Indonesian Journal of Agricultural Science 11(1), 2010: 32-40

LAND USE CHANGE AND RECOMMENDATION FOR SUSTAINABLE DEVELOPMENT OF PEATLAND FOR AGRICULTURE: Case Study at Kubu Raya and Pontianak Districts, West Kalimantan

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Submitted 4 December 2009; Accepted 25 February 2010

ABSTRACT

Peatland is an increasingly important land resource for livelihood, economic development, and terrestrial carbon storage. Kubu Raya and Pontianak Districts of West Kalimantan rely their future agricultural development on this environmentally fragile peatland because of the dominance (58% and 16% area, respectively) of this land in the two districts. A study aimed to evaluate land use changes on peatland and to develop strategies for sustainable peatland use and management for agriculture. Time series satellite imageries of land use and land cover, ground truthing, and statistical data of land use change were analyzed for generating the dynamics of land use changes in the period of 1986-2008. Field observation, peat sampling, and peat analyses of representative land use types were undertaken to assess peat characteristics and its agricultural suitability. The study showed that within 22 years (1986-2008), the area of peat forests in Kubu Raya and Pontianak Districts decreased as much as 13.6% from 391,902 ha to 328,078 ha. The current uses of the peatland in the two districts include oil palm plantation (8704 ha), smallholder rubber plantation (13,186 ha), annual crops (15,035 ha), mixed cropping of trees and annual crops (22,328 ha), and pineapple farming (11,744 ha). Our evaluation showed unconformity of the current uses of peatland with regulations and crops agronomic requirements such as peat thickness and maturity, rendering unsustainability. This study recommends that expansion of agriculture and plantation on peatland areas be limited over idle land within the agricultural production and conversion production forest areas. About 34,362 ha (9.7%) of uncultivated log-over forest and shrubs can potentially be developed for agriculture. Peat soils with the thickness of >3 m should be allocated for conservation or forest protection due to low inherent soil fertility and high potential greenhouse gas emissions if converted for agriculture.

[***Keywords***: Peatlands, land use, agricultural development, greenhouse gases, West Kalimantan]

INTRODUCTION

Peatland has a multifunctionality including water retention function, a niche for peatland-specific biodiversity, and production of agricultural and forest commodities. Peat stores carbon between 30 and 70 kg C m^{-3} or equivalent to 300-700 t C ha^{-1} per one meter depth (Agus *et al*. 2009). Peatland in Kalimantan stocks an average of about 2000 t C ha^{-1} (Wahyunto *et al*. 2005).

Under the natural forest, peat sequesters carbon and grows between 0.5 and 1.0 mm $year^{-1}$, while drained peat emits carbon and subsides at the rate of 1.5-3.0 cm $year^{-1}$. About 50% of the subsidence is attributable to oxidation (Wösten *et al*. 1997). Since the subsidence rate is 15-30 times the rate of growth under the drained, deforested and drained peats become a major source of greenhouse gas emissions (Agus and Subiksa 2008).

Peat soil fertility is largely determined by three properties, namely thickness, source of inundating water, and type of mineral soil below the peat (substratum). Generally, increases in peat depth as well as distance from the main river are related to lower fertility, because the source of nutrients mostly comes from rain water. The worst fertility condition is if the peat is underlain by quartz substratum such that the ash content is very low. The deep peat is generally poor in nutrients (oligotrophic), especially N, P, K, Ca, Zn, Cu and Si and pH values are in the range of 3.0-4.5. Nutrient availability and pH values decreased with increasing thickness of the peat (Radjagukguk 1991; Istomo 2005).

Kubu Raya and Pontianak Districts of West Kalimantan rely future agricultural development on this environmentally fragile peatland. Kubu Raya has 408,369 ha (58%) and Pontianak has 63,514 ha (16.0%) of the total land area of the respective two districts of 698,520 ha and 397,129 ha. Only about 25% of the peat is shallower than 3 m, while the rest are the 'no-go' peatland areas for agriculture (oil palm plantation) as stipulated by the Minister of Agriculture Decree No. 14/2009. However, due to the increasing population and development pressures, these environmentally fragile soils are converted to intensive agricultural lands for growing tree crops such as rubber and oil palm as well as annual food crops.

