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ALTERNATIVE TREE CROPS FOR RECONSTRUCTION OF THE GREEN INFRASTRUCTURE POST-TSUNAMI IN THE COASTAL AREAS OF ACEH BARAT DISTRICT

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ABSTRACT

Tree farming such as coconut, cocoa, coffee, rubber, and rambutan was dominant in the west coast of Aceh prior to tsunami. The farming is not only important for sustainable livelihood, but also for superior environmental protection. During the tsunami, considerable portion of this ‘green infrastructure’ was devastated. Therefore, a scientifically based land suitability evaluation is needed for supporting the redesign and reconstruction of the tree-based farming. The objectives of this research were to evaluate the current physical condition of the area and develop recommendation of land suitability for tree crops farming in the area. Field survey for inventory and evaluation of land characteristics was conducted in 2006, 15 months after the tsunami. Land suitability evaluation was conducted by matching field survey data and soil sample analyses in every mapping unit with crop growth requirements. The land suitability map was further matched with the district development plan, existing land uses and land status. The resulted land use recommendation map showed that the marine ecosystem along the coastal line was most suitable for coconut, cacao, coffee, and casuarinas. The recommended tree crops for the ancient sandy beach were areca nut, coconut, rambutan, mango, rubber and oil palm; and for the alluvial ecosystem were coconut, cacao, areca nut, mango, and bread fruit. Peatland of less than 3 m thick was marginally suitable for oil palm and rubber, while those thicker than 3 m were recommended for conservation due to its fragile ecosystem. In the undulating tectonic plain, the suitable tree crops were rubber, oil palm, coconut, and rambutan.

[***Keywords***: Tree crops, land suitability, tsunami, coastal area, Aceh]

INTRODUCTION

Aceh Barat was one of the most devastated districts during tsunami calamity in Nanggroe Aceh Darussalam (NAD) Province in 2005. Prior to the tsunami, agricultural sector played an important role in economic and farming developments in NAD. It contributed to around 60% of village income, and about 48% of villagers engage in agriculture (Subagyono *et al*. 2005).

Aceh Barat District consits of 11 subdistricts, with Meulaboh as the capital. Four subdistricts directly facing to the Indian Ocean, namely Arongan Lambalek, Samatiga, Johan Pahlawan and Meureubo were inhabited by approximately 60% of the total population of Aceh Barat District (Badan Perencanaan dan Pembangunan Daerah Kabupaten Aceh Barat 2005). These four subdistricts were severely hit by the tsunami in 2005.

Tsunami in the west coast of Aceh Barat caused widespread destruction not only to the infrastructures but also to the farmlands. Around 24.7% of agricultural land along the coast of the district was devastated by tsunami, including the perennial tree (such as citrus, cocoa, and coffee) and annual crop lands (maize, mungbean, cassava, rice, and sweet potato). The disaster has caused at least 763 households (6.7%) lost of farms and damaged 64% of irrigation networks (Dinas Pertanian Tanaman Pangan dan Hortikultura Provinsi Nanggroe Aceh Darussalam 2005). Remote sensing analyses by comparing the data before and after tsunami followed by ground truth indicated that about 1950 ha rice fields and 658 ha settlements were damaged and 24 ha areas disappeared due to the coast subsidence (Balai Penelitian Tanah 2005). The tsunami caused various damages such as changes in landscape, deposition of mud transported from the sea, sea water infiltration into the soil profile which increased soil salinity, and deposition of debris on soil surface (Rachman *et al*. 2005; Agus *et al*. 2008).

The deposition of tsunami mud on top of the original soil profile changed the soil properties. The change in soil salinity is short lived, while changes in basic cation composition stay longer. The yield of food crops such as rice and peanut from the affected areas decreased. This may be attributed to the imbalance and/or unavailability of macro- and micronutrients. Compare with annual food crops, tree crops seem more resilient to cope with the change in soil nutrient status (Rahman *et al*. 2005; Agus *et al*. 2008).

The level of salinity, in general, quickly decreased from up to 40 dS m^{-1} in the fresh tsunami mud to about 8 dS m^{-1} in 5 months and further to < 4 dS m^{-1}

in less than a year, especially in areas with high rainfall and coarse textured soils. Currently areas with the EC of >2 dS m^{-1} are only found in newly formed lagoons, in low (<1500 mm) annual rainfall and poor drained areas (Subiksa *et al*. 2006).

Tree-based farming such as coconut, casuarinas, tropical almond, cacao, and coffee along the coastal line seems to be able to attenuate the power of small and moderate waves of tsunami and can provide various other environmental services as well as sustainable livelihood. Therefore, it needs to be reconstructed via rehabilitation and/or replanting. The reconstruction of tree farming along the tsunami areas requires careful planning based on the potential natural resources such as climate and soil characteristics as well as economic consideration. Therefore, it is essential to conduct a land suitability evaluation of the tsunami areas. The objectives of the study were to evaluate the current physical condition of the area and develop recommendation of land suitability for tree crops farming in the area.

