sector, industrial sector, agricultural sector, etc., also including REDD+ projects.

Japanese Government has started negotiation with developing countries for agreement of JCM, and concluded agreements with Mongolia, Bangladesh, Ethiopia, Kenya, Maldives and Vietnam as of July, 2013, continuing negotiation with Indonesia and other interested countries.

The concept and purpose of JCM: Firstly, to facilitate diffusion of leading low carbon technologies, products, systems, services, and infrastructure as well as implementation of mitigation actions, and contributing to sustainable development of developing countries.

Secondly, to appropriately evaluate contributions to GHG emission reductions or removals from developed countries in a quantitative manner, through mitigation actions implemented in developing counties and use those emission reductions or removals to achieve emission reduction targets of the developed countries.

Thirdly, to contribute to the ultimate objective of the UNFCCC by facilitating global actions for emission reductions or removals with supplement of CDM (Government of Japan, 2013).

Japanese Government support for JCM: The Japanese Government has started the Bilateral Offset Credit Mechanism (BOCM) from 2010 and moved to JCM from 2012. Concept and scheme of BOCM and JCM (as shown in Fig. 38.5) are almost

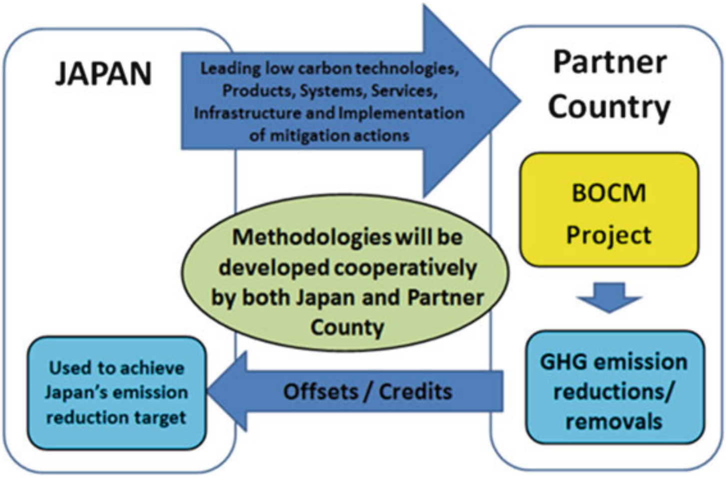


Fig. 38.5 Concept of JCM (Sources: Materials by Government of Japan, July 2013)

similar. From the fiscal year (FY) 2010–2012, 191 BOCM feasibility study (F/S) projects were supported by the Government; and the F/S projects in FY 2012 are as follows (Government of Japan, 2012):

- MOEJ

  25 projects were selected from 15 countries
  Indonesia three projects (one project REDD+)

- METI-J

  As the first stage 36 project were selected from 15 countries
  Indonesia 11 projects
  As the second stage 18 project were selected

38.7 Carbon Credit Mechanisms for Peatland Conservation

38.7.1 REDD+ and Carbon-Offset VER Scheme

The REDD+ framework is expected to have the potential to create a new scheme for evaluating tropical forest and peat land in relationship with climate change.

It will take more time to finalize modalities and procedures for the operation and financial mechanism of REDD+.

As the practical way before 2020, the financial mechanism of REDD+ can be utilized with a market-based mechanism of carbon-offset scheme.

The J-VER scheme or J-Credit scheme can be applied to REDD+ carbon-offset market-based mechanisms such as I-VER in Indonesia, T-VER in Thailand and K-VER in Korea. Those VER schemes can be established through linkage with an international network as a first step among Asian countries. Then, carbon-offset credits of REDD+ can be tradable internationally.

The framework of MRV for the VER scheme of carbon-offset should be compliant with the international standards such as ISO-14064, ISO-14065 and VCS.

"The positive incentive", credit value of REDD+ should evaluate not only carbon value but also environmental, social value of forest, peat land, and the credit price should cover the mitigation cost and transaction cost of the project.

38.7.2 Socio-Economic and Environmental Value of Carbon Sequestration by Forest and Peat Land

The REDD+ is expected to have the potential to create a new scheme of evaluation in relation to tropical forest and climate change. As shown in Fig. 38.6, the value of carbon sequestration by forest should be evaluated altogether with social and

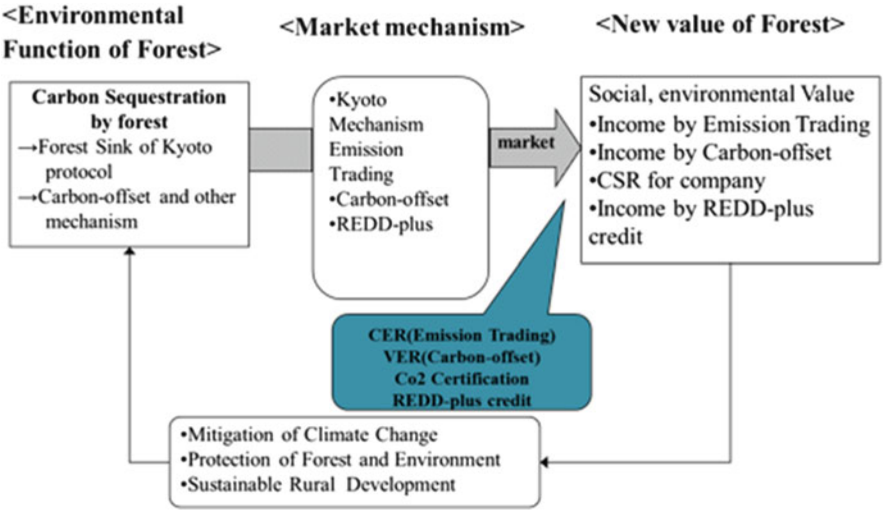


Fig. 38.6 Socio-economic and environmental value of carbon sequestration by forest and peat land

environmental values. Income from the credit should be contributed for climate change mitigation, protection of forest, increase in the people's income, and sustainable rural development.

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Chapter 39
The Potential for REDD+ in Peatland of Central Kalimantan, Indonesia

Yuki Yamamoto and Kenji Takeuchi

Abstract This chapter investigates the potential for REDD+ in peatland of the Central Kalimantan Province of Indonesia, where a large peatland area captures substantial amounts of carbon. We briefly review the key features of REDD+ that have been discussed in international negotiations as well as evaluate the estimated break-even prices for emission reductions through forest conservation. On the basis of estimation results, we conclude that, while REDD+ would be potentially beneficial for mitigating global climate change as well as beneficial to the local community, many issues need to be better understood before arriving at a workable institutional designs. Our estimates for the Central Kalimantan case show that the break-even price for carbon is USD 15.45 per ton of carbon, which is far below the average price of carbon credits in 2009. This figure would be reduced to USD 0.71 per ton of carbon, when we include carbon captured in peat. On the other hand, the break-even price becomes much higher than the price of the carbon credits when we consider the possibilities of oil palm plantations. We also discuss the significant roles of economic and noneconomic incentives in successfully implementing REDD+ thorough the households' fire prevention activities.

Keywords REDD+ • Indonesia • Central Kalimantan • Break-even price • Fire prevention

39.1 Introduction

Forests function as important carbon sinks through the process of photosynthesis. Deforestation and degradation of forests on the contrary leads to the release of carbon dioxide into the atmosphere. According to IPCC (2007), 1.6 gigatons of

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carbon are emitted every year owing to deforestation. This amounts to 20 % of global greenhouse gas (GHG) emissions, which is more than that emitted by the transport sector. When we consider emissions from forests, countries such as Indonesia, Brazil, and Malaysia are comparable to Russia, Japan, and Germany in terms of their total GHG emissions (Myers Madeira 2008).

The REDD+ (Reducing Emissions from Deforestation and forest Degradation in developing countries; and the role of conservation, sustainable management of forests, and enhancement of forest carbon stock) activity is an attempt to reduce carbon dioxide emissions due to deforestation and forest degradation in developing countries. Attempts to mitigate climate change have mainly focused on industrial emissions, and little attention has been paid to emissions resulting from deforestation. However, the role of forests in carbon fixation and the speed of deforestation throughout the world both warrant promotion of conservation efforts in forest areas, especially in developing countries.

Here, REDD+ can be regarded as a LULUCF (Land Use, Land-Use Change and Forestry) activity in developing countries. Since 1990, articles 3.3 and 3.4 of the Kyoto Protocol allow developed countries to count afforestation, reforestation, and other forestry activities to comply with the targets of the protocol. After COP7, afforestation and reforestation in developing countries are categorized as Clean Development Mechanism (CDM) projects under this protocol. The REDD+ differs from these activities in its focus on the prevention of degradation and deforestation in developing countries.

Recent discussion of climate mitigation has emphasized the potential of REDD+. At COP11 in Montreal in 2005, Papua New Guinea and Costa Rica proposed, on behalf of the Coalition for Rainforest Nations, a mechanism to issue carbon credits for avoiding deforestation in developing countries. In response to this proposal, REDD has been taken up by the SBSTA (Subsidiary Body for Scientific and Technological Advice) of the UNFCCC (United Nations Framework Convention on Climate Change).

The Bali Action Plan adopted at COP13 in 2007 called for more active national and international action, including the following: "Policy approaches and positive incentives on issues relating to reducing emissions from deforestation and forest degradation in developing countries; and the role of conservation, sustainable management of forests, and enhancement of forest carbon stocks in developing countries." Following the Bali Action Plan, the concept of REDD was expanded to REDD+, taking into account the role of forest conservation, sustainable management, and forest carbon sinks. In addition, COP13 required the relevant organizations and parties to implement verification activities for institution building in the future. One example is the Forest Carbon Partnership Facility by the World Bank. In addition, discussion of financial support was advanced, as the Norwegian government promised EUR 1.8 billion over a 5-year period. On the basis of the Bali Action Plan, the Ad Hoc Working Group on Long-term Cooperative Action (AWG-LCA) was established, and here policy relating to REDD+ was discussed. Currently, discussion on REDD+ is mainly addressed by AWG-LCA and SBSTA.

In 2009, COP15 confirmed the effectiveness of forest conservation in lessening climate change mitigation and the necessity of the REDD+ activity. The Copenhagen Accord includes the following statement: “We recognize the crucial role of reducing emission from deforestation and forest degradation and the need to enhance removal of GHG emission by forests and agree on the need to provide positive incentives to such actions through the immediate establishment of a mechanism including REDD+, to enable the mobilization of financial resources from developed countries.” Although this does not differ substantially from the Bali Action Plan, the acknowledgement of financial support from developed countries was advanced at COP15. In order to promote mitigation and adaptation, technology transfer, and capacity building in developing countries, financial assistance of USD 30 billion from 2010 to 2013, with an additional USD 100 billion per year until 2020, was included in the Copenhagen Accord. In addition, Australia, France, Japan, Norway, the United Kingdom, and the United States jointly offered USD 3.5 billion in support of REDD+. The accord also agreed that developing countries would report their reduction actions, subject to own Measurement, Reporting and Verification (MRV). This is the first time the word of “MRV” is enshrined in UNFCCC agreement.

In COP18, held at Doha, Qatar in December 2012, it was decided to extend the Kyoto Protocol until 2020 and to create a new international framework after 2020. Currently, there are two lines of proposals: to include major emitting developing countries such as China and India or to require only developed countries to accept emission reduction targets. To overcome this conflict between developing and developed countries, fund transfer mechanisms such as REDD+ would play a significant role.

Through these international negotiations, REDD+ is becoming increasingly important in the global attempt to mitigate climate change. Many NGOs and international organizations are working on pilot projects for REDD+. However, there is no consensus on the framework for implementing REDD+ or the kinds of incentives that should be offered. One reason is that it is not easy to establish a system for MRV in developing countries. Another is that it is not easy to reach a consensus on institutional arrangements that are agreeable to every country.

This chapter investigates the potential for REDD+ in Indonesia. Specifically, we focus on Central Kalimantan in Indonesia, where the extensive peatland contains vast amounts of carbon. We estimate the cost of REDD+ for this area and analyze practical hurdles in its implementation from an economic point of view.

The next section reviews the basic features of REDD+ as well as estimates of the break-even price (BEP) in various parts of the world. In Sect. 39.3, we introduce our estimates of the BEP in Central Kalimantan, Indonesia (Yamamoto and Takeuchi 2012). Section 39.4 provides key features in the implementation of REDD+ in Indonesia. Section 39.5 concludes the chapter.

39.2 Estimating the Cost of REDD+

39.2.1 Definition of REDD+

Forest conservation can be the least expensive measure for climate change mitigation (Nabuurs et al. 2007). A number of studies have analyzed the extent to which the reduction of carbon emissions can be realized under various carbon prices (Osafo 2005; Osborne and Kiker 2005; Sathaye et al. 2005; Silva-Chavez 2005; Vera-Diaz and Schwartzman 2005; Grieg-Gran 2006, 2008; Kindermann et al. 2006, 2008; Sohngen and Beach 2006; Bellassen and Gitz 2008; Strassburg et al. 2009). In this section, we provide an overview of some of the results of these studies.

The basic function of REDD+ is to offer developing countries an opportunity for financial support from developed countries in response to avoided carbon emissions through forest conservation. In exchange, developed countries can acquire carbon credits, which can be used for compliance with carbon emission targets. In this context, REDD+ could play a role in reducing conflicts between developed and developing nations regarding global warming.

The mechanisms currently under consideration can be broadly classified as either fund-based or market-based mechanisms (Parker et al. 2009; Isenberg and Potvin 2010). Under the fund-based scheme, money is distributed to participating governments on the basis of performance of forest protection. Under the market-based system, credit is issued for emission reductions by REDD+ and developed countries trade them in the carbon market.

Payments to developing countries are based on the difference between the actual amount of forest clearance and the baseline that defines the amount of forest clearance estimated from the trend of deforestation in the past. The setting of the baseline can change the amount of the payment to the country, and hence, it is not easy to reach a consensus on a baseline agreeable to every country. To obtain more funding, a country may have an incentive to exaggerate the seriousness of its current deforestation. If there is a possibility that deforestation is suppressed by changing conditions, the current deforestation rate leads to an overestimation of the effect of REDD+. In this regard, baseline settings in REDD+ are subject to issues similar to additionality in CDM (Asuka and Takeuchi 2004).