In 2008, more than 20,400 ha (4.3%) of the total peatland areas of the two districts have been planted to oil palm, pineapple, and tree crops by small holders and private or state estates. The trend in the development of agricultural areas does not necessarily comply with regulatory and agronomic suitability standards, in such a way that the development may not be sustainable. Years of research and trials and errors by farmers have developed water and nutrient management technologies to cultivate peat soils with reasonably good success (Widjaja-Adhi 1995; Subagjo and Adimihardja 2003). With relatively vast peat shrub and peat forest available for future agricultural development, it is strategically important to consider the suitability and environmental implications of peatland development, especially those related to greenhouse gas emissions and sustainability (Agus *et al*. 2007). Analyses of land use changes and evaluation of land suitability are expected to improve the management of peatland, not only for the studied areas but also elsewhere in Indonesia.

The rapid changes in the peat forest areas have drawn attention among environmentalists as peatlands pose high amount of CO_2 emissions upon peat forest clearing and peatland draining. There is opportunity of compensation, especially through the Reducing Emissions from Deforestation and Degradation + (REDD+) if the carbon in the peatland can be conserved. Therefore, planning the wise use of peatland to minimize the potential carbon emissions will be a challenge in the future regional development. A study is needed to assist the local government and other stakeholders in developing a wiser spatial planning that not only agronomically suitable, but also environmentally acceptable. The objectives of this study were (1) to evaluate land use change on peatlands of Kubu Raya and Pontianak Districts, (2) to evaluate peat properties, and (3) to recommend their use potential for agricultural development.

MATERIALS AND METHODS

Images and maps of Kubu Raya and Pontianak Districts were obtained from various sources, including: (1) satellite images of Landsat Multi Spectral Scanner (MSS) taken in 1986, Landsat Thematic Mapper (TM)-7 taken in 2008, and ALOS taken in 2007 and 2008; (2) topographic maps of 2002 at 1: 250,000 scale; (3) land system and physiographic unit maps of West Kalimantan sheet at 1:250,000 scale published by Regional Physical Planning Project for Transmigration - RePPProT 1986; (4) geological map of Pontianak sheet at a scale of 1:250,000 (Cameron *et al*. 1983); and (5) forest and land status maps at a scale of 1:500,000 published by West Kalimantan Forestry Office in 2008 and provincial land use planning map published by West Kalimantan Development Planning Agency in 2008. Schematic diagram of the spatial data analyses for sustainable peatland development for agriculture is presented in Figure 1.

The land use and vegetation cover map developed by the National Land Agency of West Kalimantan in 2002 was used and modified as a basic source for