MATERIALS AND METHODS

This study was conducted from February to August 2006. This study consisted of four activities: (1) interpretation of satellite images and secondary data, (2) field survey and laboratory soil sample analyses, (3) soil database (land characteristic) generation, and (4) data matching and suitability evaluation as schematically depicted in Figure 1.

Interpretation of Satellite Images and Generation of Physiographic Mapping Unit Map

Images and maps of Aceh Barat District were obtained from various sources, included: (1) satellite images of Landsat Thematic Mapper (TM)-5 and Landsat-7 taken in 2003 and 2004 (before the tsunami) and Landsat-7 taken on 29-30 December 2004 and January 2005 (after the tsunami) as well as the 'Ikonos' and Satellite Pour l'Observation de la Terre (SPOT) (after tsunami); (2) the topographic maps produced in 1975-1995 at 1:50,000 scale; (3) the Land Unit and Soil Maps of Takengon sheet at 1:250,000 scale (Darul Sukma *et al*. 1990); and (4) the Geological Map of Takengon sheet at a scale of 1:250,000 (Cameron *et al.* 1983).

Physiographic mapping unit (PMU) was delineated on screen digitizing of digital SPOT-5 image, based on the physical characteristic similarities of parent material, soil drainage, slope steepness, and natural

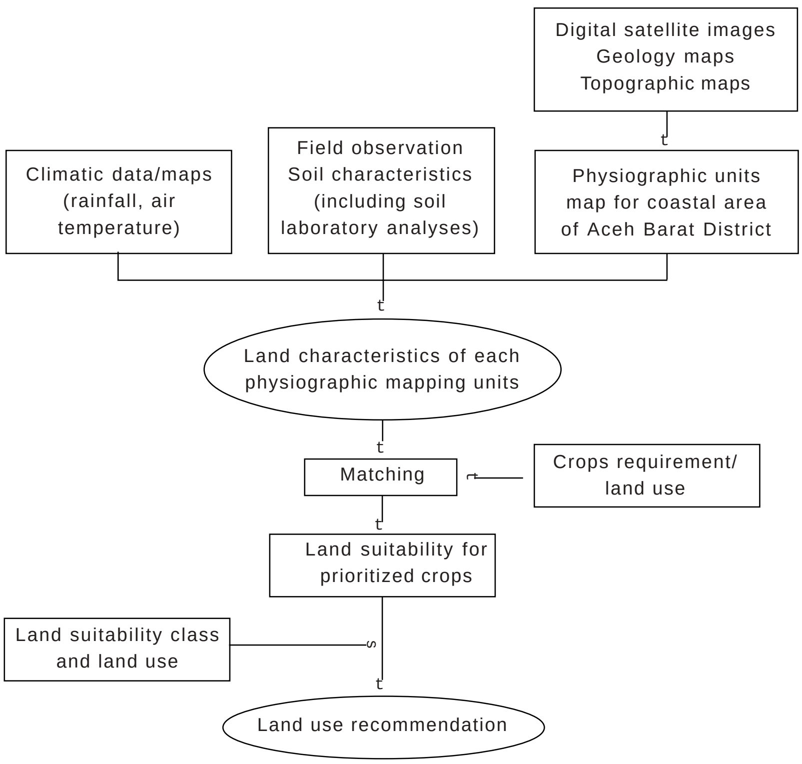

Fig. 1. Land evaluation flowchart to develop land use recommendation.

vegetation (Buurman *et al*. 1990). Landsat TM-5 digital image was also used to generate information on general physiographic unit and existing land uses. The initial analyses were conducted to evaluate morphological and lithological conditions by taking into account of soil information. The interpretation and analyses of the data were according to the Guidelines for Landform Classification (Dessaunettes and Harrop 1975; Buurman *et al*. 1990; Marsoedi *et al*. 1997). The PMU were used as a base (source) map of land suitability evaluation.

Field Survey, Soil Sample Collection and Soil Analyses

The primary objective of field/ground truth observations was to gather geo-referenced information on biophysical as well as soil and environmental land characteristics with enhanced use of satellite images. Sampling points and transect lines were determined prior to the field survey, using SPOT satellite image or other imageries. Each PMU was represented by at least one sampling point or transect. During field observations, all major landscapes were studied, either by cross sectional transect stretching from the shore to the inland or by random observations, depending on the physiographic variation or homogeneity (Buurman *et al*. 1990; Soil Survey Staff 2003).

