RECOVERY OF VEGETATION STRUCTURE, SOIL NUTRIENTS AND LATE-SUCCESSION SPECIES AFTER SHIFTING CULTIVATION IN CENTRAL KALIMANTAN, INDONESIA

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Recovery of vegetation and soil nutrients in abandoned shifting cultivation areas can provide important information, important for forest rehabilitation. For better understanding of forest recovery after the cessation of shifting cultivation, soil nutrients and vegetation structure of fallow areas were monitored at 1, 5 and 10 years after abandonment in a primary forest plot. The results showed that the number of species, the Shannon indices of diversity and evenness of large trees (diameter at breast height > 20 cm) increased with time after abandonment. Late-successional species in primary tropical rainforests, e.g. *Shorea* sp., was found 1, 5 and 10 years after abandonment. Soil organic carbon and total nitrogen levels were low in all plots and at all soil depths except in surface soil (0–2 cm), and did not significantly differ between among plots. Available phosphorous content was significantly different between the plot that had been fallow for one year and the rest of the plots, for both combined and each soil depth. It was concluded that changes in vegetation composition did not affect the status of soil nutrients in the young fallow plots, which can support the growth of late-succession species.

Keywords: Forest recovery, pioneer species, soil organic carbon, total nitrogen, phosphorous

INTRODUCTION

In Indonesia, one of the activities threatening the existence of lowland dipterocarp forest is shifting cultivation, which changes the structure and species composition of the forest landscape (Lawrance et al. 2005). Shifting cultivation is a form of subsistence agriculture practised in many tropical countries that produces annual agricultural crops for a few years after which the cultivated land is left fallow (Christanty 1986, Delang 2007). Land preparation for shifting cultivation includes the slash-and-burn of native vegetation that can result in loss of biodiversity, global warming, emissions of carbon dioxide and other green-house gases (GHGs) to the atmosphere, and watershed degradation/soil erosion with its associated downstream effects (FAO 2006).

Many studies have discussed the recovery process of vegetation (Van Do et al. 2010, Aththorick et al. 2012) and soil properties (Giardina et al. 2000, Biswas et al. 2010, Osman et al. 2013) after shifting cultivation. An early stage of vegetation succession is dominated by grass and pioneer tree species (Kenzo et al. 2010). Fallows, 10 years after shifting cultivation, were dominated by pioneer species, e.g. *Macaranga gigantean*, in Indonesia (Lawrence et al. 2005) and *Wendlandia paniculata* in Vietnam (Van Do et al. 2011). About 60% of species in primary forests recovered 35 years after shifting cultivation in Indonesia (Riswan & Abdulhadi 1992) while less than 50% recovered after 50 years in Eastern Himalaya (Teegalapalli & Datta 2016). This implies that the recovery rates of species composition after shifting cultivation are different among sites. The recovery of mixed dipterocarp forests after shifting cultivation was estimated to take more than 100 years (Riswan & Abdulhadi 1992, Aththorick et al. 2012). However, the recovery processes of dipterocarp forests abandoned after cessation of shifting cultivation, especially changes the in soil-vegetation system, are not well known. There was no correlation between soil nutrient levels (P,

N, Mg, Ca and K) and time after abandonment of shifting cultivation (Lawrence 2004). Thus, early vegetation recovery after shifting cultivation may be generally specific for each site and we need to understand how the site-specificity is characterised.

Forests degraded by shifting cultivation can be successfully rehabilitated by planting with the appropriate species for the specific site conditions (Lamb et al. 2005). Therefore, studies on vegetation succession and soil nutrient status in abandoned shifting cultivation areas are important to provide baseline information for successful reforestation programmes. To accelerate forest recovery after shifting cultivation, it is necessary to understand the relationships between soil and vegetation recovery processes. In the present study, we monitored the status of soil nutrients and vegetation structure in fallow plots, 1, 5 and 10 years after the cessation of shifting cultivation in a primary forest as the control. The plots were compared to understand how vegetation and soil conditions changed in the early stages of forest recovery.

MATERIALS AND METHODS

Study site

The research was conducted in the village of Tanjung Paku (112^0 46' E, 00^0 44' S), Seruyan Regency, Central Kalimantan, Indonesia (Figure 1). The village has a tropical rainforest climate (Af) with a mean annual temperature of 22–28 °C at night and 30–33 °C during the day. Mean annual rainfall is 3730 mm. The annual number of rainy days per year varies from 95 to 112. Soil under the litter layer remains moist throughout the year. The soil type is Ultisol, which is strongly weathered and acidic due to leaching (Chesworth 2008). Ultisol is a mineral soil with a horizon that contains 20% more clay (B2) than the upper layer (B1).