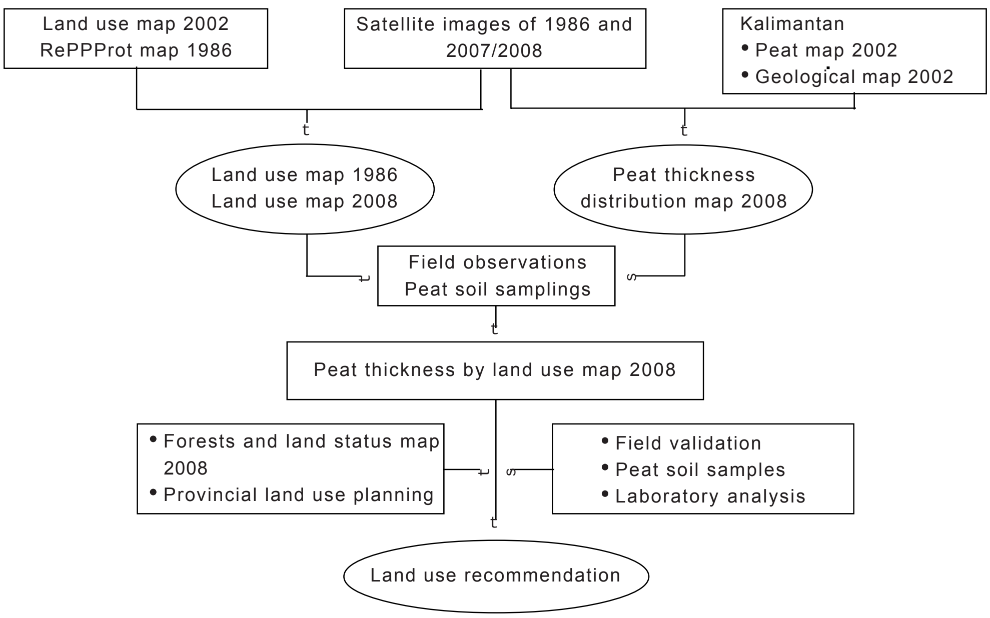

Fig. 1. Flowchart of the spatial data analysis procedure for developing sustainable peatland use recommendation.

exploring time series land use and land cover changes. Time series land use and land cover changes in the period of 1986-2008 were generated using remote sensing techniques, i.e. the Earth Resources (ER) Mapper software. The most recent images were validated by ground truthing conducted in May-June 2009, to gather geo-referenced information on existing land uses.

As many as 49 ground references were selected and peat samples with 50 cm depth increment from the surface to the substratum were collected for laboratory analysis. Sampling points were selected randomly to represent land use or land cover types, peat maturity, and peat depth. Using all the ground references as training sets, i.e. land use, land cover, peat depth, peat maturity, and soil drainage, the spectral signatures of each class category were extracted from the Landsat TM and ALOS scenes for classifying the types of land uses and land cover of the study areas. For the classification process, maximum likelihood supervised classifier was used and refined by hybrid knowledge-based approach (Abkar *et al*. 2000; Singh *et al*. 2001) to reach at least 80% assessment accuracy.

Peatland depth mapping was conducted by visual analysis (through on-screen digitizing) based on tone, texture, site, and pattern of images, then integrated with the physiographic information (Lyon and Carthy 1991). Fourty nine peat observation points were selected by cross sectional transects stretching from the river banks or canal towards the center of peat dome or by random observations depending on the types of land use and land management systems. Each layer (with the 50 cm depth increment) of the selected peat samples was analyzed for bulk density (graphimetric technique) and ash content (loss on ignition, LoI technique). Organic C was calculated based on ash content (Soil Survey Staff 2003; Agus 2009). Descriptions of peat soil characteristics such as peat thickness, maturity, drainage depth, type of substratum material, and agricultural land suitability were developed based on the field observation, secondary data from previous research (Balai Penelitian Tanah 2004) as well as on the sample analysis for the current study.

The potential uses of the peatland for agriculture (annual food crops, tree crops and plantation) were assessed based on peat properties (Djaenudin *et al*. 2003), high economic value and environmental quality impact to reduce carbon emissions (Paris 2002). Peatland of >3 m peat thickness was recommended for conservation and environment protection because of very low fertility and high potential emissions reduction as outlined by the Minister of Agriculture Decree No.14/2009.

RESULTS AND DISCUSSION

Physical Condition of the Study Area

Prior to 2008, Pontianak and Kubu Raya Districts belonged to Pontianak District with an area of 1,095,649 ha. In 2008, the district was split into two districts, namely Kubu Raya and Pontianak, each with an area of 698,520 and 397,129 ha, respectively. Based on time series satellite imagery analysis, supported by other relevant spatial data, peatland areas of Kubu Raya and Pontianak Districts are 408,369 (58% of the total district area) and 63,514 ha (16%), respectively (Table 1).

In general the rainfall in the two districts is > 3000 mm year^{-1}. The agroclimatic map of Kalimantan shows that most areas of the province have less than two dry months (<100 mm rainfall) per year (ICSARD 2005). During these dry months, the relative humidity (RH) remains high. August is the least humid month with the RH of 82%. In comparison, the average RH of November is 86.5% and of December is 86.6%.