Dominant soils representing the PMUs were observed from pits, minipits or soil auger. Soil profile pits of up to 2 m deep were used for complete soil description and classification. Soil minipits of 50 cm x 50 cm x 50 cm dimension were used to check the spatial change in soil properties on top soil horizons to determine the need of digging soil profile. For example, if sloping areas and rugged terrain existed around the soil profile pit, then a minipit was dugged for checking whether or not the change is significant. A few augerings were made from each PMU for checking the consistency in the sample properties and the extent of similarity of dominant soil groups. Auger soil samples were also taken for PMUs with poor drainage such as peat dome, swalle, and backswamp. Each of different soil groups was then represented by a soil profile. Soil samples were taken from each profile by horizon for soil analyses in the laboratory. Each field description from pit, minipit and augering were coded in a special form prepared in advance. Coding from these forms was stored in a computer database format.

The field observations were based on Balai Penelitian Tanah (2004) and FAO (1978; 2005). Soil classification at subgroup level was based on the Keys to Soil Taxonomy (Soil Survey Staff 2003). Field observations from soil pits and minipits were aimed at collecting of soil profile characteristics including the depth of soil horizons (soil layers based on minipit or soil profile evaluation), the smelt of sulfidic material (if any, evaluated by using H_2O_2), color of soil matrix (using the Munsell soil color chart), soil texture (using finger technique), soil pH (using litmus paper), and crop performance (FAO 1978; Balai Penelitian Tanah 2004). Field surveys were also aimed to verify slope data (using abney level) and surface and subsurface drainage as indicated by gley and mottle soil colors using the Munsell soil color chart. Monthly rainfall data were collected from the local Meteorology and Geophysics Agency station, as well as from the local Board of Statistics of Aceh Barat District.

Peat soil depth was observed by augering with peat sampler. Soil samples of 1 kg from first (top) layer and second layer of each representative profile were collected and labeled. The number of soil samples collected were based on the variation of PMU, soil type, and land uses. As many as 206 soil samples were collected for laboratory analyses.

Each selected layer of soil sample was analyzed for soil texture (hydrometer technique), pH (glass electrode), organic matter content (Walkley and Black), total nitrogen (Kjeldahl digestion), P_2O_5 (25% HCl and Bray1), K_2O (25% HCl) and 1N ammonium acetate exchangeable cations and cation exchange capacity (CEC). For peat soils, the analyses included peat density (graphimetric technique), ash (combustion technique), silicate and fiber contents (Soil Survey Staff 2003). Surface and ground water samples were analyzed for pH, electric condutivity, and silt content (Balai Penelitian Tanah 2004).

Soil Database Generation

A computerized database was generated from soil properties and environment data, including the site number, location, slope, existing vegetation/land uses, and soil properties (FAO 1976; 1978; 2005; Balai Penelitian Tanah 2004). PMU and a soil map at a scale of 1:50,000 were generated from the database.

Data Matching for Land Suitability Evaluation and Land Use Recommendation

Land suitability evaluation for selected tree crops were conducted by using Automated Land Evaluation System (ALES) software package (Rossiter and van

Wambeke 1995; 1997), the crop requirements referred to Crop Requirements for Land Evaluation (Sys *et al*. 1993) and Guidelines for Land Evaluation (Djaenuddin *et al*. 2003). The process of this evaluation is the matching of crop requirements against land qualities or characteristics. Land quality in this evaluation included air temperature regimes, water availability, rooting condition, nutrient retention, nutrient availability, salinity, and existence of soil toxic elements.

In this present study, three suitability classes: S1 (highly suitable), S2 (moderately suitable) and S3 (marginally suitable) and class N for not suitable were selected.

- **Class S1 (highly suitable)**; land having no significant limitations to sustain the productivity of a given land utilization type using inputs at normal (acceptable) level.
- **Class S2 (moderately suitable)**; land having limitations which in aggregate are moderately severe for sustained application of the given land utilization type; the limitations will reduce productivity or benefits and increase required inputs to the extent that the overall advantage to be gained from the use, although still attractive, will be appreciably inferior to that expected on Class S1 land.
- **Class S3 (marginally suitable)**; land having limitations which in aggregate are severe for sustained application of the given land utilization type and will so reduce productivity or benefits, or increase required inputs, that this expenditure will only be marginally justified.
- **Class N (not suitable)**; land with very high limitations in such a way that investment on that land for a particular land use type is not economically and/or environmentally justifiable.

The main restricting/limiting factors can be added as identifier to the suitability class. These included nutrient retention/low fertility (nr), slope/erosion hazard (eh), oxygen availability/poor drainage (oa), rooting condition (rc), flood hazard/water inundation (fh), and peaty soil (ps).

RESULTS AND DISCUSSION

Physical Condition of the Study Area

Along the entire west coast up to the highland of Bukit Barisan, watersheds of the Aceh Barat were characterized by more than nine consecutive wet months (with an average monthly rainfall of > 200 mm) and one dry month (with an average rainfall of < 100 mm). On the upper slopes of the Bukit Barisan, the climate was dryer as characterized by 7-9 wet months with a dry period of less than 2 months (Oldeman 1979; Badan Perencanaan dan Pembangunan Daerah Kabupaten Aceh Barat 2005).