For the REDD+ mechanism to function effectively, funds obtained by forest conservation must be larger than the benefits obtainable by development for commercial logging and agriculture. Thus, the size of the related opportunity cost (the benefit of next best alternative) is very important for the evaluation of REDD+. The opportunity cost can be estimated in two ways: by a bottom-up analysis and by a global model analysis. In the next subsection, we review the results with a bottom-up analysis that calculates the profits obtained from various land use changes.

39.2.2 Bottom-Up Analysis

In bottom-up analysis, the opportunity cost is evaluated by estimating the benefits that accrue to local residents from the transformation of forests for agriculture, commercial logging, and cattle raising. The advantage of this analysis is that it offers an insight into appropriate institutional designs by investigating local motivations for forest development. The drawbacks are that this analysis lacks comprehensiveness and does not consider the price change of agricultural products and forest products by land use changes. Table 39.1 summarizes the bottom-up analysis results. The estimated opportunity costs range from USD 0.15 to USD 30 per ton of carbon. Many of the estimates are lower than the market carbon price. This suggests that forest conservation is one of the cheapest measures for mitigating climate change.

Vera-Diaz and Schwartzman (2005) focus on deforestation in Brazil. The GHG emissions from Brazil account for 2.5 % of the world's total emissions; 75 % of emissions from Brazil are due to deforestation. Cattle raising, soybean cultivation, and logging are the major causes of deforestation. Assuming that cattle raising

Table 39.1 Summary of bottom-up analysis

Country	Cost (USD/ha)	Cost (USD/tC)	Changes in land use	Sources
Brazil	449–1,699	3–11	Logging, cattle raising	Vera-Diaz and Schwartzman (2005)
	2,215–3,465	14–22	Logging, cattle raising	Vera-Diaz and Schwartzman (2005)
	713	–	Logging, cattle raising, soybeans	Grieg-Gran (2008)
Ghana	1,776	30	Maize, cassava	Osafo (2005)
	1,090	–	Maize, cassava	Grieg-Gran (2008)
Bolivia	886	4.43	Soybeans	Silva-Chávez (2005)
	1,522	–	Cattle raising, soybeans	Grieg-Gran (2008)
Guyana	6.36–24.56	0.18–0.71	Logging (aboveground carbon only)	Osborne and Kiker (2005)
	6.36–24.56	0.15–0.58	Logging (including underground carbon)	Osborne and Kiker (2005)
Cameroon	2,221	30.08	Plantains, cassava	Bellassen and Gitz (2008)
	1,811	–	Grain, cocoa	Grieg-Gran (2008)
Congo	1,811	–	Grain, cocoa	Grieg-Gran (2008)
Indonesia	2,008	–	Oil palm, rubber, rice	Grieg-Gran (2008)
PNG	2,744	–	Oil palm, subsistence crops	Grieg-Gran (2008)
Malaysia	1,991	–	Oil palm, rubber, rice	Grieg-Gran (2008)

Nominal values. The numbers from Bellassen and Gitz (2008) are converted from costs per ton of carbon dioxide to costs per ton of carbon. The results of Grieg-Gran (2008) consider logging revenue occurs after harvesting the timber, the minimum amount of compensation for avoiding deforestation, that is, the BEP for carbon, can be estimated. The BEP per hectare is estimated as USD 1,699, which is comprised of USD 1,435 for the one-time logging and USD 264 for cattle raising after the logging. Assuming 155 tons of carbon for the carbon stock per hectare, USD 1,699 per hectare is equivalent to USD 11 per ton of carbon. Assuming a lower logging revenue, the BEP becomes USD 449 per hectare or USD 3 per ton of carbon.

Osafo (2005) examines the effect of REDD+ in Ghana. Assuming that logging and agricultural conversion are the main causes of deforestation, the BEP is estimated by dividing the sum of the logging revenue and the agricultural revenue by carbon emissions. The revenue from logging is estimated as USD 498 per hectare, and the present value of the agricultural revenue for cassava and maize is estimated as USD 1,278 per hectare at a 10 % discount rate. Assuming 60 tons of carbon per hectare, the BEP is estimated to be approximately USD 1,776 per hectare, equivalent to USD 30 per ton of carbon. Using a similar time scale and discount rate, Silva-Chávez (2005) estimates the BEP in Bolivia to be USD 886, equivalent to USD 4.43 per ton of carbon.

Osborne and Kiker (2005) estimate the BEP in the Republic of Guyana. The revenue from large-scale timber production is considered to be the opportunity cost of forest conservation. By avoiding logging, emissions of 34.76 tons of carbon per hectare can be prevented. By including the underground carbon, the estimate becomes 42.37 tons of carbon. The minimum compensation for the logging revenue thus becomes USD 0.18 per ton of carbon at a 15 % discount rate and USD 0.71 per ton of carbon at a 3 % discount rate when we consider only aboveground carbon. When underground carbon is included, the costs are USD 0.15 per ton of carbon at a 15 % discount rate and USD 0.58 per ton of carbon at a 3 % discount rate. These amounts are calculated by dividing the discounted net present value (NPV) of timber production revenue for 50 years by the carbon emissions associated with the agricultural production.

As the discount rate is assumed to be higher, the present value of compensation for avoiding deforestation becomes lower. It should be noted that the discount rate here refers to the rate employed in the calculation by a timber production company. Including the underground carbon in the estimate lowers the amount of compensation. This may seem odd, but note that preventing more carbon emissions on a hectare of land makes REDD+ cheaper.

Grieg-Gran (2008) updates Grieg-Gran (2006), which was carried out for the Stern review (Stern 2007). Countries included in the analysis are Bolivia, Brazil, Cameroon, the Democratic Republic of the Congo, Ghana, Indonesia, Malaysia, and Papua New Guinea. The target is to halve the current global deforestation rate (13 million hectares per year). Opportunity costs for alternative land use in the eight countries were adopted from existing research. The total cost becomes either USD 4 billion or USD 8 billion, depending on the inclusion of revenue from selective logging before slash-and-burn farming. When the revenue from logging is excluded, 39 % of the total cost is due to oil palm plantations and 71 % of the total cost is incurred in Brazil and Indonesia.

39.3 BEP in Central Kalimantan

This section introduces the estimation of the BEP by Yamamoto and Takeuchi (2012). In Central Kalimantan, rice and rubber cultivation have been two main causes of deforestation. According to Grieg-Gran (2008), these activities have accounted for 49 % of deforestation, with oil palm plantation and cassava cultivation accounting for the rest (32 % and 19 %, respectively).

Yamamoto and Takeuchi (2012) calculate the economic revenue from deforestation as the NPV of agriculture over a commitment period discounted by 10 %. To obtain the BEP, the total NPV is divided by the total carbon density of a hectare of forestland. The average agricultural revenue per hectare (R) is obtained using the following formula (Bellasen and Gitz 2008):

$$R = V_l + \theta \sum_{t=0}^{T} \left(\frac{1}{1+r} \right)^t \times V_s + (1-\theta) \sum_{t=k}^{T} \left(\frac{1}{1+r} \right)^t \times V_g,$$

where T is the commitment period of forest protection, V_l is the one-time net revenue from logging per hectare, V_s is the net revenue from rice cultivation per hectare, and V_g is the net revenue from rubber cultivation per hectare. Rice cultivation per hectare of expanding agricultural land is denoted by θ, and the discount rate is denoted by r. We assume $k = 11$: as it takes 11 years for a rubber tree to mature and to start to generate revenue from rubber production.

The revenue from forest protection per hectare (R^f) is obtained by multiplying the carbon density (C) by the carbon price (P_c):

$$R^f = C \times P_c.$$

To achieve forest protection, R^f must outweigh the revenue from developing the forest, R. We define $P^*{}_c$ as the minimum carbon price that satisfies the condition

$$P_c^* = \frac{R}{C}.$$

We call $P^*{}_c$ the BEP that becomes the price equivalent for the forest protection.

The parameters used to estimate the BEP are provided in Table 39.2. It is assumed that on average, two-fifths of 1 ha of additional agricultural expansion is devoted to rice cultivation and three-fifths, to rubber tree cultivation. This is adopted from Grieg-Gran (2008) who assumes the contributions of rice production and rubber production to deforestation in Indonesia as 19 % and 30 %, based on subjective assessments from qualitative statements in the literature. We use the ratio between the two values (2/5) as the share of rice production. The period committed to forest preservation is 30 years.

The estimated average revenue from rice and rubber production over the 30-year period is USD 3,477 per hectare. We used the producer price of rice and rubber in Indonesia in 2008 as reported by FAO (2010) and estimated what it would be

Table 39.2 Parameters used in the analysis

Parameter	Estimate used in models
r discount rate	10 %
θ share of rice production per hectare	2/5
T period of forest protection commitment	30 years
Ps price of rice	\$0.32/kg
P_g price of rubber	\$0.87/kg
W minimum wage	\$0.68/h
C carbon density	225 t/ha
C_p carbon density in peatland	4,863.75 t/ha

Table 39.3 Estimates of BEP

Parameter	Result
Rice net revenue per hectare (V_s)	\$60.1
NPV of rice production per hectare	\$600.8
Rubber net revenue per hectare (V_g)	\$1,643.2
NPV of rubber production per hectare	\$5,393.7
Average agricultural revenue per hectare (R)	\$3,476.5
BEP of carbon ($P^*{}_c$)	\$15.45
BEP of carbon for peatland ($P^*{}_p$)	\$0.71
BEP of CO_2	\$4.21

in 2010 by applying the inflation rate. We used 225 tons per hectare as the carbon density for Indonesia. This figure is calculated by $350 * 0.47 * 1.37 = 225$, where 350 is a ton of aboveground biomass for tropical moist forests in insular Asia, 0.47 is the carbon fraction of aboveground biomass (tropical and subtropical), and 1.37 is the conversion rate from aboveground to total biomass in a tropical rainforest (IPCC 2006). Jagau et al. (2012) also suggest that the carbon density of forest in peatland of Central Kalimantan is 250 tons of carbon per hectare.

Estimated BEP depends on different assumption of carbon densities. When we assume 56.54 tons of carbon per hectare, the lower bound estimates from Dharmawan et al. (2013), the BEP becomes USD 34.54 per ton of carbon. Further, the BEP becomes much lower when taking below-ground carbon into consideration. Dharmawan et al. (2013) reported that the total carbon stock in peatland in Central Kalimantan ranges from 2,994.65 for medium density to 4,863.75 for high density. To achieve BEP with peatland $P^*{}_p$, the total NPV is divided by the total carbon density of a hectare of peatland C_p as follows:

$$P_p^* = \frac{R}{C_p}.$$

The BEP is estimated to reach USD 15.45 per ton of carbon, USD 4.21 per ton of carbon dioxide, or USD 0.71 per ton of carbon for peatland (Table 39.3). The average carbon price of EU ETS in 2009 is USD 46.48 per ton of carbon or USD 12.7 per ton of carbon dioxide (World Bank 2010). Therefore, the carbon revenue clearly outweighs the agricultural revenue in Central Kalimantan.

Next the analysis and estimate is extended to the total compensation across Central Kalimantan Province. The amount of the compensation payment is determined by the realized deforestation rate (with REDD+ policies) compared with the expected deforestation rate (without REDD+ policies). According to the Indonesian Ministry of Forestry, the forest area in Central Kalimantan Province was reduced from 9.48 million hectares in 2002 to 8.9 million hectares in 2003, and it was assumed that the deforestation rate is approximately 6 % per year. At this rate, the forest area would be 5.75 million hectares in 2010 and 0.88 million hectares in 2040. If Central Kalimantan Province successfully prevents deforestation from 2010, the forest area maintained would be 5.75 million hectares in 2040. Thus, the size of the protected forest would be 4.87 million hectares (5.75 ha minus 0.88 ha). Multiplying the estimated BEP per hectare by this figure, the compensation payment to Central Kalimantan Province would amount to USD 16.9 billion.

The above analysis does not consider the potential gains from oil palm plantations. When the revenue by oil palm development is included, the BEP becomes much higher than the price of the carbon credit value. With high productivity and creating employment in rural communities, oil palm plantations have played a significant role in Indonesian economic growth and poverty mitigation of small households (Susila 2004). Indonesia has been increasing the provision of oil palms in response to increasing demands: world oil palm production has increased 460 % from 4.5 million tons in 1980 to 20.9 tons in 2000 (Koh and Wilcove 2007; Rist 2010). Large scale oil palm plantations yield large profits and contribute to changes in land use and land cover: agricultural land for oil palms worldwide has increased from 3.6 million hectares in 1961 to 8.1 million hectares in 2009 (Grieg-Gran 2008; Donald 2004).

To evaluate the impact of oil palm expansion on changing the costs of forest protection, we have defined the BEP for oil palm development as follows:

$$R_h = \sum_{t=j}^{T} \left(\frac{1}{1+r} \right)^t \times V_h,$$

where R_h is the average revenue of oil palm development per hectare over 30-years and V_h is the net revenue from planting oil palms per hectare. We have assumed $j = 7$: harvesting from oil palms starts from 7 years after the planting.

Results from the estimates are detailed in Table 39.4 and indicate that the NPV of oil palm plantations is USD 16,334.3 per hectare and higher than that of rice (USD 600.8) or that of rubber (USD 5,393.7). It means that oil palm planting is an attractive and profitable land use for developers and stakeholders. The BEP is

Table 39.4 BEP for oil palm plantations

Parameter	Result
Oil palm net revenue per hectare (V_h)	\$3,340
NPV of oil palm per hectare	\$16,334.26
BEP of carbon ($P^*{}_c$)	\$72.60
BEP of CO_2	\$19.78

estimated to be USD 72.60 per ton of carbon or USD 19.78 per ton of carbon dioxide. This result suggests that the revenue from oil palm plantations is much higher than the carbon price. The conclusion here becomes that the REDD+ scheme will not be able to fulfill the objective of preventing deforestation due to expanding oil palm planting. For the REDD+ scheme to be achieved here it will be necessary to combine the carbon value with other values of forest protection. Payments for environmental services (PES) or below ground carbon would increase the compensation from protecting forests.

