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Soils and Vegetation Condition of Natural Forests and Secondary Fallow Forests within Batang Ai National Park Boundary, Sarawak, Malaysia

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Abstract

Under the current upland farming systems by the Iban of Sarawak, Malaysia, lands with better accessibility are being intensively utilized for various forms of agricultural activities. This has resulted in large patches of fallow lands with difficult accessibility which were later abandoned and remained as old secondary forests. In this study, an investigation on soil and vegetation under various types of forest cover was conducted at the Batang Ai National Park boundary to determine whether the old abandoned secondary forests in the area can recover and reach an ecological status similar to that of natural forests. Investigation was conducted at 3 types of sites: young fallow lands after upland rice cultivation with fallow period of less than 5 years (YF), old secondary forests with fallow period of about 50 years (OF), and natural forests (NF). In these sites, soil surveys were conducted and soil samples were collected at tepths of 0-10 cm, 30-40 cm and 60-70 cm for soil physicochemical determination. Vegetation surveys involving plant identification, plant frequency of occurrence and measurements of stem diameter (DBH) were also conducted in these sites. The results showed that irrespective of forest types, all studied soils showed a strongly acidic nature with low nutrient contents. In addition, no clear differences were observed in the soil physicochemical properties among the forest types although soil pH in YF sites were significantly lower than those of OF and NF sites probably due to the pand use history of these sites. On the other hand, the results showed that vegetation under NF sites possessed better tree growth, in diameter, than OF and YF sites. Based on these findings, it is suggested that due to the poor soil fertility status in the area, 50 years of fallow period would be insufficient for the land to recover its vegetation condition aquivalent to that of natural forests. Taking into account ouch a situation, forests in the study area should be left undisturbed as their removal ould greatly accelerate severe land degradation, and rehabilitation of auch a land would be a difficult task.

Key words: Batang Ai, natural forest, secondary forest, soils and vegetation, Sarawak

1. Introduction

For centuries, wide forest areas in the humid tropics and subtropics had allowed diverse communities to practice variations of shifting cultivation, which enabled them to coexist in relative harmony with their environments (Cairns *et al.,* 1999). Shifting cultivation is practiced on such a wide range of soils with various types of vegetation and involves the length of cropping and fallowing periods, and the method of cultivation. The exact figures on the areas under shifting cultivation worldwide do not exist, but there are an estimated 240 million hectares of closed forests and 170 million hectares of open forests of world's arable land under some forms of shifting cultivation (FAO, 2003). Figures for the number of people depending on this system are also uncertain and range from 400 to 500 million (Stocking, 1984; Lanly, 1985; Russell, 1988; Goldammer, 1988; Klienman *et al.,* 1996;

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Sanchez *et al.,* 2005). There is no doubt that despite rapid change and conversion to other types of land use (Padoch *et al.,* 2007), shifting cultivation remains important in many tropical countries.

Amidst the worldwide concern on tropical deforestation, shifting cultivation is often condemned as the cause of deterioration of the environment. In the tropics, shifting cultivation is responsible for about 60 percent of annual losses or about 17-20 million hectares of tropical forest (World Bank, 1991). Despite the frequent negative criticisms on the system regarding its environmental impact, including keeping rural communities in poverty, millions of people particularly in the humid tropics are still practicing some form of shifting cultivation (Thrupp *et al.,* 1997; Fox, 2000; Mertz, 2002). In addition, to a certain extent, some forms of shifting cultivation practices occasionally cause environmental deterioration because of inappropriate land management and the occurrence of natural disasters such as prolonged drought (Kiyono & Hastaniah, 2000).

Recently, Sarawak has been subjected to high levels of deforestation. Much of the deforestation has been caused by logging, particularly in the rainforest, due to agricultural development, plantation development, shifting cultivation, as well as dam construction and resettlement (Jomo *et al.,* 2004). A study conducted by Wasli *et al.* (2009) revealed that the shifting cultivation practices by the Iban were conducted mainly at lands with better accessibility and those being intensively utilized for various types of crops such as upland rice and cash crops such as pepper and rubber (Tanaka *et al.,* 2009; Wasli *et al.,* 2009). This situation has created large areas of fallow lands which were left unused and remained as old secondary forests located far from the Ibans' residence.

A considerable number of studies have been conducted on the dynamics of secondary succession immediately following clearance and burning, whereas the tropical forest succession are ill documented (Uhl *et al.,* 1981; Uhl & Jordan, 1985; Ohtsuka, 1999, Kendawang *et al.* 2007). In addition, some scientists have proven that forests often recover rapidly from less severe, small-scale disturbances such as tree-fall gaps and small-scale shifting cultivation (Mackie, 1986). Meanwhile, some scientific reports hypothesized that nutrient limitation resulting from the repeated agricultural use of the secondary forest stands would be expressed as lower nutrient concentrations and stocks in the soils of those stands relative to the tha a primary forest (Johnson *et al.,* 2001). However, the impact of repeated cycles of shifting cultivation on forest regeneration and soil nutrient pools has not been well documented in Sarawak. Moreover, most of these studies have been done on during tearly stages of the succession process and less work has been done on older secondary forests. As succession proceeds, it would be expected that secondary forests will continue to grow and regenerate into similarity with the primary forests until after a certain amount of time, but, the estimatedion of timed for a secondary forts to resembles the primary foeare still indist.