Land Use and Land Use Change

Peatland forest area in Kubu Raya and Pontianak Districts sharply decreased from 391,902 ha (83.1%) in 1986 to 328,078 ha (69.5%) in 2008. The subsequent land uses included rice field, and other annual crop lands, mixed tree crops, transmigration settlements, small holder and pineapple plantation, and oil palm plantation. Agricultural land increased sharply, especially for rice field from 472 ha (0.1%) in 1986 to 41,753 ha (8.8%) in 2008, annual crops (vegetables, maize and others) from 10,282 ha (2.2%) in 1986 to 15,035 ha (3.1%) in 2008, while oil palm and pineapple plantations increased from none to 8704 ha and 11,744 ha in 2008, respectively (Table 2).

Table 1. Peatland areas for Kubu Raya and Pontianak Districts, West Kalimantan.

District	Peatland area (ha)	Upland area (ha)	Total land area (ha)
Kubu Raya	408,369 (58%)	290,151 (41%)	698,520
Pontianak	63,514 (16%)	333,615 (84%)	397,129
Total area	471,883	623,766	1,095,649

Table 2. Area of peatland under different land use types in 1986 and 2008 for the shallow (<3 m) and deep (>3 m) peat in Kubu Raya and Pontianak Districts, West Kalimantan.

Types of land use	Area in 1986 (ha)			Area (%)	Area in 2008			Areas (%)
	<3 m	>3 m	Total		<3 m	>3 m	Total	
Forest	43,285	348,617	391,902	83.1	35,307	292,771	328,078	69.5
Bushes	2408	3244	5652	1.2	5958	17,642	23,600	5.0
Shrubs and fern	1843	1932	3775	0.8	214	-	214	0
Mangrove	1273	5056	6329	1.3	1273	4633	5906	1.3
Mixed tree crops	11,448	19,521	30,969	6.6	12,483	9845	22,328	4.7
Swamp/water body	79	610	689	0.1	79	1256	1335	0.3
Oil palm	-	-		-	3022	5682	8704	1.8
Rubber Small holder	2682	19,131	21,813	4.6	6792	6394	13,186	2.8
Pineaples	-	-		-	6915	4829	11,744	2.5
Annual crops-vegetables	237	-	237	0.1	313	4640	4953	1.1
Annual crops-maize	1509	-	1509	0.3	792	848	1640	0.3
Annual crops-others	7791	745	8536	1.8	2614	5828	8442	1.8
Rice fields	472	-	472	0.1	40,082	1671	41,753	8.8
Total of peatland area	73,027	398,856	471,883	100	115,844	356,039	471,883	100.0
%	15.5	84.5	100.0		24.5	75.5	100.0	
Non peatland area			623,766	56.9			623,766	56.9
Total area of districts			1,095,649				1,095,649	
% peatland from the total area of the two districts	6.7	36.4	43.1		10.6	32.5	43.1	

Areas of deep peat (peat thickness of >3 m) decreased 9.0% from 398,856 ha (84.5%) in 1986 to 356,039 ha (75.5%) in 2008, or about 1946 ha (0.4%) per year during the 22 year period. On the other hand, shallow peat areas (peat thickness of <3 m) of both districts increased from 73,027 ha (15.5%) in 1986 to 115,844 ha (24.5%) in 2008. Bushes and shrubs in 1986 covered 9427 ha (2.0%) land, while in 2008 they became 23,814 ha (5.0%). Decrease in deep peat areas and increase in shallow peat areas as well as areas of bushes and shrubs indicated the degradation and subsidence of peatland.

Part of the peatland has been used for oil palm plantation since 1994. Until 2008, the oil palm plantation in peatland has reached 8704 ha, covering 8194 ha in Kubu Raya and 510 ha in Pontianak. Rice field in peatland in 1986 covered 472 ha (0.1%), and in 2008 it became 41,753 ha (8.8%) including 35,541 ha in Kubu Raya and 6212 ha in Pontianak.

Annual crop farming is continuously increasing, such as maize, vegetable, pineapple, and legumes. Under the traditional farming, land preparation generally involves fire to produce ash to increase the peat fertility. The burning not only increases CO_2 emissions but also produces haze. Recently, the development of pineapple plantation by private estates and small holders are managed without burning as the companies can afford fertilization.