39.4 Key Topics in REDD+ in Peatland of Indonesia

The forest area of Indonesia has decreased by 21 million hectares from the 121 million hectares in 1990 to 100 million hectares in 2005 (Hansen et al. 2009). About 75 % of this deforestation has occurred on the islands of Kalimantan and Sumatra. The average rate of deforestation from 2000 to 2005 was 710,000 ha per year. This is rather less than the 1.78 million hectares per year between 1990 and 2000, although it is still high.

Indonesia has a significant potential as a target area for REDD+. Deveny et al. (2009) use the Forest Carbon Index (FCI) to assess the capacity for implementation of REDD+ in different countries. The FCI evaluates the ability of countries to obtain carbon credits at low cost based on the condition of the economy and forest, governance capacity, and implementability. Although there are some problems with respect to Indonesian governance and implementability, the FCI evaluates it highly: sixth in the world after Brazil, Russia, Peru, Bolivia, and Colombia.

One of the key elements for implementing REDD+ in Indonesia is its thick peatland. Forestland in Central Kalimantan, Indonesia is composed of at least 55 gigatons of carbon in peatland or 2,000–6,000 metric tons of carbon per hectare (Page et al. 1999; IPCC 2006; Jaenicke et al. 2008). This carbon in peatland can be released into the atmosphere by deforestation, degradation of the land, and fires. For example, a large-scale fire in 1997 damaged 790,000 ha in Central Kalimantan Province (Page et al. 2002); 91.5 % of this was peatland. Adding the total emissions from peatland and vegetation, 0.24–0.28 gigatons of carbon were released into the atmosphere in that fire. When adding up releases from all of Indonesia, 0.81–2.57 gigatons of carbon were released in 1 year. This is equivalent to between 13 % and 40 % of the mean global carbon emissions from fossil fuels.

A wide range of policies have been implemented in Central Kalimantan over the previous decade to prevent future peatland fires. In 2006, the local government banned the use of fire on agricultural plots. However, the ban has not been successfully enforced. Farmers resist the order to stop using fire because slash-and-burn agriculture has been traditionally conducted in Kalimantan, and in many cases, farmers have no alternatives (Ketterings et al. 1999). According to a report (CARE International Indonesia 2009 pp. 63), over 63 % of households in Kapuas Regency, Central Kalimantan are unwilling to stop using fire for agriculture. The survey we conducted in Kapuas Regency showed that approximately 40 % of households used fire during the previous planting period.

Individual attention to fire prevention is necessary to maintain the common pool resources. However, the socially optimal amount of fire prevention by farmers cannot be achieved without policy enforcement (Crowley et al. 2009). The problem of controlling fires arises from the nature of peatland fires, which can be easily widespread and may burn for many months once ignited (Wooster et al. 2012). Farmers have little incentive to stop using fires because it is an important agricultural practice and they are uncertain whether neighbors will also stop using it. This leads to a situation where households may want to stop using fires but feel it is needed to grow the crops, however if the means are available they would be willing to try fire prevention.

To understand the fire prevention activities of farmers in Central Kalimantan, we conducted a field survey in 29 villages from September to December 2012 in Kapuas Regency, in where most peatland degraded. Villages consist of 11 transmigrant and 18 Dayak tribe communities. We collected information from 288 randomly selected households, and to focus on the decisions of household heads, we excluded 73 responses from other family members and 33 incomplete responses. Thus, the final number of responses used in our analysis was 182. Table 39.5 is a summary of the result. Among the respondents, 87 % were practicing some kind of fire prevention activity such as keeping careful watch of the agricultural plots or clearing unburned grass.

Economic factors play a significant role in fire prevention. In the full sample, 58 % of households have plots for rubber production and the mean estimated non-agricultural income is IDR 8.58 per day per person. However, there are substantial differences between households that engage in fire prevention and those that do not. The percentage of households that engage in fire prevention that have plots for rubber production is 63 %, while for those that do not it is 23 %. The mean exogenous income for households that do not engage in fire prevention is IDR 11.39, nearly 40 % more than the exogenous income (IDR 8.20) for households that do engage in fire prevention. These numbers imply that people tend to practice fire prevention when they own sufficiently valuable assets and the opportunity cost of fire prevention is low.

Table 39.5 Survey results in Kahayan regency

	Full sample (n = 182)	Fire prevention (n = 160)	No fire prevention (n = 22)
Number of household members	4.37	4.36	4.41
Number of children (<15 years)	0.68	0.7	0.5
Transmigrants	46 %	23 %	49 %
Plots for rubber production	58 %	63 %	23 %
Shadow wage of exogenous income (IDR/day/person)	8.58	8.2	11.39
Gotong-royong activities	64 %	69 %	27 %

Economic reasons may be significant in the decision making of farmers, however noneconomic reasons may also play a role. The data here shows that households that engage in *gotong-royong* activities are more likely to engage in fire prevention. Gotong-royong is the term for mutual aid activities in Indonesia's local communities. These mutual aid activities have traditionally been conducted in Central Kalimantan and include road construction, canal construction, ditch clearing, and cooperative agricultural work for the public good or for other villagers. Gotong-royong activities may play the role of a mutual surveillance system. Households who join in the gotong-royong activity would be able to know what the neighbors were doing on their agricultural plots, which may create more intense peer pressure, here to prevent using fires.

These findings provide policy implications for peatland fire management. Providing incentives to protect assets would enhance local household fire use. Further, the results of this survey suggest that an effective policy design should consider both the use of economic incentives and also the role of noneconomic factors such as mutual aid activity in local communities. Policies to support mutual aid activity may contribute to reducing the risk of the spread of fires in this area.

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Chapter 40
Livelihood Strategies of Transmigrant Farmers in Peatland of Central Kalimantan

Towa Tachibana

Abstract This chapter summarizes the field survey on 108 migrant farmers in the four ex-transmigration settlements constructed in the peat-soil areas in the province of Central Kalimantan, Indonesia. Our major findings are that (1) sales of agricultural produce accounted for less than one-quarter of cash earnings of our respondents, (2) many respondents had given up, or were giving up rice cultivation, (3) in the near future, rubber may become a large cash-income source for the farmers in the study area, and (4) industrial oil-palm plantations are altering the agricultural scene of the peat-soil area in Central Kalimantan.

Keywords Transmigrant • Abandon rice cultivation • Seasonal migration • Rubber

40.1 Introduction

Recent growing interest in REDD (Reducing Emissions from Deforestation and forest Degradation) has enhanced the need for information about the livelihood strategies, and their determinants, of the people living in and around the forest areas. Experiences in nature reserves have informed us that in developing countries, few conservation projects function properly without considering the needs of local people (Robinson et al. 2011, and the references therein).[1] To design a REDD project, appropriate compensation for local people needs to be estimated. Making such estimates then requires detailed information about the net benefits that the local people have extracted from the activities which may damage the forest under

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[1] In Indonesia, where our study site is located, Yonariza and Webb (2007) point out that the tighter stipulations in Forest Law often resulted in less strict enforcement of the law.

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the proposed REDD project. An example of those potentially harmful economic activities to forests is, obviously, farming (Venter et al. 2009).

The purpose of this chapter is to summarize the major findings of our household survey on migrant farmers in a cleared tropical peat-swamp forest area in the province of Central Kalimantan, on Kalimantan (Indonesian Borneo) island, Indonesia. The survey took particular note of migrants' land-use strategies that were captured by the changes in cropping patterns including fallowing and land abandonment.

The peat soil of the study area stores huge amounts of carbon, much more than is stored in the standing trees on it. Jaenicke et al. (2008), for instance, estimated that the three major peat lands of the study area stored about 3.86 gigatons (Gt) of carbon, which is more than double the annual carbon emissions of the current largest emitter, China.[2] Along with the high deforestation rate of the past two decades, carbon stored in peatlands makes Indonesia a major player in the REDD-framework discussion (Petrova et al. 2007). Central Kalimantan is, naturally, a strong contender for REDD projects. As is shown in the other chapters, several REDD pilot projects have been underway in the province for some time.

Since the widespread fires during the El Ninõ event in 1997, the study area has also been known for its frequent and devastating forest fires that sometimes cause transnational haze pollution (Page et al. 2002). Many forest fires in the area are allegedly due to fire leakage from adjacent farms, where farmers burn the agricultural residue and surface peat soil to fertilize their fields. This allegation intensifies the need for information about farming practices and cropping patterns in the study area.

40.2 Research Site and Data

There are two groups of farmers in our study sites: native Dayak and immigrants. Our study concerns the latter, most of whom are Indonesian government-sponsored migrants: transmigrants. There are two major reasons for this focus. First, in the study area, forest fires have become more frequent in recent decades along with the introduction of logging concessions and the transmigration programs. Forest clearing and drainage for transmigration settlements have converted fire-resistant forested peat soil into fire-prone soil.[3] Second, farming practices and the traditional property-rights system of the Dayak people are quite different from

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[2] Precisely speaking, Jaenicke et al. (2008) estimated the amount of carbon that was stored in the three peat domes with a total area of 13,799 km^2. World Bank (2011, p. 154) reported that, in 2007, China's emissions of carbon dioxide from the burning of fossil fuels were 6,533 million metric tons. This was converted to carbon equivalent units by multiplying the value by 0.273.

[3] For a multi-scale analysis on the causes of vegetation fires in Sumatra and Kalimantan, refer to, among others, Dennis et al. (2005) and Stolle and Lambin (2003). Both studies argued that transmigration sites would become less fire prone after the completion of land clearance in the

those of transmigrants. It is therefore difficult to analyze these two groups together. Furthermore, there is a fairly good volume of literature on the relationship between the traditional, although changing, farming systems of the Dayak and landscape in Kalimantan (e.g., Colfer and Byron 2001, Inoue 2000, Peluso 2009).

40.2.1 The Transmigration Program in the Area

The transmigration program in Indonesia is one of the largest government-sponsored internal migration programs in the world (Kinsey and Binswanger 1993). The program started as early as 1905 in the period of the Dutch East Indies. At that time, it was mainly a measure to develop the plantations in the so-called outer islands, including Kalimantan, by diverting the crowded population from Java Island. The government-controlled migration program was reinvigorated under the new-born Indonesian republic that achieved independence in 1949. Since then, the main purpose of the program has been to reduce the population pressure in Java, Bali, and Madura, while pursuing the development of the outer islands.[4] For a detailed history of the transmigration program, refer to, for example, Fearnside (1997) and Tjondronegoro (2004).

In Central Kalimantan, the first phase of the transmigration program started in 1960, followed by the second phase between 1970 and 1980. In these phases, the program focused on the area with a shallow peat layer along the rivers (Hardjono 1977, pp. 75–77). In 1995, however, the Mega Rice Project (MRP) started in an area of deeper peat layers. The MRP boldly (or recklessly) aimed to convert the peat-soil area into rice fields with 30,000 new transmigrant households. The canals constructed for drainage dried and eventually destroyed the huge amount of peat soil. The MRP, however, failed mainly due to serious flooding in the rainy seasons. In 1999, based on the Decree 80, the MRP was officially abandoned. At that time, there were 14,100 migrant households (56,400 people) in the MRP area.[5] Refer to Sabiham (2004) for the details of the MRP.

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construction phase. But the topography of our study site, a peat-swamp forest area that was drained for in-migrants, is unlike any of their study sites.

[4] Elmhirst (1999) suggests another view on the purpose of the transmigration program: it is to spread the Javanese culture and political system to the outer islands.

[5] The major cause of failure and the numbers of households were obtained in the interview (January 3, 2006) with the officials in the Mega Rice Project office in the town of Kuala Kapuas.

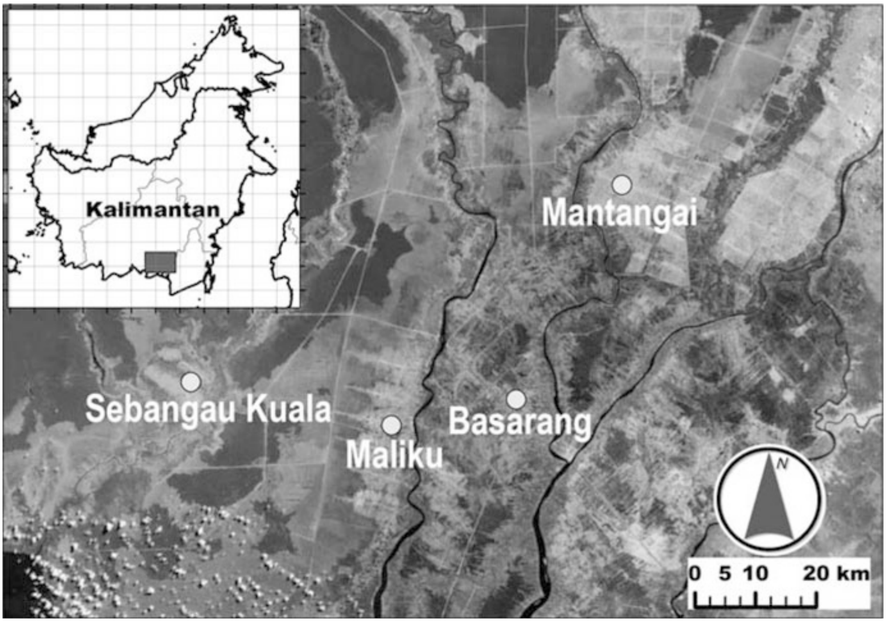

Fig. 40.1 Four study sites under the current local administration

40.2.2 Study Sites

In Central Kalimantan, four major transmigration programs in the peat soil area were selected for our study. A survey of the settlements constructed by these four programs was expected to provide rich information thanks to their variation in the construction years and access to the two urban areas: Palangka Raya and Kuala Kapuas.[6] In most cases, about 5 years after completion of the transmigration program, established settlements are integrated into the ordinary local administration system, and become or are part of a sub-district called a *Kecamatan*. As of 2010 when we completed our follow-up survey, all of our study sites already became or were integrated into a *Kecamatan*. Figure 40.1 shows the locations of our study sites by the names of *Kecamatan*.[7]

The construction of settlements at Basarang started in 1961 under the second earliest transmigration program in Central Kalimantan (Hardjono 1977, p. 75).