Most areas affected by tsunami were relatively flat tidal and alluvial plains with < 3% slope and some depressions. Their geomorphology belongs to marine, alluvial, peat dome, and tectonic plains. The soils in this study area were developed from marine and fluviatile deposits with or without mantled of organic matter. Soils in the tectonic plain were developed from clay sediment.

The estuarine plains had a thin (< 20 cm) layer of fluviatile sediments. The old levees and backswamps had thicker fluviatile layer (>50 cm) on the relatively concave areas. Peats varied in thickness from < 50 cm to very deep (> 8 m).

Based on the Soil Taxonomy (Soil Survey Staff 2003), soils in the study area could be classified as Entisols, Inceptisols, Histosols and Ultisols orders. Entisols in this district are unripe soils and located on the permanently water saturated environment. Inceptisols are formed on the drier environment. Their ground water table depths were > 40 cm from the soils surface. This condition facilitates soil weathering process (oxidation and soil structure development). Histosols are formed from organic deposits under water saturated condition in the concave areas. In the closed basin areas, deep peat (2-4 m and > 4 m in some localized areas) were formed. Ultisols are formed from clay sediment and located in the undulating to rolling uplifted ancient marine sediment, which are situated just behind (in the inner land area) of alluvial and/or peat dome groups.

Physiographic groups, soil subgroups, soils characteristics, and land uses of the tsunami-affected west coast of Aceh Barat District are presented in Table 1 and the soil map is depicted in Figure 2. The explanatory legend of the soil map, including the result of soil sample analyses for each mapping unit is presented in the Appendix 1.

The land uses on the marine and alluvial riverine areas were shrubs, bushes and in some places were settlements, home-garden, upland crops, rubber garden and oil palm and rubber plantations. The peat domes were mostly dominated by swampy peat forest and swampy shrubs and bushes, smallholder rubber plantation, settlements, and oil palm plantation. The swampy (valley floor) areas were covered by swampy forest and shrubs as well as rice fields. The upper part of tectonic plain (undulating to rolling terrain) was covered by secondary forest, shrub and bushes, mixed farming (trees and annual crops), and settlements.

Table 1. Physiographic groups, soil subgroups, soil characteristics, and land uses of the tsunami-affected west coast of Aceh Barat District.

Physiographic group	Subgroup of physiography	Soil	Soil characteristic	Land use
Alluvial (fine to coarse sediments)	Alluvial plain (transition to marine)	Hydraquents, Endoaquepts, Endoaquents	Deep-very deep, slightly acid, fine	Rice fields, coastal ponds/ ponds, swamps
	Flood plain	Endoaquepts, Endoaquents, Udifluvents	Deep-very deep, slightly acid-neutral, slightly coarse-fine	Rice fields, shrubs/bushes
	River terraces	Dystrudepts, Udifluvents, Endoaquepts	Deep-very deep, acid-neutral, slightly fine-fine	Rice fields, settlements, upland agricultural farming
	Back swamp	Endoaquepts, Endoaquents	Very deep, acid, fine	Forest, shrubs/bushes
Marine (fine to coarse sediments)	Beach ridge and swale	Udipsamments, Hydraquents	Deep-very deep, neutral, coarse (top soil slightly coarse-peaty)	Coconut garden, settlements, rice fields, shrubs/bushes
	Tidal plain	Hydraquents, Sulfaquents, Endoaquepts, Fluvaquents	Very deep, neutral, slightly coarse-fine	Shrubs/bushes, forest, swampy forest
	Estuary	Fluvaquents, Halaquepts	Very deep, neutral, slightly coarse-fine	Mangrove, forest/ swampy bushes
	Coastal plain	Udipsamments, Endoaquepts, Eutrudepts	Very deep, neutral, slightly coarse-slightly fine	Coastal ponds/ponds, settlements, rice fields, shrubs/bushes
	Marine terraces	Dystrudepts, Eutrudepts, Endoaquepts	Deep-very deep, acid-neutral, slightly fine	Upland agricultural land, tree crops
Peat dome (organic materials)	Peat dome Oligotrophic	Haplosaprists, Haplohemists	Peat depth of 0.5-3.0 m, > 3 m, saprists-hemists	Forest, swampy bushes and rubber plantation, food crops (vegetables)
Tectonic plain	Undulating and rolling dissected plain	Hapludults, Endoaquepts	Deep-very deep, acid, fine material	Forest, smallholder rubber plantation, bushes, mixed garden/ tree crops

Source: Field observations, soil laboratory analyses and supported from Description Book and Soils and Darul *et al*. (1990).