Properties and Constraints of Peatland for Crop Cultivation

Based on the latest version of Soil Taxonomy (Soil Survey Staff 2003), the peat soils are classified as Histosols. Polak (1941; 1949) was first to propose definition of Indonesian peat soils. He stated that peat soil contains more than 65% by weight organic matter, with a minimum depth of 50 cm. This definition is most widely adopted, since it is particularly meaningful for farmers in the swamp land, who find that wetland rice can still be grown on land with peat shallower than 50 cm. However, when rice are grown in deeper peats, which are mostly low in nutrient contents, their yield is very low. These deeper peatlands are nearly saturated or saturated with water, or even inundated for a long period of the year, unless they have been drained (Subagjo and Adimihardja 2003). These peat deposits were formed in basin, closed depressions, or close marshes. Most of them are on lowland or coastal plains.

Peat in West Kalimantan belongs to the suborders of fibrists (least decomposed peat), hemists (halfly decomposed), and saprists (fully decomposed). At the lower category, the most commonly found great groups are Haplofibrists, Haplohemists, Sulfihemists, and Haplosaprists (ICSARD 2004, 2005).

Carbon content and bulk density by degree of peat decomposition (maturity) levels is presented in Table 3. It shows that more decomposed peat tends to have higher organic-C content and higher bulk density.

Crop Suitability of Peatland

The types of mineral materials underlying the peat influence its inherent fertility. They may consist of non-sulfidic clay, sulfidic (marine) clay or sandy substratum. Non-sulfidic clay mineral materials underlying the peat are commonly found in inland peats, and considered as the better substratum. If the underlying substratum is quartz sand, then the peat soils have low to very low in inherent fertility. When the mineral substratum in shallow peats is sulfidic and exposed to aerobic condition, there is a possibility of formation of acid sulphate soils; a very poor peat for crop cultivation.

From the view point of chemical soil properties, the constraints of peat soils for crop cultivation are multitude. The most prominent ones are low to very low inherent soil fertility, excessively acid soil reaction (pH 3.0-4.5), and deficiency in micronutrients, particularly Cu and Zn (Riwandi 2000).

Eutrophic peats (more fertile) have a better prospect of success for cultivation than those of mesotrophic (moderate fertile) and oligotrophic (less fertile) peats. In essence, for successful cultivation, peat soils require three crucial management systems, i.e. (1) draining and good water management; (2) control of soil acidity using a combination of agricultural lime, dolomite, and rock phosphate; and (3) adequate fertilization management, both for macronutrient (N, P, and K) and micronutrient particularly Cu and Zn. For these reasons, successful agriculture on peat soils is considered "expensive", that, in many cases, unaffordable among local farmers.

Field observations showed that many agricultural crops grow well on peat soils of both districts. Successful agriculture especially vegetables farming on peats can be found in Pontianak and Kubu Raya, especially in Rasau Jaya, Pinang Luar, Jangkang, and Siantan Subdistricts.

Agricultural potential on peat soils is very much dependent on the farm management level. At low to medium management levels, rice only grow well on peaty soils and shallow peats (peat thickness of <1 m). Secondary crops (*palawija*), vegetables, and estate crops, especially oil palm, rubber, coffee, and cacao grow well on moderately deep peats (peat thickness of 1-3 m). Local farmers of both Kubu Raya and Pontianak Districts manage peat soil with high input for vegetables and fruit trees. Estate crops particularly oil palm, coffee, and cocoa can still grow well on deep peats.

In general, shallow peats (peat thickness of < 3 m) of sapric materials have a relatively better agricultural potential than those of deep peats (peat thickness of >3 m) consisting of hemic and fibric materials. The presence of mineral materials between the peat layers helps to increase the fertility of peats. The fringe parts of the dome, mostly consisted of mesotrophic and eutrophic shallow peats (< 3 m), have a better inherent fertility than oligotrophic deep peats (>3 m) located on the central part of the dome. Map of existing land use on peatland of the study area is presented in Figure 2. Table 2 presents existing land use by various peat depths, and Table 4 shows potentially suitable areas for agricultural crops on shallow peat (peat thickness of < 3 m).