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[6] Palangka Raya, the capital of Central Kalimantan province, had a population of 182,264 as of 2004, and it had grown to 224,663 by 2011. The annual population growth rate in the period was 3.0 %. Kuala Kapuas, the center of Kapuas regency, had a population of 35,984 as of 2004. In this chapter, the population and the other provincial statistics were collected from the website of BPS (*Badan Pusat Statistik*), Central Kalimantan province.

[7] This satellite image was provided by Dr. Sawahiko Shimada in October 2012.

The constructed settlements currently form *Kecamatan* Basarang. Under the road conditions of 2010, it was less than 20 min drive from the town of Kuala Kapuas to Basarang, and 4–5 h drive from Palangka Raya. *Kecamatan* Basarang consists of 13 villages (called *Desa* according to the local administration). Out of these 13 villages, we randomly sampled six as a first-stage sampling scheme. Then from each village, five households were randomly sampled based on the household list provided by the village office. According to the statistics obtained from the provincial government office, in 2004, the number of households in Basarang was 4,361 with a population of 16,543. In the six villages in our sample, there were 2,032 households.

The transmigration program at Pangkoh started in 1980, and had constructed 11 blocks along the Kapuas river by 1987.[8] The constructed settlements are currently a part of either *Kecamatan* Maliku or *Kecamatan* Pandih Batu. Under the road conditions of 2010, it was about 4–5 h drive from Palangka Raya to the center of *Kecamatan* Maliku. But in the rainy season, several villages often lost road connections and could not be reached by vehicles. Similar to the case of Basarang, we randomly sampled 30 households from the six villages located in the previous Pangkoh settlements. According to the provincial government statistics, in 2004, there were 2,957 households in these six villages.

Lamunti is one of the most recent transmigration programs in Central Kalimantan. Its construction started in 1997 as a center of the Mega Rice Project (MRP). On May 17, 1998, President Suharto visited Lamunti to encourage the MRP. In 1997 when our main survey was conducted, Lamunti was still under the transmigration program. We randomly sampled two sub-blocks from the area accessible by vehicles and five sub-blocks from the area without motor roads. The number of sampled households is the same as those from the settlements at Basarang and Pangkoh: 30 households. As of the year 2010, the transmigration settlements at Lamunti were already incorporated into *Kecamatan* Mantangai.

The transmigration program at Paduran started in the late 1980s and constructed three blocks, which are currently a part of *Kecamatan* Sebangau Kuala. The program site is located along the Sebangau river, and the most remote among our four study sites. Regarding the road condition as of 2010, in the dry season, we could drive to the Paduran area by the road going through *Kecamatan* Maliku. In the rainy season, however, road access to the Paduran area was cut off and people in the area had to rely on the Sebangau river for transportation. It was about 6 h boat trip from Palangka Raya to the center of Sebangau Kuala. In 2006–2007 when we conducted the main survey, a chapter of poor harvests prompted rapid out-migration from the ex-transmigration settlements in the area. In one village, for example, 324 households were registered at the village office, but officers there told us that only about 230 households actually stayed in the village. In this area, using the major streets as a first-stage sampling scheme, we randomly sampled 20 households from

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[8] The information about the construction of Pangkoh was obtained in the interview with a *Kecamatan* officer on December 31, 2005.

the three villages on the three blocks constructed by the transmigration program.[9] Due to some missing information, however, the final sample from the Paduran area consists of only 18 households.

In sum, we sampled 118 households from the 21 villages that were originally constructed as transmigration settlements. The sample size may be too small to adequately describe the general picture of the area. But we were instead able to conduct in-depth interviews on the complicated issues interesting us, such as changes in cropping patterns and income from various activities.

40.2.3 Survey Design

The study area has two seasons. The rainy season usually runs about 7 months from September to March, while the dry season correspondingly starts in April and ends in August. Between these two seasons, most farmers change their annual crops and/or off-farm activities. We therefore divided the baseline survey into two parts. The rainy season survey was conducted from March to September 2006. The survey included, for example, modules on basic household demographics, mode of land acquisition, (if any) relinquishment of plots which the respondent had managed since his/her arrival at the area, income sources, and crops in their fields in the last rainy season (from September 2005 to March 2006).

For the module on the land-use strategy, we selected one plot from each sample household. The selection was based on the following three criteria: (1) the plot was not to be a home garden adjunct to the household building, (2) the plots that the respondent managed at the time of our interview, including the fields that were fallow, and (3) among the plots criteria (1) and (2) were satisfied, the field that the respondent acquired in the earliest year.[10]

Any home garden was excluded from the study of cropping patterns due to their two notable characteristics. First, the proximity to residence renders the possibility of abandonment or fallowing of home gardens almost nil. Second, the intensity of mixed cropping is much higher in home gardens than in the other fields. For example, there can be one mango tree in a home garden of a farmer mainly for home consumption. Without proper evaluation by calories or by sale, this one mango tree in the home garden greatly obscures the major cropping pattern of the farmer. Regarding the intensive use of home gardens, refer to Holden et al. (1995) and Kehlenbeck and Maass (2004).

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[9] According to the provincial government statistics, in 2004, there were 761 households in these three villages. But as was discussed in the main text, this household count in the official statistics might be significantly larger than the number of residents in 2006.

[10] Suppose a respondent has three plots, Plots A, B, and C, that satisfy the criteria (1) and (2). Suppose further that the respondent purchased Plot A in 1986, was presented Plot B in 1990, and inherited Plot C in 2004. Then we choose Plot A for our sample.

The land-use strategy module collected detailed information about the changes in cropping patterns on the selected plot from the year of plot acquisition to 2006. In addition, both in the baseline and follow-up surveys, soil samples were collected from these plots.

In the dry season survey conducted from November 2006 to February 2007, we revisited 118 sampled households and investigated their income sources and the crops that were in their fields during the last dry season. In the dry season survey, however, we missed 13 sampled households. In nine out of these 13 missing households, the heads were working out of their villages on seasonal migration referred to as *merantau* in Indonesian. One household moved out to South Kalimantan, one respondent passed away, and two respondents declined further interviews.

On the sample households in the ex-transmigration area of Pangkoh and Paduran, a follow-up survey was implemented in August 2009. Due to the limited time for the survey, however, only 23 out of the 48 sample households in these two areas were resurveyed. Similarly, a follow-up survey was conducted in March 2010 on the sample households in the Lamunti area, where we could re-interview 25 out of the 30 sample households. These resurveys focused on the module about the land-use strategy on the plots selected from each household.

40.3 Livelihood Situation

40.3.1 Major Characteristics of Sample Households

Table 40.1 shows sex, age, education attainment, ethnicity, place of birth, and mode of in-migration of the heads of the sample households. Among the 108 sample households, only two had female heads. On average, our respondents were in their late middle age: about 47 years old, while the eldest was 80 and the youngest was 24 years old.

Panel (A) of Table 40.1 indicates that the education attainment of our respondents is not high: 42.6 % of the respondents did not complete primary-school education.[11] This fact partially reflects the improvement in Indonesia's education system over the years. The average age of those respondents who did not complete primary school is 51.3, while the average age of those who completed junior-secondary school and above is 39.2.

Panel (B) shows that more than half of the respondents, 64 household heads, are Java ethnic. This observation is quite natural in ex-transmigration areas. The second largest ethnic group is Banjar from South Kalimantan. Ten respondents are Dayak ethnic, a group indigenous to Central Kalimantan. This is not uncommon

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[11] In Indonesia in 2005, among those who worked in the sector of 'Agriculture, Forestry, Hunting, and Fisheries (15 years of age and above)', 20.1 % does not complete primary-school education (Badan Pusat Statistik 2008, p. 86).

Table 40.1 Characteristics of households heads in the sample

	Total	Basarang (Basarang)[a]	Pangkoh (Maliku)	Lamunti (Mantangai)	Paduran (Sebangau K.)
Sample size (Male head)	108 (106)	30 (29)	30 (30)	30 (29)	18 (18)
Age Std. dev.	47.1 (11.9)	47.0 (11.4)	49.8 (12.4)	44.6 (11.4)	47.0 (12.5)
(A) Education					
Not completed primary school	46	9	17	12	8
Primary school	32	11	7	8	6
Junior secondary school (SLTP)	21	8	4	5	4
Higher education	9	2	2	5	0
(B) Ethnic					
Java	64	8	29	16	11
Bali	8	5	1	2	0
Banjar	21	14	0	3	4
Dayak	10	3	0	7	0
Others	5	0	0	2	3
(C) Place of birth					
From the same *Kecamatan* as the current residence	10	5	0	5	0
if different, province					
Central Kalimantan	10	6	0	2	2
South Kalimantan	13	8	0	3	2
West Java	10	0	1	6	3
Central Java	26	2	14	4	6
Yogyakarta	1	0	0	0	1
East Java	29	6	13	7	3
Bali	6	3	1	2	0
Lampung	2	0	1	1	0
South Sulawesi	1	0	0	0	1
(D) Moved in as					
Transmigrant	51	3	16	22	10
Voluntary migrant	19	6	2	6	5
Others	38	21	12	2	3
(E) Household size					
Number	4.5	4.9	4.1	4.2	4.8
Std. dev.	(1.7)	(1.9)	(1.4)	(1.6)	(1.7)

[a] Names of *Kecamatan* in Fig. 40.1 where the ex-transmigration settlement currently belongs

because transmigration programs usually spare the share for the applicants from local ethnic groups (referred to as *transmigrasi lokal* in Indonesian). In our sample, there are seven Dayak respondents in the Lamunti area, which was constructed under the MRP. From its inception, the MRP solicited applicants from the local villages.[12]

The birth places of the respondents shown in panel (C) of Table 40.1 mirror the ethnic composition of the respondents. Ten respondents who were born in the same *Kecamatan* as their current residence live either in Basarang or in Lamunti. Among these 10 respondents, the five respondents in Basarang were born into transmigrant families, while the five in Lamunti are all Dayak people participating in the MRP.

Panel (D) of Table 40.1 shows that less than half of the respondents, 51 heads, came to the area participating in the transmigration programs. In Lamunti, which is the most recent transmigration area among our four sites, the majority came as transmigrants. But in Basarang, the oldest settlement, there were only three transmigrants among its 30 respondents. Sixteen respondents in Basarang came to the area either by following their parents when they were small kids, or by marriage. As was mentioned above, five of the 30 respondents in Basarang were born there.

The bottom panel of Table 40.1 displays the household size: on average 4.5 persons in a house. It is larger than both the national average of Indonesia, 4.0, and the provincial average of Central Kalimantan, 4.2, in 2005 (Badan Pusat Statistik 2009, p. 85). This observation may reflect the fact that most of our respondents are in their late middle ages.

40.3.2 Land Acquisition

In our study area, transmigration programs provided a participant with 2 hectares (ha) of farm land in addition to a home lot of 0.25 ha.[13] Table 40.2 shows the number of plots that the respondents *have ever managed* in the area, and the mode of their acquisition. In this part of the survey, the focus was both on the mode of land acquisition and, if any, reasons of land abandonment. Thus Table 40.2 includes 70 plots that were already sold out, abandoned, or returned to the government. Another note is that home lots, many of which are intensively used as home gardens, are not included in Table 40.2. This is mainly because transmigrants often manage home gardens under a farming strategy that is quite different from the ones for larger

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[12] The recruitment of the Dayak applicants by the MRP was based on the interview (January 3, 2006) with the officials in the Mega Rice Project office in Kuala Kapuas. In addition, there were Dayak people who were eager to apply for the MRP. Informal interviews in the study sites suggested that these Dayak applicants had aimed to obtain new land for their tree crops.

[13] Transmigration programs focusing on food crops generally provide a lot of 0.25 ha as space for house building and a home garden, a plot of 1.0 ha of cleared farm land (ideally as an irrigated rice field: *sawah*), and a plot of 0.75 ha of uncleared farm land (usually as an upland field: *ladang*).

Table 40.2 Number of plots respondents ever managed, and mode of their acquisition

	Total	Basarang (Basarang)[a]	Pangkoh (Maliku)	Lamunti (Mantangai)	Paduran (Sebangau K.)
Number of plots	303	82	73	77	71
Average size (ha) Std. dev.	1.30 (0.94)	1.18 (0.71)	1.10 (0.64)	1.82 (1.34)	1.05 (0.62)
Mode of land acquisition					
Transmigration program	78 (25.7 %)	6 (7.3 %)	22 (30.1 %)	25 (32.5 %)	25 (35.2 %)
Purchase	111 (36.6 %)	39 (47.6 %)	30 (41.1 %)	23 (29.9 %)	19 (26.8 %)
Inherited or presented	33 (10.9 %)	18 (22.0 %)	4 (5.5 %)	3 (3.9 %)	8 (11.3 %)
Rented	4 (1.3 %)	2 (2.4 %)	2 (2.7 %)	0 (0.0 %)	0 (0.0 %)
Borrowed[b]	45 (14.9 %)	5 (6.1 %)	13 (17.8 %)	11 (14.3 %)	16 (22.5 %)
Occupy abandoned land	22 (7.3 %)	5 (6.1 %)	2 (2.7 %)	12 (15.6 %)	3 (4.2 %)
Others	10 (3.3 %)	7 (8.5 %)	0 (0.0 %)	3 (3.9 %)	0 (0.0 %)

[a] Names of *Kecamatan* where the study sites currently belongs
[b] Without rent payment. Refer to the text

plots. Refer to Sect. 40.2.3 about the distinctive characteristics of home gardens. On average, after settling in the village of current residence, a respondent has managed 2.8 plots in addition to a home garden.

Two features stand out in Table 40.2 about the mode of land acquisition. First, there were more purchased plots than those allocated from the transmigration programs. Second, 45 plots (14.9 % of all the plots) were 'borrowed' without rent payment while only four plots were under rental contract.

As time passes after the construction of transmigration sites, villagers other than the participants of the transmigration program naturally increase (panel (D) of Table 40.1). In Basarang where migration started as early as 1961, the major mode of land acquisition is 'purchase' (47.6 %) followed by 'inherited or presented' (22.0 %), while 'transmigration program' accounts for merely six plots (7.3 %). In the recently constructed two settlements, Lamunti and Paduran, about one third of the plots were still held by the transmigration-program participants.