This paper will discuss our investigations on the soil and vegetation of secondary forests as well as natural forests within the Batang Ai National Park. The initial purpose of the investigation was to be able to foresee when the land would, once affected by shifting cultivation, recover and if it is possible for these fallows to reach ecological properties similar to those of natural forests under a tropical environment. In relation to this subject, vegetation condition and soil fertility between secondary fallow forests and natural forests will be analyzed in order to provide information on the ecological characteristics of each forest type.

2. Material and Methods

1) Study area

This study was conducted at the Batang Ai area located at about 30 km northeast of Lubok Antu, Sarawak, Malaysia (Figure 1). The area consisted of patches of various forest types and is generally classified as lowland dipterocarp forests (Meredith, 1993). It should be noted that high proportions of these forests seem to be of old secondary forest or abandoned rubber gardens. Data collected from stations located outside the protected areas indicated a mean annual rainfall of about 3,500 mm (Department of Irrigation and Drainage, 2006). Rainfall levels fluctuate substantially from month to month, with the wettest months (October to January) receiving

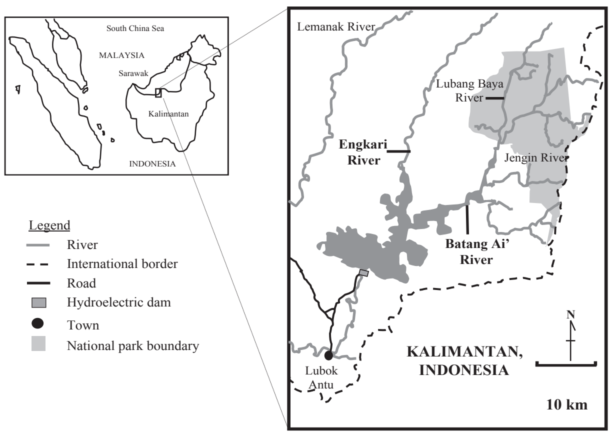

Fig. 1. Map of the study area.

about 300 to 350 mm per month, while the driest months receive about 200 mm. The mean annual temperature in the area from 1996 to 2005 was 26.5ºC (Meteorological Department, 2006). Located at more than 500m above sea level, the hilly and extremely steep terrain of Batang Ai area (slope gradient around 30º) almost certainly receives a higher amount of rainfall (Soepadmo & Chai, 2000). Soils in Batang Ai are originated from sedimentary rocks, predominantly shale and coarse-grained sandstones, varying widely in texture, structure and chemical content. Under the Sarawak soil classification, such soils were classified into the Kapit family of the Skeletal Soil Group (Teng, 2003), which corresponds to Udorthents of the USDA system (Soil Survey Staff, 2006).

In this study, two locations were selected: Batang Ai National Park (N01°18.32', E112°04.35') and one Iban longhouse community (Griffin: N01°15.12', E111°56.33') located within the national park boundary along a small stream connected to Batang Ai River. Located upriver of Batang Ai River, an area of about 270 km2 was gazetted by the Sarawak state government as the Batang Ai National Park in 1991 for the purpose of biodiversity conservation in the state (Meredith, 1993). Prior to the establishment of this park, the area was formerly inhabited by several Iban communities but these communities have since left the area due to the communist insurgency and border confrontation with Indonesia during the early 1950's. However, some who were against the idea of resettling to a new area prepared by the government still remained in longhouses along the national park boundary.

2) Data collection and analysis

Field survey was conducted at 3 types of sites: young fallow lands (YF), old secondary forests (OF) and natural forests (NF). The fallow length of YF sites were less than 5 years after upland rice farming. According to the "landowners," upland rice farming was conducted for 1 to 2 years continuously with 3 to 4 years of fallow period before the next burning. Chemical fertilizers as well as agrochemicals such as herbicides and insecticides were applied during upland rice farming. Meanwhile, NF sites were located in a small patch of reserved forests (*pulau galau*) which has never been cut or cleared for any form of agricultural purpose related to cultural practices, i.e. sacred graveyard of their ancestors. Meanwhile, OF sites were selected along the Lubang Baya River and Batang Ai River within the Batang Ai National Park area at the suggestion of the staff from the Sarawak Forestry Corporation, who were Iban and were natives of the area. OF sites were established from the fallow lands developed after upland rice farming about 50 years ago. The slope gradient of all study sites ranged between 25º to 35º. For YF and OF, the altitude of all sites ranged between 100 and 200 m a.s.l while for NF, the altitude of the sites ranged between 300 and 400 m a.s.l. In total, 14 sites were surveyed including 5 sites each in YF and NF, and 4 sites in OF.