Land Suitability

Land suitability evaluation resulted in 28 PMUs are as follows:

- PMU 1 was dominated by recent sand beach and thus was not suitable (N) for any kinds of crops. The main limiting factors was rooting condition/ loose sand accumulation.
- PMU 2, 3, 4 and 5 (complex of recent beach ridge and swale in marine region) were marginally suitable (S3) for casuarinas, cacao, coconut, coffee, rambutan, papaya, banana, *duku* (langsat), durian, citrus, mango, mangosteen, and pineaple. The major limiting factors were low nutrient availability and rooting condition (sandy texture of subsoil), and brackish water.
- PMU 6 and 8 (marine deposit) were not suitable for tree crops, but moderately suitable for wetland rice with the limiting factors of water inundation, low nutrient content, and sandy texture subsoil.
- PMU 9 and 10 (complex of subrecent beach ridge and swale in marine region) were moderately suitable (S2) for cacao, coconut, coffee, rubber, oil palm, langsat, rambutan, durian, citrus, mango, and

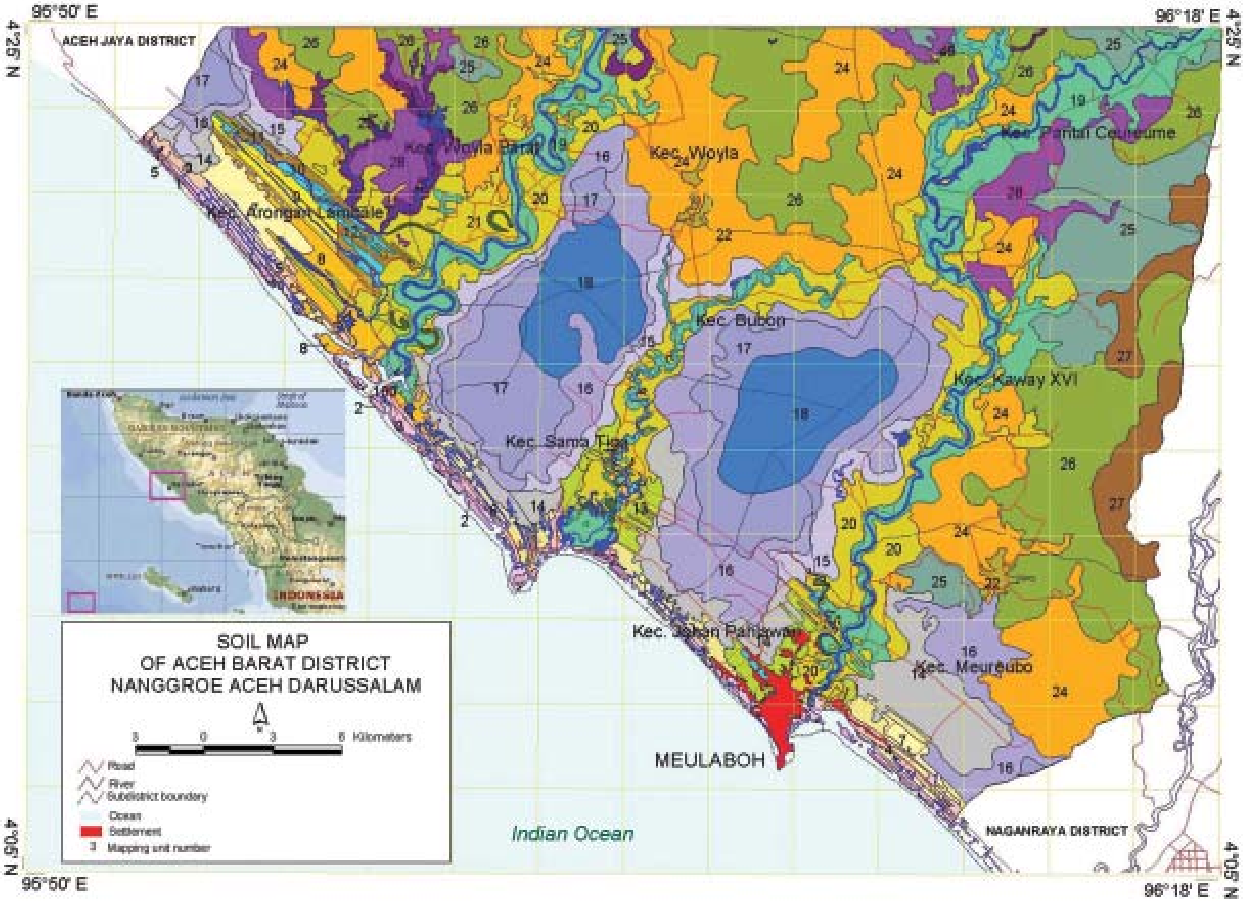

Fig. 2. Soil map and the physiographic mapping unit of the coastal area of Aceh Barat District (refer to Appendix 1 for the legend).

water melon. The main limiting factors were low nutrient content and sandy texture subsoil.