Many respondents in Lamunti and Paduran obtained several farm plots for free: 'borrowed' without rent payment or 'occupying abandoned land'. The sum of these two modes represents 29.9 % of the plots in Lamunti and 26.7 % of the plots in Paduran. The transmigration program at Lamunti, which was under the MRP, did not have as many migrants as planned. The MRP office requested the settled farmers to arbitrarily cultivate any vacant plots. In the ex-Paduran program area, those farmers who left the area due to successive poor harvests often trusted one of their neighbors with the management of their fields. Thus, on average, a respondent in Paduran has managed about one plot more, 3.9 plots, than an ordinary respondent in the other three study sites: 2.6 plots.

40.3.3 Cash Income and Its Sources

This subsection investigates the cash income of the respondents and its sources. Due to the missing households in the dry-season survey, the valid sample for *annual* cash income is reduced to 95 from the 108 sample households. Before analyzing the results, two caveats are in order here.

First, cash income is not the ‘income’ in economics textbooks. This is because cash income does not enumerate the home consumption of agriculture produce.[14] As will be shown in the next section, in the study sites, fruits and vegetables were the main crops for market sale. In the preliminary field surveys, however, the author noticed that no respondents could answer home consumption of fruits and vegetables on their fields. For home consumption, farmers frequently and irregularly harvest fruits and vegetables in small amounts. They could answer neither the number of times of such small harvests, for example, per week nor the estimate of total amount of fruits and vegetables consumed at home. In contrast, respondents easily provided details on their gross output of rice, which was usually harvested on one occasion with intensive labor input. At the designing phase of the survey, therefore, the author decided to focus on the sale of agricultural produce. For the gross output, the questionnaire investigated only about rice.[15]

The second caveat is that we collected the information of cash income of the respondents and their spouses only, rather than all members of a household. In other words, cash income in the chapter indicates the combined cash income of the household head and, if any, of his/her spouse.[16]

Table 40.3 shows the average cash income of the sample households in each season, and the ratios of its major components. On average, our respondents and their spouses had a combined annual cash income of 8.6 million Indonesian Rupiah (Rp), which was about 960 US dollars. As per capita, the annual cash income was about 4.6 million Rp, which was significantly lower than the per capita GDP of Indonesia in 2006: about 15 million Rp (Badan Pusat Statistik 2009,

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[14] For example, a subsistence farmer, who produces just enough to feed his/her family, has no ‘cash income’. But this farmer has ‘income’ equal to the market sale of his/her produce. Such a farmer could have sold all of his/her produce at a market, and used the sale to purchase other goods.

[15] Later, the author noticed that the use of cash income and the focus on the rice harvest were common practice in the literature on transmigrants: e.g., Holden et al. (1995).

[16] Table 40.3 shows the combined cash income of 95 household heads and 89 of their spouses. Five respondents do not have spouses. And one spouse lived in a different province with independent livelihood.

Table 40.3 Cash income: 95 households (unit: 1,000 Rp)

	Over the year	Rainy season	Dry season
Mean in USD[a]	8,638 (960)	5,128 (570)	3,510 (390)
Std. dev. in USD[a]	7,856 (873)	5,403 (600)	3,539 (393)
Max	36,088	27,592	15,500
Min	465	170	60
Ratio (%) of major cash-income sources[b]			
Sales of agricultural produce	22.7	24.2	19.2
Hired agricultural works	8.9	6.7	11.0
Livestock	10.9	12.1	8.1
Fishing	1.2	1.9	0.4
Logging	1.7	2.2	0.8
Others	54.6	52.9	60.5

[a] Use the exchange rate in 2006: 9,000 Rp = 1 USD

[b] Averages of the ratios of the 95 households

p. 577). But note again that the cash income in our estimates did not include home consumption of agricultural produce, which might be a significant amount in small farm households.

Among the cash income, the sales of agricultural produce accounted for less than one-quarter: 22.7 %. Even cash income from agricultural activities in general, which adds wages from hired agricultural work and sales of livestock to the sales of agricultural produce, represented less than half of the total cash income: 42.5 %. In the dry season, cash income from agricultural activities in general constituted less than 40 % of the total cash income. Correspondingly, ‘others’ accounted for more than 50 % of the total cash income. The major components of ‘others’ are, for instance, subsidy from the government for fuel purchase, remittance, hired work in road construction, and petit trading activities. Such a high ratio of non-agricultural activities in income sources is not uncommon in transmigration areas. Refer to, among others, Leinbach et al. (1992) and Holden et al. (1995).

One more important note here is that the respondents often engaged in wage work and petit trading included in ‘others’ at some places out of the study sites during their seasonal migration known as *merantau*. In fact, even employment opportunities for farm labor were sometimes found at places out of the study sites: three of the 27 cases of hired agricultural works in the rainy season and five out of the 32 cases of hired agricultural works in the dry season were done during *merantau*.

Only six out of the 95 respondents were engaged in logging for their cash earnings: merely 1.7 % of the total cash earnings (second row from the bottom of Table 40.3). Four of them were in the Paduran area. This is a smaller number than expected in a region known for intensive logging and rapid deforestation (Burgess et al. 2012, Curran et al. 2004, Miettinen et al. 2011). Under the tighter government regulations on logging, this is likely to be an underreported number. But it is also a fact that much of the good timber in the area had already been harvested before 2006. Among the valid 95 respondents in the dry-season survey, for instance, 46 respondents reported that they *used to* be engaged in logging activity.

Table 40.4 decomposes Table 40.3 into four study sites. Although we have to note large standard deviations, sharp contrasts can be observed between Paduran (a collapsing ex-transmigration settlement) and Basarang (an old settlement). First, the respondents at Paduran had one-third cash income (3.8 millon Rp) of those at Basarang (11.8 million Rp). Second, the sales of agricultural produce represented a mere 6.7 % of cash income in Paduran, while it accounted for 29.9 % in Basarang. Conversely, ‘others’ constituted 74 % of cash earnings in Paduran.

In an old settlement such as Basarang, the current residents are mostly successful migrants or their successors. Those who failed to sustain a satisfactory livelihood had already left the area. In contrast, the Paduran area was experiencing rapid population outflow by 2006. As was explained in Sect. 40.2.2, Paduran is located far from Palangka Raya, the main market in the region. Conversely, Basarang is located next to the town of Kuala Kapuas. Access to the market resulted in the larger sales of agricultural produce in Basarang than in Paduran.

40.4 Land Use Pattern and Its Changes

40.4.1 Crops on the Fields

Table 40.5 shows the count of crop varieties on the fields which the 108 sample households managed in the rainy season from September 2005 to March 2006. Here we examine only the rainy-season crops because, if we counted the annual crop varieties, we would need to drop the 13 missing households in the dry-season survey. Note that this is a simple count of crop varieties with duplication. For example, suppose Farmer I who manages two plots: Plots A and B. Farmer I divides Plot A into an area for cabbage and an area for fruit crops. In the area for fruits, there are nine banana trees, 30 mango trees, and many pineapples. Then the count of crop varieties on Plot A would be one ‘Vegetables’ and three ‘Fruits’. The questionnaire did not investigate either seeded area for annual crops or number of stands for perennial crops. Under the mixed cropping practice in the study sites, measurement of crop intensities was beyond the capacity of our survey.

Now we continue the example of Farmer I. Suppose that Farmer I divides Plot B into an area for rice and an area for banana trees. The count of crop varieties on Plot B would be one ‘Rice’ and one ‘Fruits’. Then the count of the crop varieties of Farmer I would be one ‘Rice’, one ’Vegetables’, and four ‘Fruits’. In the aggregation into the farmer’s crop varieties, banana would be counted twice. Precisely speaking, therefore, what we can examine in Table 40.5 is the intensity of mixed cropping, which is captured by the crop count per plot.

Table 40.4 Cash income in each village (unit: 1,000 Rp)

	Basarang: 26 HHs			Pngkoh: 25 HHs			Lamunti: 30 HHs			Paduran: 14 HHs		
	Annual Income	Season		Annual Income	Season		Annual Income	Season		Annual Income	Season	
		Rainy	Dry		Rainy	Dry		Rainy	Dry		Rainy	Dry
Mean	11,869	6,303	5,566	7,433	4,730	2,702	9,064	5,894	3,171	3,874	2,013	1,861
in USD[a]	(1,319)	(700)	(618)	(826)	(526)	(300)	(1,007)	(655)	(352)	(430)	(224)	(207)
Std. dev.	8,976	5,023	4,682	5,505	3,928	2,571	9,090	7,277	3,142	1,582	1,052	1,131
in USD[a]	(997)	(558)	(520)	(612)	(436)	(286)	(1,010)	(809)	(349)	(176)	(117)	(126)
Ratios (%) of major cash-income sources[b]												
Sales of agricultural produce	29.9	29.2	29.5	25.3	28.7	21.2	21.8	23.0	17.1	6.7	9.7	1.4
Hired agricultural works	8.2	4.0	9.3	8.7	10.0	7.8	10.0	5.1	16.3	8.2	9.5	8.2
Livestock	10.8	13.3	10.2	16.0	18.4	8.0	8.2	7.9	7.9	7.4	7.6	4.8
Fishing	0.5	0.9	0.0	0.0	0.1	0.0	3.0	4.7	1.3	0.6	1.2	0.0
Logging	0.0	0.0	0.0	0.0	0.0	0.0	4.1	4.3	2.7	2.9	5.7	0.0
Others	50.5	52.7	51.1	50.0	42.9	63.0	52.9	55.1	54.7	74.1	66.3	85.7

[a] Use the average exchange rate in 2006: 9,000 Rp = 1 USD

[b] Averages of the ratios of the households in each village

Table 40.5 Crop varieties on the farm fields: 108 sample HHs in the rainy-season survey

	Total	Basarang (Basarang)[a]	Pangkoh (Maliku)	Lamunti (Mantangai)	Paduran (Sebangau K.)
Number of plots	180	52	49	53	26
Plots under fallow	23	1	8	10	4
Number of households	108	30	30	30	18
Total counts of crop varieties	461	161	110	153	37
(With home garden)	(1405)	(381)	(397)	(433)	(194)
per plot	2.56	3.10	2.24	2.89	1.42
Counts of each crop variety					
Rice	71	9	23	23	16
per plot	0.39	0.17	0.47	0.43	0.62
(With home garden)	(71)	(9)	(23)	(23)	(16)
Cassava	27	12	9	4	2
per plot	0.15	0.23	0.18	0.08	0.08
(With home garden)	(63)	(18)	(17)	(13)	(15)
Fruits	161	72	24	54	11
per plot	0.89	1.38	0.49	1.02	0.42
(With home garden)	(760)	(216)	(201)	(240)	(103)
{Pineapple}	{22}	{17}	{0}	{5}	{0}
per plot	0.12	0.33	0.00	0.09	0.00
(With home garden)	(65)	(28)	(1)	(24)	(12)
Vegetables	105	27	24	51	3
per plot	0.58	0.52	0.49	0.96	0.12
(With home garden)	(290)	(72)	(75)	(108)	(35)
Rubber	54	25	9	16	4
per plot	0.30	0.48	0.18	0.30	0.15
(With home garden)	(82)	(35)	(13)	(23)	(11)
Oil palm	1	0	1	0	0
per plot	0.01	0.00	0.02	0.00	0.00
(With home garden)	(14)	(2)	(3)	(5)	(4)

[a] Names of *Kecamatan* where the study sites currently belongs

Three observations in Table 40.5 are worth noting. First, we can reconfirm the intensive use of the home garden for agricultural production. It can be starkly seen in fruit planting. There were 161 fruit counts over the 180 farm plots: 0.89 fruit varieties per plot. But if we included the fruit counts in home gardens, the number jumped up to 760 fruit counts over the 288 plots (180 farm plots plus 108 home gardens): 2.64 fruit varieties per plot. Many fruit varieties, though each of them may consist of a few stands, were planted in home gardens. Second, we can again see sharp contrasts between Paduran (collapsing ex-transmigration settlement) and Basarang (old settlement). This time, the contrasts are found in the intensity of mixed cropping and in the number of plots for rice cultivation. On average, the plots in Paduran (1.4 crop varieties per plot) were under less intense mixed cropping

Table 40.6 Sales of agricultural products: 95 sample HHs (unit: 1,000 Rp)

	Number of HHs sold	Average sale per HH (over 95 HHs)	Max sale	Ratio to total agricultural sale (%)
Total	83	2,253	20,510	100
Rice	11	158	6,000	7.0
Cassava	12	37	1,300	1.6
Vegetables	41	696	13,810	30.9
Fruit	64	987	16,010	43.8
Rubber	5	182	9,000	8.1
Coffee	22	101	2,250	4.5
Tree	2	8	500	0.4
Others[a]	14	85	6,200	3.8

[a] Others include peanut, taumeric, and Mekinjo

than in Basarang (3.1 crop varieties per plot). There are differences in the popular crops, too. There were 1.38 fruit varieties on a farm in Basarang, which was much higher than 0.42 fruit varieties on a farm in Paduran. Among the fruit, pineapple was especially preferred by the farmers in Basarang. Most notably, rice was planted on the 61.5 % of the plots in Paduran (16 out of the total 26 plots), compared to only 17.3 % in Basarang (nine out of the total 52 plots).[17] Over the four study sits, the portion of farm fields with rice, 39.4 % , was woefully low considering the fact that transmigration programs in the area aimed to increase rice production.

Next, Table 40.6 shows the annual sales of agricultural products. That is, Table 40.6 provides a detailed description of the row of ‘Sales of Agricultural Produce’ in Table 40.3. To calculate the annual sales, the number of sample households was reduced to 95 that were re-interviewed in the dry-season survey. As was mentioned above, vegetables (30.9 %) and fruits (43.8 %) accounted for more than 70 % of the agricultural-produce sales. In most cases, we could not identify the fields from which the crops sold were harvested.[18] The large sale of fruits, however, suggests the importance of home garden as a source of cash earnings.[19] Rice, the major banner of ordinary transmigration programs, accounted for merely 7 % of the agricultural-produce sales. In fact, there were only 11 households who sold rice from the harvest of the year 2006.