Vegetation and soil surveys were carried out in a quadrat of 20 × 20 m^2 or 40 × 40 m^2 in each study site. In the vegetation survey, the name, density and stem diameter at breast height (DBH) of all woody plants were recorded based on the Iban's nomenclature system. The names and density of other smaller plants (grasses, ferns, tree seedlings, etc.) were recorded at three sub-quadrats (2 × 2 m^2 or 5 × 5 m^2) established within the main quadrat. All encountered plants during the survey were categorized into 11 plant groups: bamboos, ferns, gingers, grasses (including herbs except for ginger), vines (including woody and non-woody vines), palms, rattans, shrubs, trees, and wild bananas.

Soil samples were collected at depths of 0 - 10 cm, 30 - 40 cm and 60 - 70 cm from three points located randomly within the same quadrat for vegetation survey. The soil samples obtained were mixed well to yield one composite sample. The samples were air-dried and passed through a 2 mm mesh sieve for physicochemical analyses. Core samples (100 mL) were collected from the same depths in triplicate for determination of bulk density. The analytical methods for soil analysis are as follows; soil pH was determined in water or 1 M KCl in a soil to solution ratio of 1:5 using glass electrodes. Total C and N contents (T–C and T–N) were analyzed using an NC analyzer (Sumigraph NC-80; Sumika Chemical Analysis Co., Osaka, Japan). The contents of exchangeable bases (Ca, Mg, K, and Na) and the cation exchange capacity (CEC) were measured after successive extraction using 1 M ammonium acetate adjusted to pH 7.0 and 10% NaCl, respectively. The amount of NH_4 replaced by Na was determined for CEC using the steam distillation and titration method. The contents of exchangeable bases were determined by atomic absorption spectrophotometry for Ca, Mg, and K, and by flame photometry for Na (AA-6800; Shimadzu Corp., Kyoto, Japan). Exchangeable Al, H, and NH4 were extracted with 1 M KCl. Exchange acidity (Al + H) was determined by titration with 0.01 M NaOH, and the content of exchangeable Al was determined with 0.01 M HCl. The content of exchangeable H was calculated as the difference between the values of the exchange acidity and exchangeable Al. The content of exchangeable NH_4 was measured using the indophenole blue method (Mulvaney, 1996). Available phosphorus was quantified by the Bray II method (Kuo, 1996). Particle size distribution was determined using the pipette method. Soil hardness was examined at depths of 0-10 cm, 30-40 cm and 60-70 cm using a Yamanaka-type push cone penetrometer.

3. Results and Discussion

1) Vegetation condition under secondary fallow forest with different age stand and natural forests

In all study sites, the total of 96 plant species from various plant groups were encountered including 38, 46 and 41 at YF, OF and NF, respectively (Table 1). The tree species accounted for about 70% of the 96 species observed. Other plant groups such as fern, ginger, grass, rattan, shrub and vine groups were also recorded in the study sites. The species numbers of tree groups in NF and OF were significantly higher than those of YF (Figure 2). In contrast, the species numbers of grass and fern groups in YF were significantly higher than those in OF and NF.

Several plant species were observed with higher frequencies in YF, OF and NF (Table 2). According to the generic names of the plant species listed in Table 2, non-woody plant species (fern, grass, ginger and shrub) were common in YF. Among the encountered plant species in YF, some of the species were plants perceived by the Iban as plant indicators for infertile soils, i.e. *Kelindang* (*Blechnum orientale*), *Kejuru* (*Soleria purpurescens*), *Lemba* (*Amischotoltype marginata*) and *Kemunting* (*Melastoma polyanthum*). Other plant species such as *Aras* (*Illex cissoidea*), *Jambu* (*Eugenia sp.*), and *Purang* (*Macaranga trachyphylla*) were also common in YF. As for *Macaranga*, it is a light-demanding pioneer species which commonly occurs in abandoned lands after forest clearance (Davies & Ashton, 1999). Meanwhile, *Melastoma* grows on acidic soils with very low nutrients and does not dominate at the early succession stage of lands with fertile soils (Davies & Semui, 2006).

Table 1. Number of plant species observed during field survey in YF, OF and NF.

Plant group	Number of plant species			
	Whole survey (n = 14)	YF (n = 5)	OF (n = 4)	NF (n = 5)
Fern	9	7	3	2
Ginger	3	2	2	3
Grass	7	4	3	2
Vine	4	1	1	1
Rattan	2	1	1	2
Shrub	1	2	1	1
Tree	70	21	33	31
SUM	96	38	44	42

Vine group includes woody and non-woody vines.