- PMU 7 and 14 (subrecent of beach ridges and swalles covered by shallow peat), were marginally suitable for rubber, oil palm, papaya, pineapple, rambutan, coconut, and banana. The limiting factor were water inundation, low nutrient, and sandy material of subsoil.
- PMU 13 (beach ridges subrecent) was moderately to marginally suitable for cacao, coconut, coffee, langsat, mango, mangosteen, rambutan, banana, pineapple, and areca nut. The limiting factors were low nutrient, sandy material of subsoil, and water availability.
- PMU 15 (thin peat: 0.5-1.0 m) was marginally suitable (S3) for rubber, oil palm, and coconut. The limiting factors were water inundation, low nutrient content, and the peat susceptibility to subsidence and oxidation.
- PMU 16 and 17 (moderately thin and moderately thick peat with thinckness of 1.0-2.0 m and 2.0-3.0 m) were marginally suitable for rubber, oil palm, and coconut. The limiting factors were water inundation and low nutrient content.
- PMU 18 (thick peat with thickness of > 300 cm and in some localized areas it reached 6-9 m) was not suitable for agriculture and recommended for conservation due to its fragile ecosystem.
- PMU 19 (levee) was moderately suitable for coconut, cacao, rubber, oil palm, langsat, durian, mangosteen, rambutan, pineapple, and citrus. The limiting factors were low nutrient and water inundation.
- PMU 21, 22, 24 and 28 (alluvial plain and former meander belt) were moderately suitable for rubber, oil palm, rambutan, coconut, coffee, mangosteen, mango, banana, papaya, and pineapple. The limiting factors were low nutrient content and drainage accessibility.

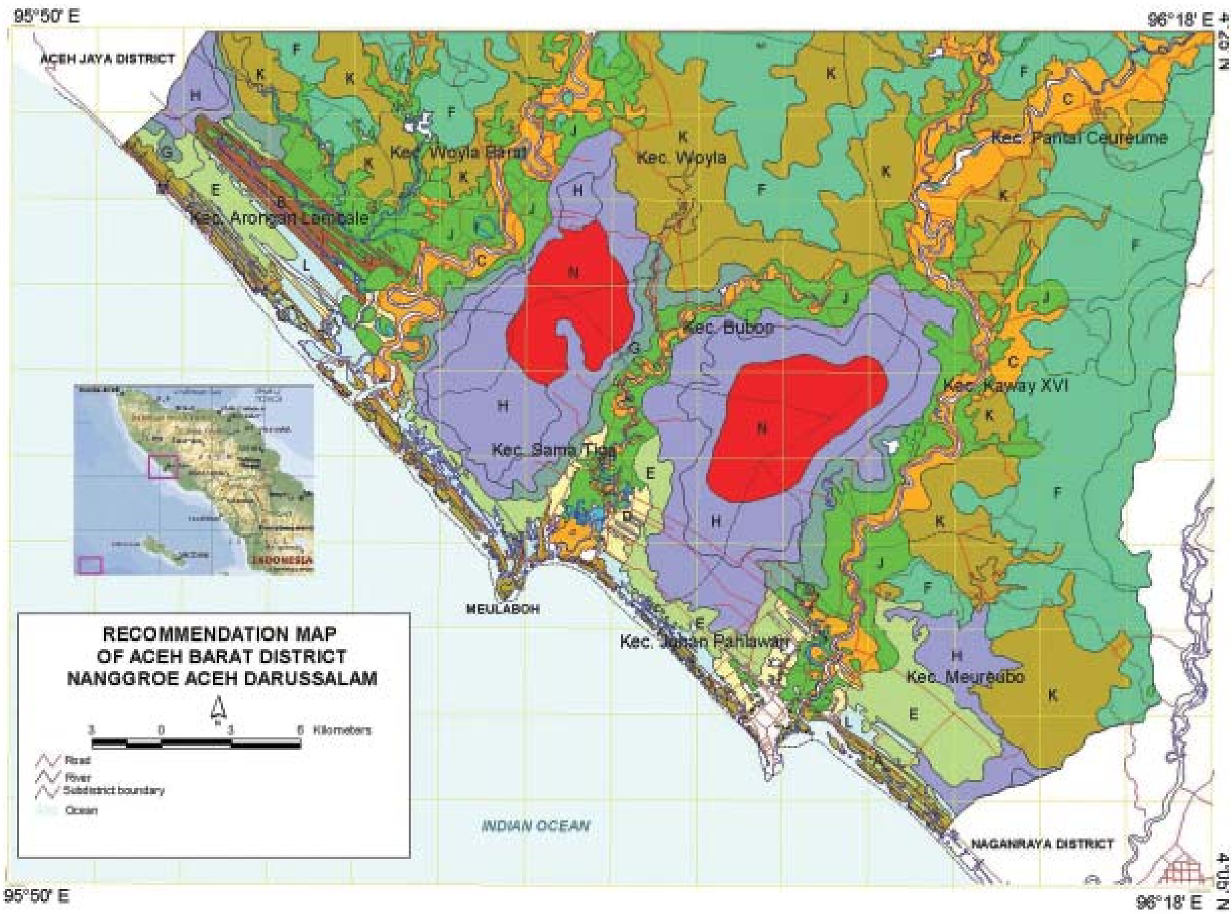

Fig. 3. Land use recommendation map of the coastal area of Aceh Barat District based on 1:25,000 scale map (refer to Table 2 for the legend).