From the early 2000s, the provincial government of Central Kalimantan began to promote rubber plantation to the cultivators in the previous transmigration sites. At the time of our main survey in 2006, rubber trees in the study area were still young,

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[17] Table 40.5 does not distinguish between rice varieties. So the count of rice is equal to the number of plots with rice.

[18] Suppose that a farm household sows spinach on two of its fields: plot A and B. Without a detailed survey on each plot, we cannot tell how much spinach was sold from the harvest on plot A.

[19] Refer to Perry (1985) for a similar argument about home gardens as a source of income.

and only five respondents tapped latex. In the Pangkoh area, however, latex sales already accounted for more than 20 % of the agricultural-produce sales. Note that among the 30 respondents in Pangkoh, only two respondents sold latex. This fact suggests that in the near future, latex will be a major source of cash earnings in the study sites.

40.4.2 Changes in Land Use

As was explained in Sect. 40.2.3, on one of the farm plots each respondent managed in the period of our main survey from 2006 to 2007, we gathered detailed information about the changes in cropping patterns. Among our 108 respondents, five respondents managed only a home garden, and we could not collect enough information from one respondent. Thus, we have 102 plot-wise data describing the changes in cropping-patterns. As was discussed with Table 40.5, many fields in the study area have been under mixed cropping with various crop combinations. In the 2006 crop season, for example, 78 out of our 102 sample plots had mixed cropping patterns. The major cropping patterns presented here are based on the author's classification focusing on rice and rubber.

Table 40.7 presents a transition matrix from the first cropping patterns chosen by the respondents to the cropping patterns in the 2006 crop season.[20] The rows describe the cropping patterns in the 2006 season, while the columns show the cropping patterns in the first cultivation. The element X_{AJ} (row (A) and column (J)), for instance, indicates that a cassava field in the first cultivation was converted to a rice (monoculture) field in the 2006 season. The summary of initial cropping patterns is shown at the bottom row, while that in the 2006 season is shown in the rightmost column of Table 40.7.

Table 40.7 clearly confirms (1) a decline in rice cultivation, (2) an increase in rubber planting, and (3) an increase in fallow plots. Either as in monoculture or in mixed cropping, many respondents initially planted rice, 79.5 % (85 plots) in the first cropping patterns. This observation is consistent with the purpose of ordinary transmigration programs: expansion of rice production. The high ratio of rice cropping decreased to 51.0 % in the 2006 season. Monoculture of rice, in particular, decreased to 13.7 % (14 plots), less than half of the initial ratio (32.4 %, 33 plots). In contrast, plots with rubber increased from 6.9 % (7 plots) to 29.4 % (30 plots). Symbolically, the elements X_{GA} and X_{HA} of Table 40.7 show that eight plots

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[20] The first cropping pattern in this chapter consists of the crops in the field during the second-year of respondents' own cultivation: not during the first-year of respondents' own cultivation. This is because in many tropical countries including Indonesia, when farmers intend to plant perennial crops on a plot, they often cultivate some annual crops in the first year along with land clearing. In such cases, we often observe only annual crops in the first year of cultivation. The farmer's land-use strategy, using the plot for perennial crops, will be recognized from their second-year of management.

Table 40.7 Cropping patterns and their changes in 102 plots: first cultivation up to the 2006 season

	(A) Rice	(B) Rice + vegetables/fruits + others (ex. rubber)	(C) Rice + rubber + others	(D) Rice + other-crop combinations	(E) Vegetables	(F) Fruits + others (ex. rice and rubber)	(G) Rubber	(H) rubber + others (ex. rice)	(I) Commercial crops and/or trees	(J) Cassava + others (ex. rice, fruits, rubber)	(K) Fallow	(Total 2006 cropping pattern
(A) Rice	12	0	0	0	0	1	0	0	0	1	0	14 (13.7 %)
(B) Rice + vegetables/fruits + others (ex. rubber)	1	24	0	2	0	0	0	0	0	0	0	27 (26.5 %)
(C) Rice + rubber + others	4	3	1	1	0	0	0	0	0	0	0	9 (8.8 %)
(D) Rice + other-crop combinations	2	0	0	0	0	0	0	0	0	0	0	2 (2.0 %)
(E) Vegetables	0	0	0	0	1	0	0	0	0	0	0	1 (1.0 %)
(F) Fruits + others (ex. rice and/or rubber)	0	3	0	1	1	2	0	0	0	1	0	8 (7.8 %)
(G) Rubber	4	0	0	0	0	0	1	0	0	0	1	6 (5.9 %)
(H) Rubber + others (ex. rice)	4	3	1	1	0	1	0	4	0	1	0	15 (14.7 %)
(I) Commercial crops and/or trees	0	0	0	0	0	0	0	0	2	0	0	2 (2.0 %)
(J) Cassava + others (ex. rice, fruits, rubber)	0	1	0	0	0	1	0	0	0	1	0	3 (2.9 %)
(K) Fallow	6	6	0	1	0	0	0	0	0	0	2	15 (14.7 %)
Initial cropping pattern	33	40	2	6	2	5	1	4	2	4	3	102
(Ratio)	(32.4 %)	(39.2 %)	(2.0 %)	(5.9 %)	(2.0 %)	(4.9 %)	(1.0 %)	(3.9 %)	(2.0 %)	(3.9 %)	(2.9 %)	(100.0 %)

under the monoculture of rice were converted to the rubber fields as of 2006. The sum of the elements of row (K) and that of column (K) jointly indicate that fallow plots increased from three to 15.

Here we should note that changes in cropping pattern are sometimes much more complicated than those described in Table 40.7. A cropping pattern, for instance, monoculture of rice shown in column (A), is not free from significant changes. Many migrants initially planted improved rice varieties designed for irrigated fields (*Padi Sawah*). Within a few years, however, many of these rice farmers had abandoned *Padi Sawah*, and adopted the local rice varieties used on upland fields (*Padi Tegalan*). Another complication is the changes after fallowing. The element X_{AF} of Table 40.7 seems to indicate that a farmer converted his fruit field into a rice field. This field was in fact left fallow from the cropping season of 2002 to 2005. Thus the 2006 season was the first cultivation after being fallow. It is a common practice that rice is planted as a first crop after a field has been fallow (refer to footnote 20).

The resurvey in 2009 and in 2010 investigated the changes in cropping patterns since the 2006 cropping season. The resurveys, however, were conducted only on the 47 plots in the areas of Pangkoh, Lamunti, and Paduran. For ease of comparison, Table 40.8 shows the same contents as Table 40.7, but only details the 47 plots resurveyed in 2009 or 2010. In Table 40.8, we can observe the same three trends that are revealed in Table 40.7. A major difference from Table 40.7 is the proportion of rice cultivation. Without including the observations in Basarang, an old transmigration settlement, the ratio of rice cultivation remains high in the 2006 cropping season: 63.9 % of the 2006 cropping pattern (sum of the ratios from rows (A) to (D) in the rightmost column of Table 40.8).

Table 40.9, which deals with the same 47 plots as in Table 40.8, is a transition matrix from the cropping pattern in the 2006 season to the 2009 or 2010 season. The design of the transition matrices renders the rightmost column of Table 40.8 as the bottom row of Table 40.9. But Table 40.9 has a new row (L), 'Sold/Abandoned/Rent Out'. Between the completion of the dry-season survey in 2007 and the resurveys in 2009/2010, for example, five respondents left the area and two respondents abandoned the sampled plots. Row (L) accounts for such changes.

Although it was only 3–4 years after the main survey, Table 40.9 reveals two notable developments in the agricultural scene in the study area. The first one is the acceleration of the three trends since the establishment of the settlements. The number of plots with rice drastically decreased to seven (14.9 %) in the 2009/2010 season from 29 (63.9 %) in the 2006 crop season. It is clear that recently, many migrant farmers have given up rice cultivation.

Second, the expansion of industrial oil-palm plantation arrived at the MRP site.[21] A few transnational oil-palm plantations started operations in the Lamunti area. In Lamunti, six respondents rented out their plots to an oil-palm plantation, while one respondent sold out all his plots to an oil-palm plantation. Such transactions are

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[21] About the expansion of oil palm plantation into the peatland areas in Indonesia, refer to Koh et al. (2011)

Table 40.8 Cropping patterns and their changes in 47 plots with resurvey: first cultivation up to the 2006 season

	(A) Rice	(B) Rice + vegeta-bles/fruits + others (ex. rubber)	(C) Rice + rubber + others	(D) Rice + other-crop combi nations	(E) Veg etables	(F) Fruits + others (ex. rice and rubber)	(G) Rubber	(H) rubber + others (ex. rice)	(I) Com-mercial crops and/or trees	(J) Cassava + others (ex. rice, fruits, rubber)	(K) Fallow	Total 2006 cropping pattern
(A) Rice	9	0	0	0	0	1	0	0	0	1	0	11 (23.4 %)
(B) Rice + vegetables/fruits + others (ex. rubber)	0	9	0	1	0	0	0	0	0	0	0	10 (21.3 %)
(C) Rice + rubber + others	3	3	1	0	0	0	0	0	0	0	0	7 (14.9 %)
(D) Rice + other-crop combinations	2	0	0	0	0	0	0	0	0	0	0	2 (4.3 %)
(E) Vegetables	0	0	0	0	0	0	0	0	0	0	0	0 (0.0 %)
(F) Fruits + others (ex. rice and/or rubber)	0	0	0	0	1	0	0	0	0	0	0	1 (2.1 %)
(G) Rubber	4	0	0	0	0	0	0	0	0	0	1	5 (10.6 %)
(H) Rubber + others (ex. rice)	1	2	0	0	0	0	0	0	0	0	0	3 (6.4 %)
(I) Commercial crops and/or trees	0	0	0	0	0	0	0	0	0	0	0	0 (0.0 %)
(J) Cassava + others (ex. rice, fruits, rubber)	0	0	0	0	0	0	0	0	0	1	0	1 (2.1 %)
(K) Fallow	4	2	0	1	0	0	0	0	0	0	0	7 (14.9 %)
Initial cropping pattern	23	16	1	2	1	1	0	0	0	2	1	47
(Ratio)	(48.9 %)	(34.0 %)	(2.1 %)	(4.3 %)	(2.1 %)	(2.1 %)	(0.0 %)	(0.0 %)	(0.0 %)	(4.3 %)	(2.1 %)	(100 %)

Table 40.9 Cropping patterns and their changes in the 47 plots with resurvey: from the 2006 to the 2009/2010 crop season

	(A) Rice	(B) Rice + vegetables/fruits + others (ex. rubber)	(C) Rice + rubber + others	(D) Rice + other-crop combinations	(E) Vegetables	(F) Fruits + others (ex. rice and rubber)	(G) Rubber	(H) Rubber + others (ex. rice)	(I) Commercial crops and/or trees	(J) Cassava + others (ex. rice, fruits, rubber)	(K) Fallow	2009/2010 cropping pattern
(A) Rice	1	1	0	0	0	0	0	0	0	0	0	2 (4.3 %)
(B) Rice + vegetables/fruits + others (ex. rubber)	0	2	0	1	0	0	0	0	0	0	1	4 (8.5 %)
(C) Rice + rubber + others	0	1	0	0	0	0	0	0	0	0	0	1 (2.1 %)
(D) Rice + other-crop combinations	0	0	0	0	0	0	0	0	0	0	0	0 (0.0 %)
(E) Vegetables	0	0	0	0	0	0	0	0	0	0	0	0 (0.0 %)
(F) Fruits + others (ex. rice and/or rubber)	0	0	0	0	0	1	0	0	0	0	0	1 (2.1 %)
(G) Rubber	3	1	1	0	0	0	1	1	0	0	0	7 (14.9 %)
(H) Rubber + others (ex. rice)	1	3	3	0	0	0	2	1	0	0	0	10 (21.3 %)
(I) Commercial crops and/or trees	0	0	0	0	0	0	0	0	0	0	0	0 (0.0 %)
(J) Cassava + others (ex. rice, fruits, rubber)	0	0	0	0	0	0	0	0	0	0	0	0 (0.0 %)
(K) Fallow	3	1	0	1	0	0	0	0	0	0	0	5 (10.6 %)
(L) Sold/abandoned/rent out	3	1	3	0	0	0	2	1	0	1	6	17 (36.2 %)
2006 Cropping pattern	11	10	7	2	0	1	5	3	0	1	7	47
(Ratio)	(23.4 %)	(21.3 %)	(14.9 %)	(4.3 %)	(0.0 %)	(2.1 %)	(10.6 %)	(6.4 %)	(0.0 %)	(2.1 %)	(14.9 %)	(100 %)

captured in row (L) of Table 40.9. The rapid expansion of the oil-palm plantations altered the scene of the Lamunti area. Those six respondents who rented out their plots to an oil-palm plantation became hired wage workers of that plantation, and were mainly engaged in planting oil-palm seedlings. They preferred the current hired work to their own farming mainly because they could earn a steady wage income across the seasons.

The impact of the expansion of oil-palm plantations is not limited to the Lamunti area. Many residents in the Paduran area, including one of our 18 respondents, moved out to seek jobs at oil palm plantations. In the peat soil area in Indonesia, an important empirical question in the near future is whether large transnational oil-palm plantations will induce surrounding small farmers to plant oil palms. Among our respondents, no one had planted oil palm in their first cropping. The main survey in the year of 2006/2007 found only one plot with oil palm. In the 2010s, will oil palm planting increase on the plots of small farmers? If so, the long-run impact of oil-palm trees on peat soil may need to be carefully evaluated.

40.4.3 Soil Analysis

To analyze the impact of peat-soil characteristics on the land-use strategy of the respondents, from the same plot about which we investigated the changes in cropping patterns, we collected soil samples both in the main survey and in the resurveys in 2009 and 2010. In each plot, we collected two soil samples: surface peat and the mineral soil below the peat layers. With two missing soil-sample sets, we have 100 plot-wise soil data out of the 102 plots with the information of cropping patterns.