In OF sites, plants of tree groups were commonly observed followed by plants of fern, ginger, grass and rattan. Among the tree species observed, some plant species were pioneer species which commonly existed in the abandoned field after shifting cultivation after 5 to 8 years of fallow, i.e. *Cratoxylum* and *Nephelium* (Ipor & Tawan, 2004), with less occurrence of pioneer species. It was also reported that *Cratoxylum* commonly occurred in forests with high soil acidity and lower nutrient content (Katagiri *et al.,* 1991). OF also consisted of genetic stocks of important exotic fruit species including *Sibau hutan* (*Nephelium lappaceaum*) and *Kedundong* (*Canarium sp.*). In addition, rubber trees (*Hevea brassiliensis*) were commonly observed in OF which indicates that it was an abandoned rubber farm by the Iban who previously lived in the area. However, based on our field observation, the lack of scars on most of the rubber trees suggests that these rubber trees have never been tapped since the time the Iban left the area. Moreover, numerous trees in OF showed signs of coppicing which further indicated that OF had a history of long fallow periods as cultivation would obviously favor tree species capable of coppicing.

For NF, common plant species encountered in NF were from the tree group. Among the common tree species encountered, some species were climax species such as Dipterocarpaceae (*Shorea sp., Shorea foxworthyi*) and Leguminosae (*Koompasia malacecensis*). These climax species were rarely observed especially in OF while none of these climax species were observed in

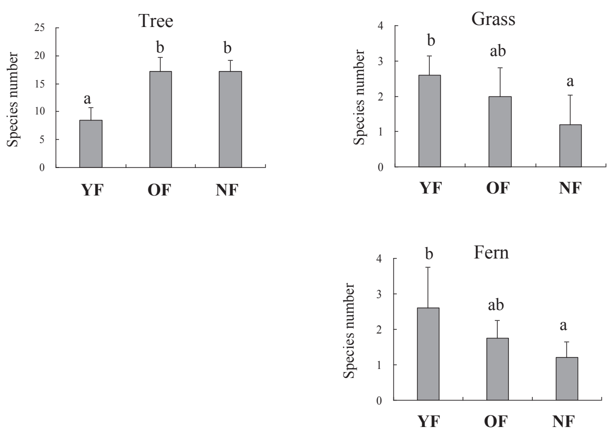

Fig. 2. Species number of tree, grass and fern group in YF, OF and NF.
Different letters show significant difference at p < 0.05 (Tukey's HSD test).

YF. Based on the field observation in NF, the buttresses of these tree species were large and these high rising trees provided canopy to other emerging undergrowth seedlings. In addition, some plant species such as *Paku helang* (*Selenodesmium obscurcum*), *Tepus* (*Etlingera triorgyali*), *Wi* (*Calamus sp*.), *Berangan* (*Castanopsis costata*), *Kedundong* (*Canarium sp*.) and *Ubah* (*Eugenia sp*.) which were commonly observed in OF were also common in NF.

Species diversity of the plant species, as evaluated by the Shannon-Wiener index, was 2.56 in YF, 2.62 in OF and 2.88 in NF. In comparing the similarity between YF, OF and NF, Sørensen's index of similarity (SI) was used to compare floristic composition of YF, OF and NF.

Table 2. List of the common plant species observed during field survey in Batang Ai area.

Common plants observed in YF

Plant group	Local name	Family	Scientific name
Fern	*Kelindang*	Blechnaceae	*Blechnum orientale*
Ginger	*Tepus*	Zingiberaceae	*Etlingera triorgyali*
Grass	*Kejuru*	Cyperaceae	*Soleria pupurescens*
Grass	*Lemba*	Commelinaceae	*Amischotoltype marginata*
Shrub	*Kemunting*	Melastomataceae	*Melastoma polyanthum*
Tree	*Aras*	Aquifoliaceae	*Ilex cissoidea*
Tree	*Jambu*	Myrtacaceae	*Eugenia sp.*
Tree	*Purang*	Euphorbiaceae	*Macaranga trachyphylla*

Common plants observed in OF

Plant group	Local name	Family	Scientific name
Fern	*Paku helang*	Hymenophyllaceae	*Selenodesmium obscurcum*
Ginger	*Tepus*	Zingiberaceae	*Etlingera triorgyali*
Grass	*Nas*	Pandanaceae	*Pandanus sp.*
Rattan	*Wi*	Palmae	*Calamus sp*
Tree	*Berangan*	Fagaceae	*Castanopsis costata*
Tree	*Bintangor*	Guttiferae	*Calophyllum blancoi*
Tree	*Geronggang*	Hypericaceae	*Cratoxylum glaucum*
Tree	*Pulo*	Melastomataceae	*Pternandra sp.*
Tree	*Kedundong*	Burseraceae	*Canarium sp.*
Tree	*Sibau hutan*	Sapindaceae	*Nephelium lappaceum*
Tree	*Ubah*	Myrtaceae	*Sysgium hirtum*