Table 3. Peat soil carbon content and its bulk density by degree of decomposition.

Degree of peat decomposition	Bulk density[1 and 2] ($g\ cm^{-3}$)		Carbon content[3] (% by weight)	
	Range	Average	Average	Standard deviation
Fibric	0.09-0.26	0.13	40	11
Hemic	0.15-0.33	0.23	50	13
Sapric	0.26-0.38	0.27	66	20
Peaty soil	0.26-0.40	0.30	31	11

[1]ICSARD (2004, 2005).
[2]Wahyunto *et al.* (2005).
[3)]Peat samples of Kubu Raya and Pontianak Districts.

Future Peatland Utilization

The Government of Indonesia has long issued the Presidential Decree No. 32/1990, allocating peatland of >3 m thickness for conservation purposes, although in reality there is little compliance on this decree. Nevertheless, this criterion was applied in the land use recommendation under this study. The Indonesian Center for Soil and Agroclimate Researh and Development (ICSARD 2004, 2005) suggested that peatland with the peat thickness of 0.5-1.0 m can be used for annual crop cultivation, while that with 1.0-3.0 m thickness may be used for perennial tree crops.

In addition other criteria including legal status and peat properties (degree of decomposition and maturity) were also taken into account in the suitability evaluation. By regulation, peatland within the protec-