For the collected peat and mineral soil samples, we have implemented the following analyses. For peat samples, we measured only solid (ash) content: C-organic (organic matter content: defined as 100 % minus ash content (%)). For mineral soil samples, we measured C-organic, pH, Electric Conductivity (EC), and pyrite (FeS_2). C-organic in the mineral soil samples was measured because it was possible that some of the mineral soil samples were in fact peat. Samples with C-organic value of less than 18 % are considered as mineral soil. Table 40.10 summarizes the depth of peat layers at the sampling points, and C-organic measurements of the collected peat samples. All the sampled farm fields have a shallow peat layer, less than 50 cm. Even the sample plots in Lamunti, the MRP area, are on a shallow peat layer.

Table 40.11 summarizes the chemical characteristics of the mineral-soil samples collected from the bottom of the peat layer. As is expected, the bottom soil is highly acidic (low pH). Among the 94 mineral-soil samples, 28 samples showed a pH of less than three. All of these 28 samples are from the Basarang and the Lamunti area. Many soil samples also contained a lot of pyrite. EC measurements are in general

Table 40.10 Surface peat

	Number of samples		Depth of peat (cm)	C-organic (%)
Total	100	Average	42.7	42.5
		Std. dev.	(30.0)	(19.2)
		Max	179.0	84.5
		Min	0.0	12.5
Basarang	25	Average	53.4	46.8
		Std. dev.	(40.6)	(23.3)
		Max	179.0	83.8
		Min	0.0	12.5
Pangkoh	28	Average	42.7	38.1
		Std. dev.	(22.1)	(15.2)
		Max	85.0	81.0
		Min	(10.0)	17.7
Lamunti	30	Average	42.9	48.0
		Std. dev.	(25.1)	(20.8)
		Max	100.0	84.5
		Min	10.0	18.6
Paduran	17	Average	26.7	33.9
		Std. dev.	(25.9)	(9.8)
		Max	108.0	61.2
		Min	5.0	21.5

low, suggesting low fertility with little minerals.[22] Over all, Table 40.11 reconfirms the suspicion of fragile sustainability of agricultural production in the study area, in particular, if the surface peat is lost (e.g., Furukawa 1994).

One of our interests is whether these characteristics of peat layer are a significant determinant of farmers' land-use strategy. The author has run several regression specifications, but could not find statistically significant impacts of peat-layer characteristics on farmers' crop choice. For example, Table 40.12 shows the probit regression on a dummy variable for the plots where the initial cropping pattern consisted of only annual crops: 53 observations in Table 40.7. This dummy variable takes the value one if perennial crops replaced annual crops as of 2006: 23 cases out of the 53 observations. No explanatory variables in Table 40.12, including C-organic of surface peat and pH of the bottom soil, have statistically significant coefficients. Only the coefficient of household head's age shows marginally significant positive impact. To make conclusive discussions, further analyses are obviously needed.

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[22] A few exceptionally high EC measurements in the Basarang area may need to be reexamined.

Table 40.11 Chemical characteristics of the bottom soil

	Total	Basarang	Pangkoh	Lamunti	Paduran
	pH				
Number of valid samples	94	24	26	28	16
Average	3.4	3.2	3.6	3.2	3.6
Std dev.	0.5	0.7	0.5	0.5	0.2
Max	4.5	4.5	4.3	4.0	4.0
Min	2.2	2.2	2.7	2.3	3.3
	Electric conductivity				
Number of valid samples	93	23	26	28	16
Average	1.4	2.4	0.7	1.6	0.5
Std dev.	1.7	2.0	1.4	1.6	0.6
Max	7.1	7.1	5.0	5.0	2.1
Min	0.04	0.05	0.04	0.14	0.13
	Pyrite[a]				
Number of valid samples	94	24	26	28	16
Average	2.1	2.4	1.9	2.4	1.4
Std dev.	0.8	0.7	0.9	0.7	0.6
Max	3	3	3	3	3
Min	1	1	1	1	1

[a] Qualitative indicator: 1 = little, 2 = moderate, 3 = a lot of pyrite

Table 40.12 A probit regression

Dependent Var: changes from annual to perennial crops 53 observations			
	Coefficient	Std. error	z-value
Constant	–1.77	1.98	0.89
Head's age	0.03	0.02	1.92
Number of family members in production age	0.26	0.21	1.25
Dummy for Java and Bali heads	–0.03	0.45	0.06
C-organic of surface peat	0.01	0.01	1.17
Depth of peat layer	–0.00	0.01	0.09
pH of bottom soil	–0.32	0.46	0.70
Size of plot	–0.10	0.27	0.36
Travel time to plot	0.01	0.02	0.90
Dummy for Paduran HHs	–0.64	0.48	1.32
Pseudo R^2	0.18		

40.5 Discussion

This chapter summarizes the field survey on 108 migrant farmers in the four ex-transmigration settlements constructed in the peat-soil areas in the province of Central Kalimantan, Indonesia. Our survey revealed that sales of farm produce was not a large source of cash income among our respondents: it accounted for less than one quarter of their cash earnings. Such low cash income from agricultural activities may imply relatively low cost for the implementation of REDD projects in the peat-soil area in Central Kalimantan. But the rubber trees, many of which are maturing in our study sites, may drastically change the cash flow of the transmigrant farmers. Even at the stage of the baseline survey in 2006–2007, a few farmers obtained good income from latex tapping (Table 40.6). Our survey also found that rice cultivation was rapidly decreasing in the area, and the industrial oil-palm plantations were drastically changing the scene in the study sites.

An alleged main cause of wild fire in the area has been leakage of fire used for land preparation by small farmers: burning the surface peat along with the agricultural residue for fertilizing the field. Such an allegation and the cropping-pattern evolution toward perennial crops among our respondents jointly suggest a hypothesis to be examined: a vicious circle of poverty and forest fire. Those farmers who are poor cannot invest in perennial tree crops such as rubber, and therefore stick to the annual crops such as rice and vegetables. They then annually burn the field for land preparation. Such agricultural burning may again cause uncontrolled wild fire. The risk to lose the investment in perennial crops by forest fire further increases the cost of tree planting for poor farmers. This can be a typical vicious circle of poverty.

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Chapter 41
Sustainability Education and Capacity Building in Central Kalimantan, Indonesia

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Abstract Hokkaido University started its first sustainable education program in 2005 in collaboration with five Japanese universities. In 2009, this collaboration was expanded to include several foreign universities, including two Indonesian Universities. We started using an internet remote lecturing system, to develop a "global classroom", which merged several classrooms around the world into one. In these comprehensive birds-eye view education programs, diversity is probably the important keyword. New professionals – in science and technology especially – could learn about the three pillars of sustainability (environment, economy and society), while sharing diversified interests, values and opinions. This method afforded them the ability to work with other field personnel in the environmental, social and economic sectors to come up for holistic strategies for sustainable development. We also conducted field tours in Central Kalimantan, Indonesia, in collaboration with the University of Parangka Raya. Our Project also facilitated capacity-building between Japanese and Indonesian NPO's.

Keywords Sustainable development • Global classroom • Holistic approach • Field tour

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41.1 Introduction

Sustainability has been on the central agenda of many international organizations for the last two decades. Besides, sustainability studies and education do not have any concrete foundations or acceptance in many of the world's universities. It is still not unusual to meet scholars and professionals who refer to sustainability science as a pseudoscience. Indeed, it is not a conventional science but a science with totally new paradigm, and well-trained or well-established sustainability scientists are presently rare if not non-existent.

At the United Nations (UN) Millennium Summit in 2000, the Millennium Development Goals (MDGs) were declared to be the eight most urgent international goals for assuring fair, and well-balanced development by 2015, namely; (1) Eradicate extreme poverty and hunger, (2) Achieve universal primary education, (3) Promote gender equity and empower women, (4) Reduce child mortality, (5) Improve maternal health, (6) Combat HIV/AIDS, Malaria and other diseases, (7) Ensure environmental sustainability, and (8) Global partnerships for development. Since the 2012 Rio+20 summit (United Nations Conference on Sustainable Development), the international community – including governmental and non-governmental organizations (NGO's) – have started committing to the implementation of green development strategies and fostering the new kinds of professionals needed to achieve them.

In 2005, five universities in Japan, namely, Hokkaido University, The University of Tokyo, Osaka University, Kyoto University and Ibaraki University, formed the "Integrated Research System for Sustainability Science" (IR3S) and started to establish and develop Science for Sustainability. The IR3S also promoted the establishment of unique education programs for sustainability science in each member university, together with core lectures in sustainability science, which should be shared by all IR3S member universities via the global classroom system (described below). Under the IR3S umbrella, Hokkaido University has developed a unique sustainability education course, "Hokkaido University Inter-departmental Graduate Studies for Sustainability" (HUIGS) program. This program offers seven subjects to graduate students from any graduate school in Hokkaido University. The HUIGS program aims to foster three competences (deepen professional knowledge, widen professional insight into other disciplines, and connect them for holistic approaches). From 2009, the HUIGS program was expanded to include several non-Japanese universities and to embrace a more comprehensive set of training programs known as "Special coordinated training program for sustainability Leaders and Sustainability 'Meisters'" (StraSS) under the financial support from Japan Science and Technology Agency (JST) (Center for Sustainability Science 2012). Four universities in China, Japan, Indonesia, and Taiwan (the 2iE institute from Burkina Faso recently withdrew from StraSS due to logistical difficulties) are assembled under the auspices of the International StraSS Alliance for conducting global classroom (mentioned later) education and establishing joint diploma programs.

On the other hand, a NPO, the Hokkaido Kalimantan Exchange Association, which is based in Sapporo, Japan, has assisted with reforestation activities at the University of Palangka Raya (UNPAR), and provided environmental education to schoolchildren since 2008. The objectives of these activities, which are in line with the "Science and Technology Research Partnership for Sustainability Development Project" (SATREPS) entitled as "Wild Fire and Carbon Management in Peat-forests in Indonesia", have proven very effective at improving awareness in local communities of the importance of forest fire prevention and reforestation. These activities have also allowed Japanese to understand many of the issues concerning illegal logging and forest fires in tropical peatlands, and issues that have can a large impact on global warming.

To restore burnt and ruined peat forests, it is necessary to raise local awareness. Among the local population are the Dayak, who have lived in the peatland forests, taking it for granted that they are the recipients of the natural blessings of the forests. The idea of protecting and growing their forests has not taken root among those living around the peat forests that have been lost due to illegal logging and reckless national projects conducted during the last few decades to develop the peatlands. The purpose of the activities is to make clear the necessity and importance of conservation and restoration of forests and to implant this sense of awareness into the local community through activities such as tree planting with the local schoolchildren.

41.2 Basic Competencies Expected from HUIGS and StraSS

Here, we introduce the rationale behind the intra- and international collaborative sustainability education programs and describe the essential competencies needed to foster students into professionals capable of assuring global and regional sustainable development in the twenty-first century.

41.2.1 Fundamentals for a Novel New Training Program

In sustainability education, eight urgent MDGs have been envisioned. Bird's-eye and holistic perspectives are the central pedagogical themes in our education program. Sustainability science has to meet immediate and urgent demands for high quality solutions to very complex, interwoven and diverse multilayered issues in natural and social systems. On the other hand, the quest to establish sustainability as the discipline of "sustainability science" in professional communities is still ongoing. The nature of sustainability science is recognized to be beyond normal science since its strongly trans-disciplinary core takes it far beyond the ordinal framework boundaries of modern science.

Under present conditions, it is no easy task to raise so-called “professionals in sustainability science” in conventional higher education institutions. The education system is still under a disciplinary basis and our society still strongly demands professionals with accepted disciplinary skills and thinking. One approach to this situation is to reconsider post-graduate programs in the traditional university higher education system. In this way, a university could maintain its own professional education system as is and also incorporate new programs simultaneously without any troubled negotiations with vested interests within the university. Therefore we can reach our objective of raising professionals, who can engage in solution-oriented projects under any geographical, disciplinary, cultural, traditional, linguistic, and ethnical difficulties. New professionals are expected to utilize their conventional professional skills by integrating with other professionals, stakeholders and interested parties and individuals. The newly-designed programs could provide trainees with such practical field abilities.

Recently, a variety of programs have begun worldwide aimed at the development of environmental leaders (Morishita et al. 2009). Literature reviews and web searches of those closely involved with the environmental leadership training programs in higher education around the world were conducted. These revealed that there is a worldwide trend for the education programs to foster new environmental leaders. Examples of these programs include the Kansas Environmental Leadership Program held at Kansas State University (USA), environmental leadership program at the University of California (USA), and the TERRA environmental leadership program at Thierry graduate school of leadership (Belgium). Japan has launched several environmental leadership programs since 2008. Five projects were adopted in 2008 and seven more were inaugurated in 2009. The special coordinated training program for StraSS in Hokkaido University is one of these programs.

Environmental leadership is not only an issue of the developed world but it is also of prime concern to the developing world. It is important to promote collaborative educational programs for better knowledge and practical experience to solve sustainability-related problems. Japan has decided to assist Asian and African institutions in implementing environmental leadership programs. This can be illustrated in the Asia and Africa science and technology strategic cooperation promotion programs or the so-called international environment leaders training programs. Indeed, during the 1960s and 1970s Japan gained invaluable experience in solving environmental-related problems such as pollution. However, developing countries in Africa and Asia are threatened by multiple environmental problems and lack the proper experience and knowledge to mitigate these threats. The exchange of both knowledge and experience is a fundamental requirement to help imperiled countries overcome their issues. Transferring environmental technologies and practical training to help solve real environmental problems can be achieved through the dissemination of international education systems. These programs develop strong networks among participating institutions and target the creation of “networks of networks”. As aforementioned, networking is very important for mutual knowledge exchange and learning, and makes it possible to impart a sense of experience.

To foster viable sustainability professionals as leaders, our programs seek to augment students' conventional professional disciplinal abilities, by instilling them with viable skills in six key competences. These are (1) Sustainability thinking, (2) Leadership, (3) Ethics, (4) Policy making, (5) Culture, language and regionalism, and (6) Field ability and team work. Each competence is taught in active participatory classes with mixed nationalities, gender, age group, and conventional professions.

The HUIGS program consist of seven subjects (see Table 41.4). Two of the subjects are compulsory but others are elective for the HUIGS diploma. Other elective subjects can also be selected from a range of special lectures given by participating Graduate Schools in Hokkaido University. Students have to take at least two elective subjects. The StraSS program also consists of seven subjects (see Table 41.2), although in this case all subjects must be completed to be eligible for the StraSS diploma. Sustainability I and II are offered as core subjects for global classroom setting. Successful StraSS students are also entitled to receive the HUIGS diploma after they complete their graduate program courses.