Common plants observed in OF

Plant group	Local name	Family	Scientific name
Fern	*Paku helang*	Hymenophyllaceae	*Selenodesmium obscurcum*
Ginger	*Tepus*	Zingiberaceae	*Etlingera triorgyali*
Rattan	*Wi*	Palmae	*Calamus sp*
Tree	*Berangan*	Fagaceae	*Castanopsis costata*
Tree	*Engkeranji*	Fagaceae	*Dialium sp.*
Tree	*Medang*	Hypericaceae	*Cratoxylum cochinchinense*
Tree	*Menggeris*	Leguminosae	*Koompassia malaccensis*
Tree	*Meranti*	Dipterocarpaceae	*Shorea sp.*
Tree	*Kayu malam*	Annonaceae	*Monocarpia marginalis*
Tree	*Kelampai*	Euphorbiaceae	*Pimeleodendron griffithianum*
Tree	*Kerniung*	Anacardiaceae	*Trema orientalis*
Tree	*Kesindu*	Unid	Unid
Tree	*Kumpang*	Myristicaceae	*Horsfieldia grandis*
Tree	*Resak*	Euphorbiaceae	*Aporusa sp.*
Tree	*Kedundong*	Burseraceae	*Canarium sp.*
Tree	*Selangan batu*	Dipterocarpaceae	*Shorea foxworthyi*
Tree	*Ubah*	Myrtaceae	*Sysgium hirtum*

Vine group includes woody and non-woody vines.

The result showed that the SI between YF and OF was 0.20 while the SI between YF and NF, and OF and NF were 0.13 and 0.28, respectively. The SI values between the study sites reflected that the floristic compositions between them differed.

The plant densities of tree, grass and fern groups in YF, OF and NF are shown in Figure 3. The results showed that the densities of grass and fern groups in YF were significantly higher than those at OF and NF. As compared to the results obtained in the young fallow lands under intensive shifting cultivation in Lubok Antu and Engkari River, the average densities of the grass and fern groups in YF were found similar. On the other hand, although the species number of tree groups in NF and OF was higher than those of YF, no significant difference was observed in terms of the plant density of tree groups among these sites. Thus, in YF, the plants of grass and fern groups were dominant in species number and plant density. On the other hand, although the species number of tree groups in OF and NF was higher than that at YF, no substantial difference in terms of the plant density of tree groups was observed among the sites.

Figure 4 shows the number of tree stem and relative frequency of tree species according to various DBH size class in YF, OF and NF. The results showed that the number of large tree species in NF sites were higher than OF and YF sites. In addition, the vegetation in YF consisted of tree species with small DBH. On the other hand, the high numbers of tree stems with larger DBH were observed in NF sites as compared with OF and NF sites.

The size of some climax trees in NF were equivalent to the size of climax species observed in some primary forests under lowland Dipterocarp forests in Sarawak (Proctor *et al.,* 1983). It was observed that even after 50 years of fallow, the DBH of tree species in OF were only half of those observed in NF. Brearley *et al.* (2004) reported that after 40 years of succession in Central Kalimantan, the forest biomass was slightly lower than the primary forest but there were still major differences in terms of floristic properties. Their results were found similar to the findings in OF and NF of the present study. For YF, the size of trees observed were smaller and were found similar to the size of trees observed in the sites with a short fallow period in Lubok Antu and Batang Ai area as reported by Wasli *et al.* (2009).

2) Soil fertility status of YF, OF and NF

The average values of soil physicochemical properties in YF, OF and NF are presented in Table 3. The soil texture in the study area is relatively clayey. The clay content ranged from 27.9 to 51.0 % in the surface soils (0–10 cm). At the layers of 30 - 40 cm and more than 60 cm, the clay content ranged from 28.1 to 53.4 % and 28.0 to 52.9%, respectively. The clay content at the surface soils in NF was significantly higher than those at YF. The soil pH(H2O) and pH(KCl) of the soils in all study sites ranged from 3.77 to 4.55 and from 3.03 to 3.62, respectively. As compared with the surface soils, the soil pH was higher in the subsoils of 30 - 40 cm and 60 - 70 cm depths. In the surface soils, the contents of exchangeable bases were low compared with that of exchangeable Al, resulting in a very high level of Al saturation. The contents of available P in the surface soil were low, ranging from 10 to 24 mg kg^{-1}. The CEC values varied widely, ranging from 13.7 to 25.7 $cmol_c kg^{-1}$ in the surface soils (0-10 cm). At the soil layers of 30 - 40 cm and more than 60 cm, the CEC values ranged from 9.6 to 18.1 $cmol_c kg^{-1}$

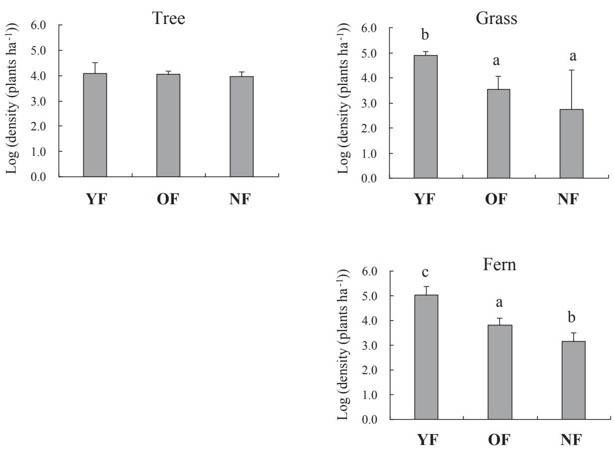

Fig. 3. Plant density of tree, grass and fern group in YF, OF and NF.
Density is transformed to log (density (plants ha^{-1}) and different letters show significant difference at $p < 0.05$ (Tukey's HSD test).