- PMU 11, 12, 20 and 23 (aluvio-marine deposits dominated by aquepts and aquents) were unsuitable for most tree crops. The major limiting factor were low nutrient availability and poor drainage.
- PMU 25, 26 and 27 (undulating to rolling tectonic plain) were moderately suitable for rubber, oil palm, cacao, banana, coconut, clove, langsat, durian, and citrus. The limiting factors were low nutrient and erosion hazard/slope steepness.

It can be summarized that almost all evaluated tree crops fall into marginally suitable (S3) because of various limiting factors including rooting condition (sandy textured subsoil, poor soil drainage and peat layer) and low nutrient availability. Landscape with poor drainage ecosystem such as river backswamp, marine swalle with or without shallow peat cover are not suitable for tree crops, but moderately suitable for lowland rice.

Land Use Recommendation

The approach in screening of land suitability to produce land use recommendation follows the guidelines by Ritung *et al.* (2007). The suitable tree crops were further selected and screened with the regional spatial planning and existing land uses.

The land that is currently being utilized, especially for perennial tree crops/estate crops and rice fields are left as such as long as they fall into suitable class. The lands that currently are not optimally used or not being used such as shrub, conversion forest or absentee lands were recommended for extensification of other suitable commodities. Land use recommendation map is presented in Figure 3 and their suitability description is presented in Table 2.

Table 2. Land use recommendation for tree crops for coastal area of Aceh Barat District.

Symbol	PMU	Suitability class	Tree crop recommendation	Area (ha)	Limiting factor	Input recommendation
A	2, 3, 4, 5	S3	Cacao, coconut, coffee	2093	Low nutrient, sandy texture of subsoil (brackish water)	Fertilizer, soil structure management
B	9, 10	S3	Coconut, rubber, oil palm, rambutan, mango	1093	Low nutrient, sandy texture of subsoil, fresh water	Fertilizer, soil structure management
C	19	S3	Cacao, coconut, coffee, rambutan, mango, langsat, mangosteen, durian, pineapple	3620	Water inundation, low nutrient, moderately well drained	Fertilizer, drainage
D	13	S3	Cacao, coconut, coffee, langsat, mango, durian, mangosteen, rambutan	1038	Low nutrient, sandy texture of subsoil	Fertilizer, soil structure management
E	7, 14	S3	Rubber, oil palm	3356	Water inundation, low nutrient, sandy texture of subsoil	Fertilizer, drainage
F	25, 26, 27	S3	Rubber, oil palm, cacao	18391	Low nutrient, slope	Fertilizer, conservation practices
G	15	S3	Rubber, oil palm, coconut	5401	Water inundation, low nutrient, thin peat (<100 cm)	Drainage, fertilizer
H	16, 17	S3	Rubber, oil palm, coconut	14726	Water inundation, low nutrient, moderate shallow to moderately thick peat (100-300 cm)	Drainage, fertilizer
I	21	S3	Rubber, oil palm	216	Water inundation, low nutrient, somewhat poorly drained	Drainage, fertilizer
J	11, 12, 20, 23	N	Not suitable for tree crops	10022	Low nutrient, stagnant water	
K	22, 24, 28	S3	Rubber, oil palm	1698	Low nutrient, poor soil drainage	Fertilizer, drainage
L	6, 8	N	Not suitable for tree crops	2160	Water inundation, low nutrient, sandy texture of subsoil	
M	1	N	Not suitable for agriculture	120	Loose tsunami sand	
N	18	N	Forest conservation due to its fragile ecosystem	6510	Very thick peat (>300 cm)	
Total area (ha)				73564		

PMU = physiographic mapping unit

CONCLUSION

Land use recommendation map for Aceh Barat District at the scale of 1:50,000 had been developed based on the soil and climate conditions, environmental consideration, and the district priority and current land uses. This map can serve as the main input in the district land use planning.

This study recommends that: (1) areas close to the coastal line may be developed for the improvement of existing smallholder coconut plantation as well as for casuarinas green belt; (2) the ancient sandy beach is recommendable for areca nut, rambutan, mango and rubber; (3) the alluvial eco-system is recommendable for coconut, cacao, areca nut, mango, bread fruit and cacao; and (4) the thin to moderately thick (< 3 m deep) peat domes could be developed for oil palm and rubber while the thicker peat (> 3 m deep) is recommended for conservation due to the fragile ecosystem. The utilization of this land use recommendation map is expected not only to improve farmers, livelihood, but also to protect the environment of the west coast of Aceh Barat District.