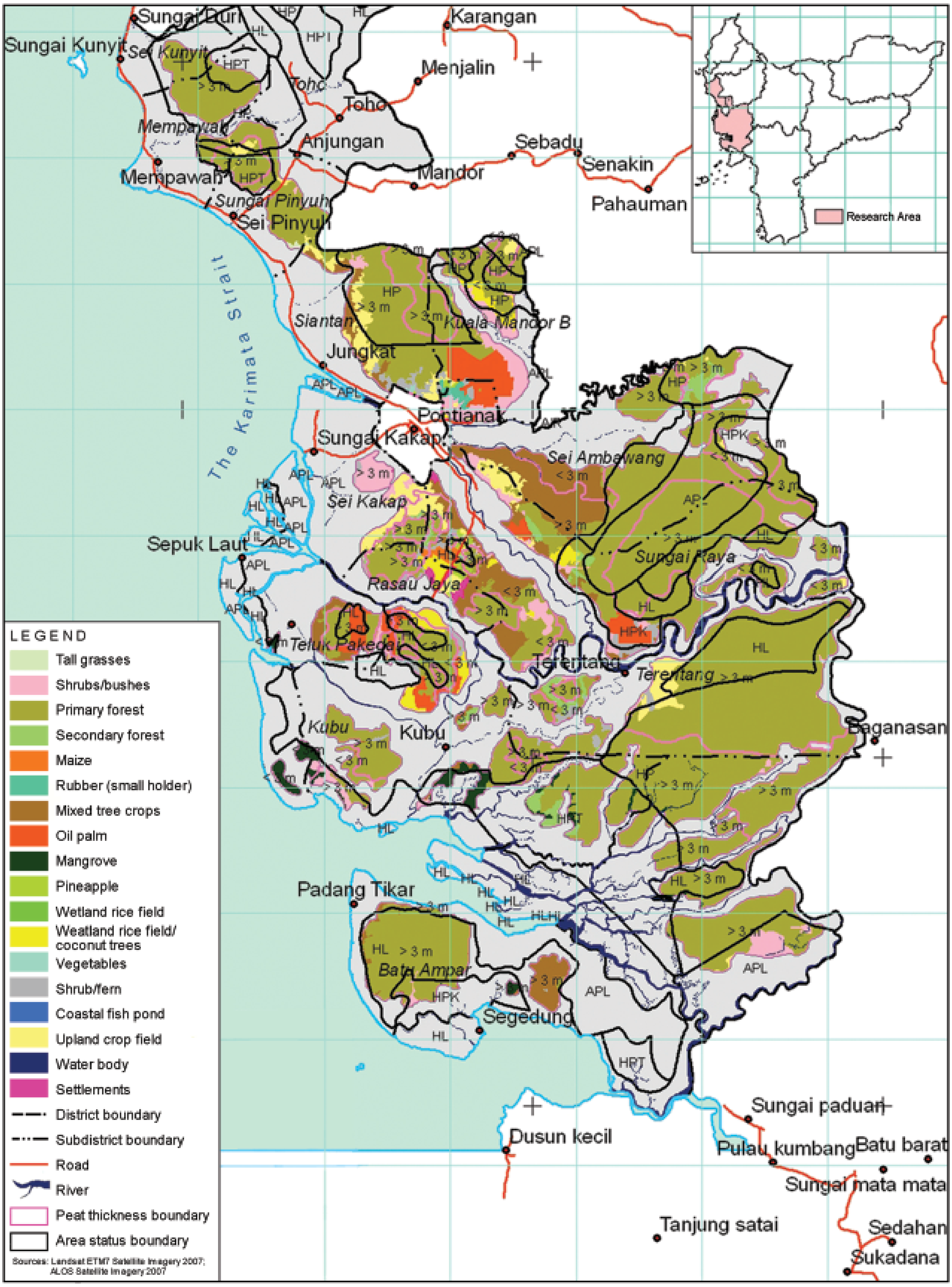

Fig. 2. Existing land use on peatland by indicative peat depth for Kubu Raya and Pontianak Districts, West Kalimantan.

Table 4. Potentially suitable areas for agricultural crops on peatland in Kubu Raya and Pontianak Districts, West Kalimantan.

Land use types	Areas	Land status[1]	Potential crops/land use recommendation
Forest	26,773	APL	Estate crops, annual crops, horticultural crops
	6787	HPK	Estate crops, annual crops, horticultural crops
	1747	HL	Forest conservation
Bushes and shurbs	688	APL	Annual crops (including paddy field), horticultural crops
	214	HPK	Annual crops, horticultural crops
	5270	HL	Forest conservation
Mangrove	1273	HL	Forest conservation

[1]Land status referred to the agreed forest use catagories map published by the Ministry of Forestry in 2008; APL = areas allocated for non-forestry, including agriculture, HPK = conversion production forest, HL = forest reserve areas for conservation.