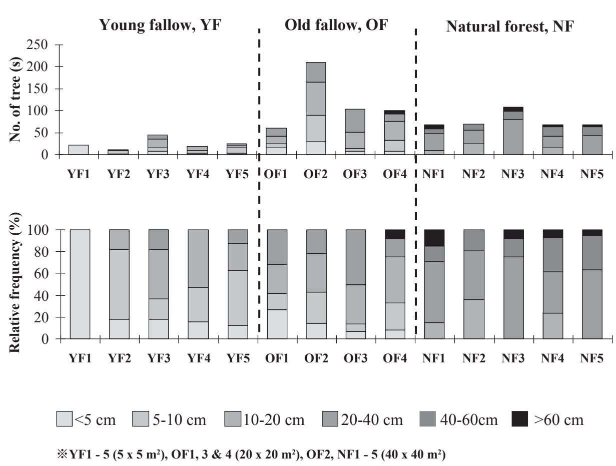

Fig. 4. Number of tree stem and relative frequency of tree species according to various DBH size class in YF, OF and NF.

Table 3. Soil physicochemical properties of YF, OF and NF sites in Batang Ai area.

		0 - 10 cm depth			30 - 40 cm depth			60 - 70 cm depth		
Soil properties		YF	OF	NF	YF	OF	NF	YF	OF	NF
pH(H_2O)		4.35 (0.12)b	4.13 (0.26)ab	3.97 (0.12)a	4.49 (0.05)b	4.39 (0.05)ab	4.33 (0.08)a	4.55 (0.10)	4.45 (0.05)	4.48 (0.08)
pH(KCl)		3.47 (0.11)	3.41 (0.10)	3.29 (0.15)	3.51 (0.07)	3.37 (0.08)	3.38 (0.27)	3.52 (0.16)	3.34 (0.0)	3.42 (0.26)
T-C	($g{\cdot}kg^{-1}$)	31.6 (6.7)	25.6 (8.0)	29.8 (16.1)	9.5 (3.0)	5.8 (1.5)	7.8 (2.8)	5.4 (0.7)	4.0 (1.2)	3.8 (0.8)
T-N	($g{\cdot}kg^{-1}$)	2.1 (0.2)	1.7 (0.3)	1.9 (0.9)	0.8 (0.1)	0.7 (0.2)	0.8 (0.2)	0.6 (0.1)	0.6 (0.1)	0.6 (0.1)
C/N ratio		15.0 (1.9)	14.7 (2.3)	15.3 (2.0)	11.2 (2.9)	8.2 (0.6)	9.4 (2.5)	9.6 (2.1)	6.7 (0.6)	6.4 (1.8)
CEC	($cmol_c{\cdot}kg^{-1}$)	18.6 (4.4)	17.9 (3.8)	19.8 (2.0)	12.0 (2.1)	12.0 (1.2)	13.9 (3.1)	9.8 (0.9)	11.9 (1.2)	11.6 (2.6)
Exchangeable Ca	($cmol_c{\cdot}kg^{-1}$)	0.14 (0.25)	0.02 (0.00)	0.03 (0.02)	0.02 (0.02)	0.02 (0.00)	0.01 (0.00)	0.02 (0.01)	0.01 (0.00)	0.01 (0.00)
Exchangeable Mg	($cmol_c{\cdot}kg^{-1}$)	0.08 (0.06)	0.04 (0.00)	0.05 (0.03)	0.02 (0.01)	0.01 (0.00)	0.01 (0.01)	0.01 (0.01)	0.01 (0.00)	0.01 (0.00)
Exchangeable K	($cmol_c{\cdot}kg^{-1}$)	0.09 (0.02)	0.07 (0.01)	0.08 (0.07)	0.05 (0.01)	0.03 (0.01)	0.04 (0.02)	0.04 (0.01)	0.03 (0.00)	0.03 (0.01)
Exchangeable Al	($cmol_c{\cdot}kg^{-1}$)	3.27 (1.62)	4.65 (1.43)	5.60 (2.32)	2.39 (0.89)	3.17 (0.97)	3.74 (1.10)	2.08 (0.63)	3.89 (1.45)	2.97 (0.80)
Exchangeable NH_4	($cmol_c{\cdot}kg^{-1}$)	0.13 (0.02)	0.14 (0.01)	0.15 (0.09)	0.08 (0.03)	0.06 (0.02)	0.09 (0.04)	0.08 (0.04)	0.04 (0.02)	0.06 (0.04)
ECEC	($cmol_c{\cdot}kg^{-1}$)	3.60 (1.43)	4.82 (1.43)	5.78 (2.22)	2.51 (0.87)	3.25 (0.98)	3.83 (1.10)	2.17 (0.61)	3.95 (1.44)	3.04 (0.81)
Al saturation	(%)	87.4 (15.6)	96.3 (1.2)	95.4 (5.6)	94.7 (2.9)	97.5 (0.7)	97.4 (1.0)	95.3 (2.7)	98.2 (0.8)	97.7 (0.9)
Available P	($mg{\cdot}kg^{-1}$)	13.7 (1.7)	12.7 (3.1)	16.6 (5.5)	7.1 (1.5)	6.7 (1.0)	8.7 (1.0)	6.6 (1.7)	5.4 (0.7)	6.7 (1.1)
Clay	(%)	33.3 (3.3)a	34.8 (6.6)ab	42.3 (5.2)b	39.3 (3.7)	34.8 (7.0)	40.5 (8.3)	40.2 (7.9)	34.3 (7.1)	39.5 (6.9)
Silt	(%)	20.1 (2.6)	23.6 (3.7)	19.3 (7.7)	19.3 (4.4)	21.1 (4.7)	22.2 (6.1)	18.6 (5.2)	24.1 (5.2)	23.7 (6.0)
Sand	(%)	46.6 (5.3)	41.6 (3.2)	38.4 (10.0)	41.4 (7.3)	44.1 (6.9)	37.3 (13.3)	41.3 (6.2)	41.6 (3.1)	36.8 (10.7)
Bulk density	($g\ mL^{-1}$)	0.76 (0.18)	0.88 (0.08)	0.81 (0.05)	1.18 (0.07)	1.10 (0.15)	1.10 (0.09)	1.32 (0.03)	1.29 (0.12)	1.24 (0.03)
Soil hardness	(mm)	16 (2)b	12 (3)a	13 (2)ab	18 (2)	17 (2)	17 (1)	19 (3)	19 (1)	19 (1)