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Appendix 1. Soil classification, physiographic subgroup, slope and altitude for each physiographic mapping unit (PMU) of land resources of Aceh Barat District.

PMU	Dominant soil type (suborder)		Physiographic unit (subgroup) (Marsoedi *et al.* 1997)	Parent material
	Soil classification (USDA 2003)	Proportion		
	Marine Group			
1	Typic Udipsammets	P	Sand beach recent (Mq.1.2)	Marine sediment
2	Typic Udipsamments	P	Sand beach recent (Mq.1.2)	Marine sediment
3	Association: Typic Psammaquents Typic Udipsamments	P M	Sand beach recent (Mq.1.2)	Marine sediment
4	Typic Udipsamments	P	Beach ridges recent (Mq.1.1.1)	Marine sediment
5	Typic Udipsamments Typic Psammaquents	P M	Beach ridges & swales recent (Mq.1.1.1)	Marine sediment
6	Typic Psammaquents	P	Beach ridges & swales recent	Marine sediment
7	Association: (Histic) Psammaquents Typic Psammaquents	D F	Beach ridges & swales recent (Mq.1.1.1)	Marine and organic sediment
8	Association: Typic Psammaquents Histic Psammaquents	P M	Beach ridges & swales recent Mq.1.1.1	Marine and organic sediment
9	Association: Typic Udipsamments Typic Dystrudepts	P M	Beach ridges & swales subrecent (Mq.1.1.2)	Marine sediment
10	Association: Typic Dystrudepts Typic Udipsamments	P M	Beach ridges & swales subrecent (Mq.1.1.2): overflow mantle	Marine and fluvial sediment
11	Typic Fluvaquents	P	Beach ridges & swales subrecent (Mq.1.1.2)	Marine and fluvial sediment
12	Typic Endoaquepts	P	Beach ridges & swales subrecent (Mq.1.1.2)	Marine and fluvial sediment
13	Association: Aquic Dystrudepts Typic Psammaquents Typic Udipsamments	D F M	Beach ridges subrecent (Mq.1.1.2/Mfq.1.1.2)	Marine and fluvial sediment
14	(Histic) Psammaquents Typic Haplosaprists	P M	Beach ridges & swales subrecent (Mq.1.1.2)	Marine and organic sediment
	Peat Dome Group			
15	Typic Haplohemists Typic Haplosaprists	D F	Shallow peats (0.5-1.0 m) (G.2.1.1.1)	Organic sediment
16	Typic Haplohemists Typic Haplosaprists	D F	Moderately deep peat (1.0-2.0 m) (G.2.1.1.2)	Organic sediment
17	Typic Haplohemists	P	Deep peats (2.0-3.0 m) (G.2.1.1.3)	Organic sediment
18	Typic Haplohemists	P	Very deep peat (3.0-6.0 m) (G.2.1.1.4)	Organic sediment
	Alluvial Group			
19	Fluventic Eutrudepts Fluvaquentic Endoaquepts	P	Levee (Au.1.1.2.1)	Alluvium
20	Fluvaquentic Endoaquepts Typic Endoaquepts	P	Backswamp/meander belt (Au.1.1.2.2)	Alluvium
21	Typic Fluvaquents Fluvaquentic Endoaquepts	P	Aluvial plain/meander belt (Au.1.1.2.8)	Alluvium
22	Typic Endoaquepts	P	Narrow river valley	Alluvium
23	Association: Typic Fluvaquents Aquic Eutrudepts	P M	River belt (Au.1.5)	Alluvium

Appendix 1. (continued).

PMU	Dominant soil types (sub-order)		Physiographic unit (sub-group) (Marsoedi *et al*. 1997)	Parent material
	Soil classification (USDA 2003)	Proportion		
	Tectonic Plain Group			
24	Hapludults Dystrudepts Endoaquepts	D F M	Undulating tectonic plain moderately dissected (Tfq.11.2.2)	Claystone, sandstone, mudstone
25	Hapludults Dystrudepts	D F	Rolling tectonic plain, moderately dissected (Tfq.11.3.2)	Claystone, sandstone, mudstone
26	Hapludults Endoaquepts	P M	Rolling tectonic plain, strongly dissected (Tfq.11.3.3)	Claystone, sandstone, mudstone
27	Hapludults Dystrudepts	D F	Rolling tectonic plain, extremely dissected (Tfq.11.3.4)	Claystone, sandstone, mudstone
28	Hapludults Dystrudepts Endoaquepts	D F M	Undulating tectonic plain, slightly dissected (Tfq.11.2.1)	Claystone, sandstone, mudstone

P = predominant (> 75%); D = dominant (50-75%); F = fair (25-49%); M = minor (10-24%).