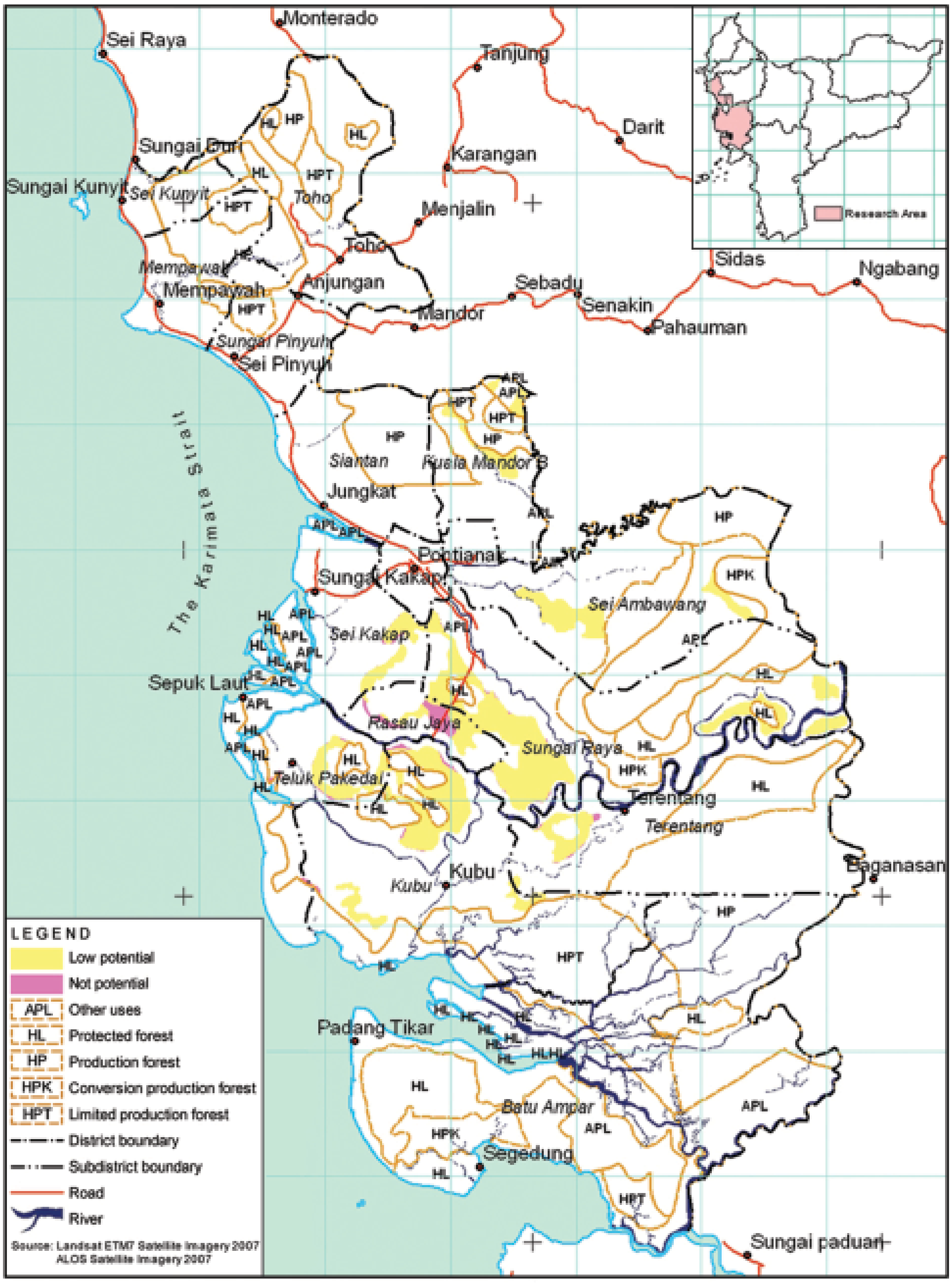

Fig. 3. Recommendation for sustainable peatland development for agriculture in Kubu Raya and Pontianak Districts, West Kalimantan.

tion forest, national park, conservation reserves, wildlife sanctuaries, and recreation forest may not be converted for agricultural uses.

Ministry of Agriculture Decree No. 14/2009 allows future concession for oil palm plantation only on < 3 m thick peat, non-acid sulphate within 100 cm depth, clay substratum and sapric or hemic peat maturity. Peat dominated by fibric maturity and sand/quartz substratum should be conserved as peat swamp forest. Based on the above, legally complied and agronomically suitable criteria, Figure 3 shows agricultural land resources potential as a land use recommendation map for the two districts. In total, about 42,752 ha peatland are potential for future agricultural development.

CONCLUSION

During the past 22 year period from 1986 to 2008, peatland forest areas in Kubu Raya and Pontianak Districts have been decreasing by 13.6% from 391,902 ha to 328,078 ha with shrub, oil palm plantation and rice fields as the dominant subsequent land uses. Deforestation is continuing, but not all of the deforested lands were used for agriculture and this has caused expansion of shrubland. This study has provided a map of future land use recommendation, by taking into account the legal status and agronomic suitability. The recommendation prioritizes the use of underutilized peat shrub and peatland that meet the criteria as stipulated by the existing regulations. The map may be used as a basis for the two districts' spatial plan for agricultural development as well as a reference in developing the REDD+ project in the area.

ACKNOWLEDGEMENTS

This research was funded by the State Ministry of Research and Technology in 2009. Sincerely thanks are extended to the West Kalimantan Plantation Office, West Kalimantan Development Planning Agency, and West Kalimantan Assessment Institute for Agricultural Technology for providing information and facilitation.

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