ECEC, effective CEC, sum of exchangeable bases and Al. Al saturation, ratio of exchangeable Al to ECEC. Hardness was measured using a Yamanaka-type penetrometer. Values in parentheses refers to the standard deviation. Different letters show significantly different between YF, OF and NF at $p < 0.05$ (Tukey's HSD test)

and 7.3 to 14.4 $cmol_c kg^{-1}$, respectively. The effective CEC (ECEC), i.e. the sum of exchangeable cations (Na, K, Mg, Ca, and Al), was low compared with the CEC suggesting that a certain amount of variable negative charges occurred in the soils.

Figure 5 shows the levels of pH(H_2O), exchangeable Al, Ca, Mg and K in the surface soils study sites. In YF, the soils were less acidic and tended to possess higher amounts of exchangeable bases, compared to the soils in OF and NF. This could be ascribed to the effects of fertilizer application at cropping time which were not taken up by the poor vegetation regrowth during the fallow period. In addition, the soil acidity in soils of YF was found similar with those of the soils in short fallow lands after intensive shifting cultivation in Engkari River areas (Wasli *et al.,* 2009), which is located adjacent to Batang Ai area (Figure 1).

In contrast, when compared with the soils under a less-intensified shifting cultivation system as represented by the sites along Mujong River (Tanaka *et al.* 2007), the soils in YF were more acidic with less contents of exchangeable bases. This result suggested that the shortening of fallow periods in the previous upland rice farming, especially at YF sites, had resulted in less ash addition to soils during burning periods done to alleviate soil acidity and supply nutrients for plant growth. Although chemical fertilizers (mostly urea) were applied during upland rice farming, it is likely that fertilizer application could not compensate sufficiently for the loss of soil nutrients. On the other hand, the soils in OF and NF were strongly acidic with low amounts of exchangeable bases indicating nutrient depletion from

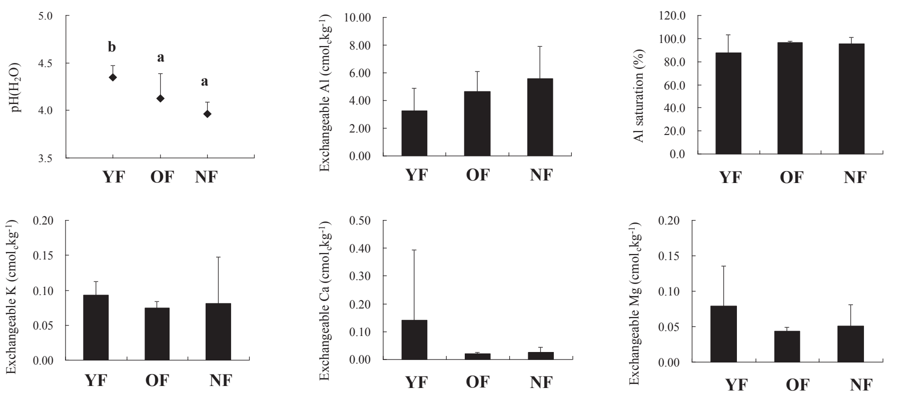

Fig. 5. pH(H_2O), exchangeable Al, Al saturation and exchangeable bases (K, Mg and Ca) in YF, OF and NF.
Different letters show significant difference at $p < 0.05$ (Tukey's HSD test).

soil ecosystems or due to uptake by the above vegetation. For OF, another possible reason for the concomitant soil acidification in the area was due to a long history of agricultural activities before their resettlement had began about 40 years ago.