Table 41.1 Subjects in HUIGS course

Title	Competencies	Credits	Remarks
Sustainability Sci. I	Understanding sustainability in natural science and technology	2	Compulsory
Sustainability Sci. II	Understanding sustainability in sociology and human science	2	Compulsory
Sustainability Sci. III	Sustainability in rural areas (field tour)	2	Elective
Sustainability Sci. IV	Up-skilling for self-learning on sustainability and report writing	2	Elective
Sustainability Sci. V	Learning cutting-edge global sustainability studies	2	Elective
Sustainability Sci. VI	International cooperation for sustainability development	2	Elective
Sustainability Sci. VII	Sustainable land use change	2	Elective

Table 41.2 Subjects in StraSS course

Title	Competencies	Credits	Remarks
Sustainability Sci. I	Understanding sustainability in natural science and technology	2	Compulsory
Sustainability Sci. II	Understanding sustainability in sociology and human science	2	Compulsory
Environmental ethics	Ethical thinking for sustainability	2	Compulsory
Environmental public policy	Up-skilling for developing sound policy under sustainability	2	Compulsory
Culture, language, regionalism	Learning to interpret and understand diversity	1	Compulsory
Environmental leadership	Leadership training as project managers	1	Compulsory
Extensive course for sustainability (ECOSUS)	Fostering field ability and team work through field tours in Japan and foreign countries	2	Compulsory

41.3 Global Classroom

Sustainable activities that can bring changes to local communities will originate from natural, cultural, industrial and human resources that have close ties to those local areas. As such, programs limited to one-way delivery of educational content from developed to developing countries will ultimately fail to realize their true potential – inputs from developing countries are equally important if a project is to succeed. In addition, even though the participants may have totally different social, cultural, and historical backgrounds, their aims concerning the establishment of a sustainable society need to be identical. Sufficient time for communication is required to allow them to nurture a mindset that they have to collaborate with people from totally different social backgrounds through understanding and mutual respect. Such activities cannot possibly be provided by any intensive short course. In Hokkaido University, we use an Internet-based video conferencing system to establish a virtual global classroom environment that provides precisely these opportunities to the students of our collaborative universities. Here, students from across Asia and Africa can share the same lectures at the same time and are provided with regular opportunities to discuss and exchange opinions with each other.

We define the global classroom as an Internet-based virtual conference room, where students and lecturers can share identical lectures and communication forums at the same time but in different places – in this case the students are in different countries. Using this system, we can simultaneously communicate multidirectionally among several universities, allowing students and lecturers to exchange their questions, answers, and opinions during the lectures. This is the most striking point of difference from the current e-learning system model, where users can download lecture materials from specific websites at their convenience but cannot share simultaneous communication.

There are many "differences" among universities; time, academic calendars (the number of semesters, start and end dates of semester . . . etc.), school and national holidays, cultural and religious, and so on. The design of our common virtual lecture room takes all the above issues into account.

41.4 Field Tours in Central Kalimantan, Indonesia

It is not enough for students to study sustainability in a classroom only. We have conducted two field tours in Central Kalimantan: one organized by the StraSS project, and the other by the SATREPS project. Both tours were conducted in close collaboration with the University of Palangka Raya (UNPAR), Indonesia.

Several times each year StraSS conducts the "Extensive Course for Sustainability" (ECOSUS) field tour. These are conducted both in Hokkaido and in a foreign country, and are one of the compulsory components of the StraSS program: students visit a range of local towns and work together to obtain information on

Table 41.3 Time schedule of ECOSUS, Kalimantan

Day	Classification	Title	Location
1		Registration/opening ceremony	UNPAR
	Lecture	General introduction to sustainability	UNPAR
	Lecture	Introduction to sustainable fisheries	UNPAR
	Lecture	Sustainable forestry in Central Kalimantan	UNPAR
2	Lecture	Electricity development plan	UNPAR
	Lecture	Preservation of health in rural communities	UNPAR
	Lecture	Forest fire protection and prevention	UNPAR
3	Tour	Drinking water supply facilities	Palangka Raya
	Tour	Rattan handicrafts	Palangka Raya
	Tour	Ex-sand mining development	Palangka Raya
	Tour	Local freshwater fish breeding	Tangkiling
4	Tour	Peatland agriculture	Kalampangan
	Tour	A brief history of KHDTK Tumbang Nusa	Tunmbang Nusa, FORDA
5	Lecture	Policies for sustainable local governance	UNPAR
	Lecture	Challenges of managing domestic waste	UNPAR
	Tour	River cruise to observe aquaculture activities plus a short lecture	Kahayan River
6	Tour	Mushroom cultivation venture	Palangka Raya
	Tour	Orangutan reintroduction program	Nyaru Menteng
	Tour	Crumb rubber factory	Crumb rubber factory
7	Lecture	Sustainable oil palm industry	Katingan
	Tour	Oil palm plantation and factory	Katingan
8	Lecture	Environmental education	UNPAR
	Exercise	Group work: preparation for presentation	UNPAR
9	Exercise	Group work: preparation for presentation	UNPAR
10	Exercise	Final presentation	UNPAR
		Closing ceremony and farewell party	UNPAR

local problems affecting regional sustainability. Finally, the students work in groups to propose action plans to host local governments. Even though most of the lectures provided by StraSS are given from a global perspective, regional view points are equally important, because most attempts at resolving sustainability issues usually begin from a regional starting point. Between September 12th and 21st, 2011, in conjunction with UNPAR, we conducted this tour in Central Kalimantan. The schedule is shown at Table 41.3. Students from eight countries participated in the tour. They got to listen lectures from UNPAR staff, and representatives of companies based in Palangka Raya. They also got to visit facilities closely related to local sustainability (drinking water, biodiversity, waste treatment, and so on). The students were divided into three groups, and each group had to propose action plans on waste management, energy, and agriculture to the local government (Fig. 41.1).

SATREPS also organized a field study tour to Palangka Raya during March 4–7th, 2012 (Shiodera et al. 2012a, b) (Fig. 41.2). There were 17 participants from

Fig. 41.1 Final presentations in ECOSUS Kalimantan at UNPAR

Fig. 41.2 Visiting a gold mine during the field tour

Table 41.4 Time table of field tour organized by SATREPS and Civil Engineering Society of Japan

Date	Activity
March, 3	To Palangka Raya from Japan
March, 4	Visit peatland swamp forest, and orangutan conservation area
March, 5	Lecture and group discussions at UNPAR
March, 6	Visit water company at Parangka Raya, visit Mega Rice Project region, visit tree planting area
March, 7	Visit small-scale gold mine, and explanation by NGO
March, 8	Visit JICA Indonesia, and return to Japan

Japan – mainly undergraduate and graduate students – and 5 graduate students from UNPAR. This tour was co-organized by the Japan Society of Civil Engineering. The objectives of this tour were to see and touch environmental problems in an overseas country, and to communicate with local researchers and municipal staff. The tour committee provided lecture handouts to the participants via e-mail prior to the tour. The committee also compiled a mailing list for the participants. This participant-organizer network was used extensively after the tour. The organizers asked the participants to submit their comments to "Friends of SATREPS", an Internet community site organized by JST, in the hope that the participants would keep discussing environmental problems even after the tour concluded (Table 41.4).

41.5 Capacity Building and Environmental Education

41.5.1 The Activity Framework

As shown in Fig. 41.3, this activity, which was conducted within a framework aimed at enhancing volunteer forest restoration activities in the tropical peatlands of Central Kalimantan, saw Japanese NGO's, NPO's and several Indonesian universities working in close collaboration. A key component of the activity was the environmental education team assembled by the SATREPS project to provide environmental education.

Researchers participating in the Japan Society for the Promotion of Science (JSPS) Core University Program "Conservation of environment of ecosystem and land use in Southeast Asia wetlands" established one Japanese NPO, the Hokkaido Kalimantan Exchange Association (HKEA), which has been conducted by Hokkaido University and the Indonesian Institute of Sciences. HKEA has extensive research experience in Indonesia, specifically in the tropical peatlands of Central Kalimantan, and has long worked with UNPAR. The NGO "Eco-Network" (EcoNet) was established as a private organization about 30 years ago, aiming to collect and provide environmental information, mainly about Hokkaido. Since then, EcoNet has engaged in a variety of social education activities, mainly by holding events, such as nature studies and development of a nature walk.

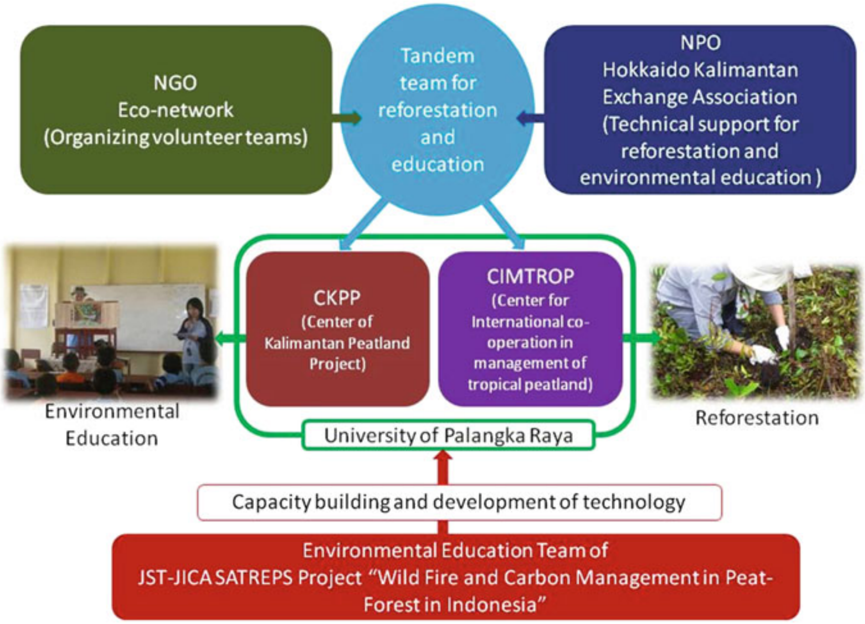

Fig. 41.3 The arrangement of the collaborative reforestation and environmental education activities undertaken by the NGO's and NPO's in Japan, activity centers in the University of Palangka Raya, Indonesia, and the JST-JICA SATREPS project

An Indonesian collaborating organization, the Center for International Cooperation in Management of Tropical Peatlands (CIMTROP) is a research institute established at UNPAR in 1997, with the purpose of tropical peatland conservation. The Buying Living Tree System (BLTS) organization led by this institute is an arrangement that entrusts locals to grow seedlings of tree species that are effective in tropical peatland. It covers all expenses for any young trees grown for up to 2 years after planting. Under this arrangement CIMTROP collects funds to buy trees grown for 2 years by local farmers, and regularly calls for volunteers in Japan to engage in tree-planting activities together with the local farmers.

Another collaborating Indonesian organization, the Center of Kalimantan Peatland Project (CKPP) is a research institute established to design policies for the restoration of local environments ruined by the Mega-rice Project – the large-scale but ultimately unsuccessful development project undertaken in the late 1990s that sought to transform the tropical peatlands of Central Kalimantan into farmlands. The CKPP conducts educational training activities for the local inhabitants, and in collaboration with HKEA, plays a leading role in the volunteer tree-planting activities.

The tree-planting volunteer program is a joint-collaboration between four organizations: HKEA, EcoNet, CIMTROP, and CKPP. This program launched in 2008, and dispatches volunteer teams twice a year. As the SATREPS project started in

Fig. 41.4 Planting a young *Shorea balangeran* tree

2009, the tree-planting volunteer activities have also benefitted from the invaluable assistance of the SATREPS environmental education team.

41.5.2 Tree-Planting Activity

The call for Japanese tree-planting volunteers was conducted via a website and the EcoNet network. There were two courses available: one that did not include planting activities (A) and one that did (B). "A" volunteers met the cost of buying young trees and entrusted the planting to the local farmers. They did not actually go to the site to plant. "B" volunteers paid the cost of the trees and planted the young trees themselves. In November 2007, 12 participants each planted 20 young *Shorea balangeran* trees (240 in total) at sites chosen for forest restoration by CIMTROP (Fig. 41.4). In November 2008, "B" course volunteers planted 200 trees, and in March 2009, they planted 320 trees.

However, the large-scale peat forest fires that occurred during the dry season in 2009 largely destroyed the area where the volunteers had planted young trees, and resulting in the loss of 760 trees (90 %). Furthermore, it became impossible to maintain and manage the area planned for reforestation by CIMTROP because of pressure from the local population who supported deforestation to enable oil palm cultivation and expansion of farmland areas.

Therefore, it was decided to plant 600 young *S. balangeran* trees on 20 ha of land in the Taruna Jaya area managed by the Forestry Science Department, School of Agriculture, UNPAR in November 2012. All the local work and activities were entrusted to the research group of the Forestry Science Department, with the expenses borne by HKEA. Currently, more than 90 % of these young trees have taken root, and are growing well. The department is planning to plant more young trees in the near future.

Fig. 41.5 Environmental education using picture-cards at Taruna elementary school

41.5.3 Environmental Education

The tree-planting volunteer team created a picture-card to make it easier to understand the negative effects of peat and forest fires, and teachers of the educational department of UNPAR translated it into Dayak, the local language, and told the story to third to sixth grade elementary school students. In recent years, environmental education using TV sets and computers has become commonplace, but the handmade picture-card show appeared to give the students a fresh impression (Fig. 41.5). After the picture-card show the children planted young trees together with the participants of the volunteer activity group.

The local schoolchildren measured the heights of the trees that they planted together with the volunteer participants 1 year earlier (Fig. 41.6). By recording the growth of the trees, it was found that the indigenous tree species selected by the JST-JICA project forest restoration team was advantageous in terms of water tolerance and fire resistance and easily took root. These results show that the species is exceptionally well suited to the local conditions, has high value as a building material when mature, and it is expected to significantly contribute to the local economy in the near future.

Fig. 41.6 Giving instructions about how to measure tree height

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