The contents of Total C and N in the surface soils of the study sites ranged from 16.9 to 57.1 gkg^{-1} and from 1.2 to 3.4 gkg^{-1}, respectively. In the subsoils (depth of 30-40 cm and more than 60 cm), total C ranged from 3.6 to 13.4 gkg^{-1} and 2.3 to 6.4 gkg^{-1}, respectively, whereas total N in the subsoils ranged from 0.5 to 1.0 gkg^{-1} and 0.4 to 0.8 gkg^{-1}, respectively. No significant differences were observed in the contents of total C and N between YF, OF and NF. From the result obtained in NF, it was found that the content of total C in NF in the surface soils were lower than the amount of total C in the surface soils under primary forests in Gunung Mulu, Sarawak (Proctor *et al.,* 1983) and, lowland dipterocarp primary forests in East Kalimantan (Ohta *et al.,* 2000). Although a large supply of organic mater and its accumulation in soils can be expected in NF due to its well-grown vegetation and undisturbed canopy, the steep slope of more than 30o in NF as well as the high amount of rainfall throughout the year in Batang Ai area might have caused soil erosion which resulted in the low amount of soil organic matter remaining in surface soil layers. According to Ishizuka *et al.* (1999), under a steep slope area, continuous supply of organic matter and its accumulation in soils could not be expected.

Surface soils (0-10 cm depth) of YF were harder than the soils in OF and NF while at the subsoils (30-40 cm and more than 60 cm depth), no significant differences in term of the soil hardness were observed between YF, OF and NF (Fig. 4). The result suggests that due to the human impact during farming, soil compaction was more significant in YF than OF and NF.

3) Have these old fallow lands possessed similar ecological criteria to the natural forests in relation to vegetation condition and soil fertility?

The result of the vegetation survey indicated that the vegetation compositions among YF, OF and NF were significantly different. In YF, the vegetation composition and condition resembles the fallow lands commonly utilized under intensive shifting cultivation systems in Lubok Antu and Engkari River area where grass and fern species dominated the lands with common occurrence of pioneer tree species such as *Eugenia*, *Melastoma* and *Macaranga*. This suggested the farming practices in the area could have been conducted in a similar way as the Iban farmers in Lubok Antu and Engkari River. On the other hand, the species composition and diversity in OF were not similar to NF and less climax species were encountered in the former. The size of tree species in NF were significantly larger than trees in OF. According to Saldarriaga (1987), a longer fallow period is necessary in order to accumulate an aboveground biomass similar to that of a primary forest as the trees in the 50-year-old secondary forest are still smaller and their wood is likely to be less dense.

The soils in Batang Ai area are characterized as strongly acidic with poor nutrient status. In terms of fallow period, no substantial difference were observed between the soils in YF, OF and NF although YF showed a slightly less acidic nature probably due to the effect of fertilizer application during the previous cropping. Meanwhile, the high acidity and low nutrient status in the soils at OF and NF could be due to nutrient uptake by the abovesoil vegetation.

Environmental implications associated with tropical land use intensification are widespread and severe. If no preventive measures are proposed to find proper solutions to this intensification, loss of primary tropical forests (Whitmore, 1975; Ashton, 1981), deterioration of soil nutrient status and physical structure (Nye & Greenland, 1960; Ewel *et al.,* 1981) and increased soil erosion (Lal, 1984) could result. Based on our findings, considering the high acidity, lack of nutrients in the soils and steep topography ofBatang Ai area, remaining forests should be left undisturbed as their removal would greatly accelerate severe land degradation, and rehabilitation of such land would be a difficult task. In addition, elimination of the forests in Batang Ai area could entail not only the loss of forest diversity and all forest products for the farmers' livelihood, but could also contribute to a rapid increase in soil erosion. Taking into account such a situation, conservation of the forest in the study area could prevent water pollution upriver of Batang Ai River since most of the communities living downriver largely depend on the river as their only source of water for various daily uses.

Although the actual time taken for old secondary forests to be transformed into natural forests will depend on various environmental variables, i.e. climate, intensity and scale of the disturbance, amount of forest remaining in the surrounding landscape and the distance from the seed sources of natural forest species, the results from the present study suggested that due to the acidic and poor fertility condition of the soils, a fallow period of 50 years would be insufficient for the land which was once affected by shifting cultivation to recover its vegetation condition equivalent to that of natural forests. Although these forests did not recover within a century, taking into account that natural forests remain only as protected areas or national parks in Sarawak, proper conservation of old secondary forests similar to that for natural forests, should be required since, at present, large patches of abandoned old secondary forests that are of withccessibility were are still avle.

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