Shifting cultivation is carried out in Tanjung Paku to produce rice and vegetables. Land preparation begins with slashing and burning all vegetation using axes or chain-saws. In this agricultural system, there is no tillage, terracing or mounding, irrigation or inputs of green manure,

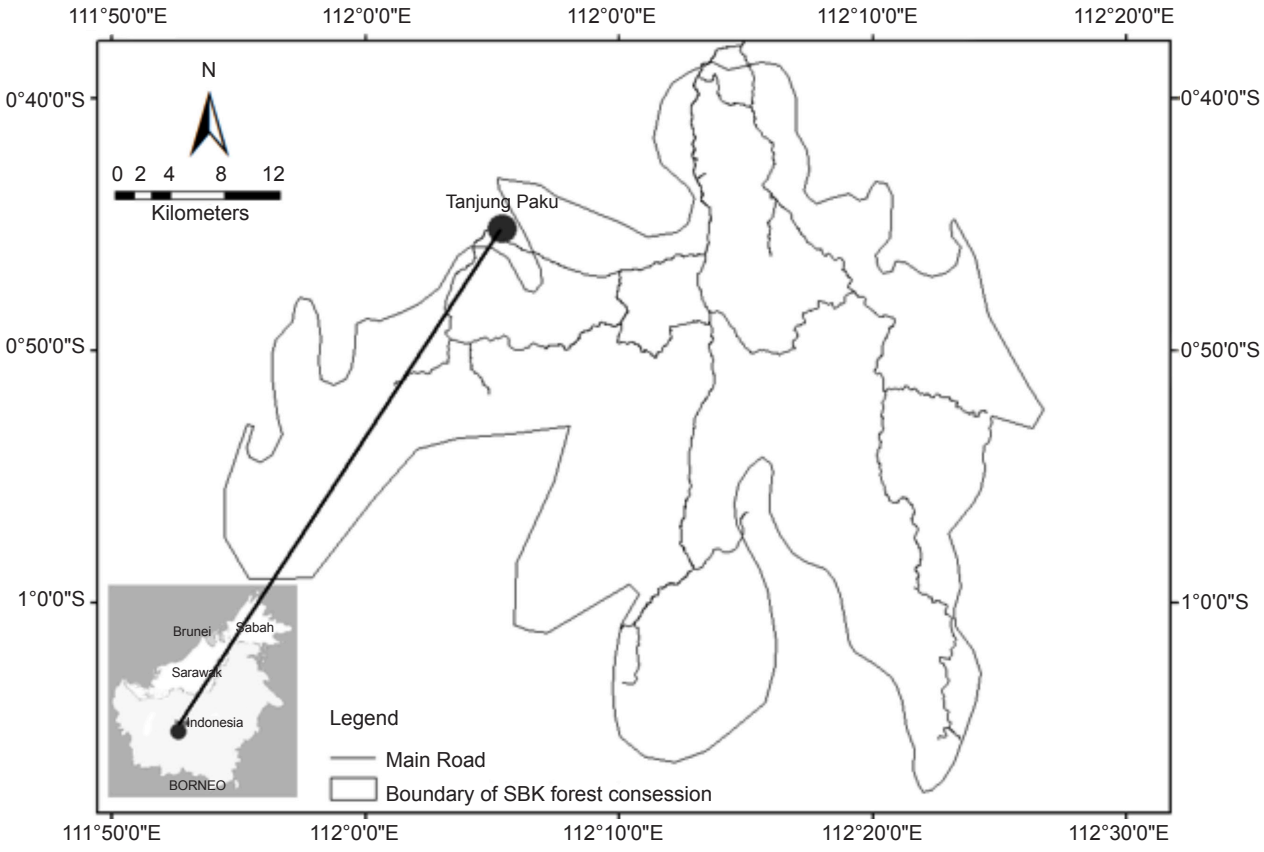

Figure 1 Location of the Bornean village of Tanjung Paku in Indonesia

fertiliser, herbicides or pesticides (Lawrence 2005). The croplands are abandoned after 2 to 3 years as soil nutrients become depleted, and the interval between crop production varies between 5 to10 years.

Plot selection

Data on vegetation structure and soil nutrient status were collected in 1-ha permanent plots (100 m × 100 m). Three plots were established on cultivated sites that had been abandoned 1, 5 and 10 years (A1, A5 and A10, respectively) before the survey. A 1-ha plot in a primary forest was also established.

Vegetation survey

All individual trees within the plots were classified into one of the following growth stages: seedling (height ≤ 1.5 m), sapling (height > 1.5 m, DBH < 10.0 cm), small tree (DBH 10.0–19.9 cm) and large tree (DBH ≥ 20.0 cm). Each plot was divided into 25 subplots (20 m × 20 m) (Figure 2). In each subplot, the species of all small and large trees were identified and their DBH recorded. Similarly, the species of all seedlings (in 2 m × 2 m) and saplings (in 5 m × 5 m) within the subplots were identified. For taxonomic nomenclature of plants, all names of plants were updated as documented by the Angiosperm Phylogeny Group III (APG III 2009) taxonomic classifications using Tropicos.

Soil survey

Soil samples in each plot were collected at the following depths with three replicates: 0–2, 2–10, 10–20 and 20–30 cm (Figure 2). The soil samples were air dried and passed through a 0.5-mm mesh sieve. Soil organic carbon (SOC), total nitrogen(TN) and available phosphorus (P_2O_5) were measured in each soil sample using H_2SO_4. K_2CrO_7 oxidation, Kjedhal and Bray methods respectively (Sulaeman et al. 2005).

Data analysis

Vegetation structure

The numbers of individuals, species, species diversity, Shannon's Diversity Index (H') and Evenness Index (J') were calculated to quantify the vegetation structure in each plot (Magurran 1988):

$$H' = -\sum_{i=1}^{s} p_i \ln p_i \quad \text{and} \quad J' = \frac{H'}{\ln S}$$

where, $p_i = n_i/N$, n_i = number of individuals of the i species, N = total number of individuals of all species and S = total number of species in the plots. The indices were calculated for each of the four growth stages (seedling, sapling and small and large tree). The data were subjected to one-way analysis of variance (ANOVA) to test the effects of fallow years. Tukey's HSD test was used

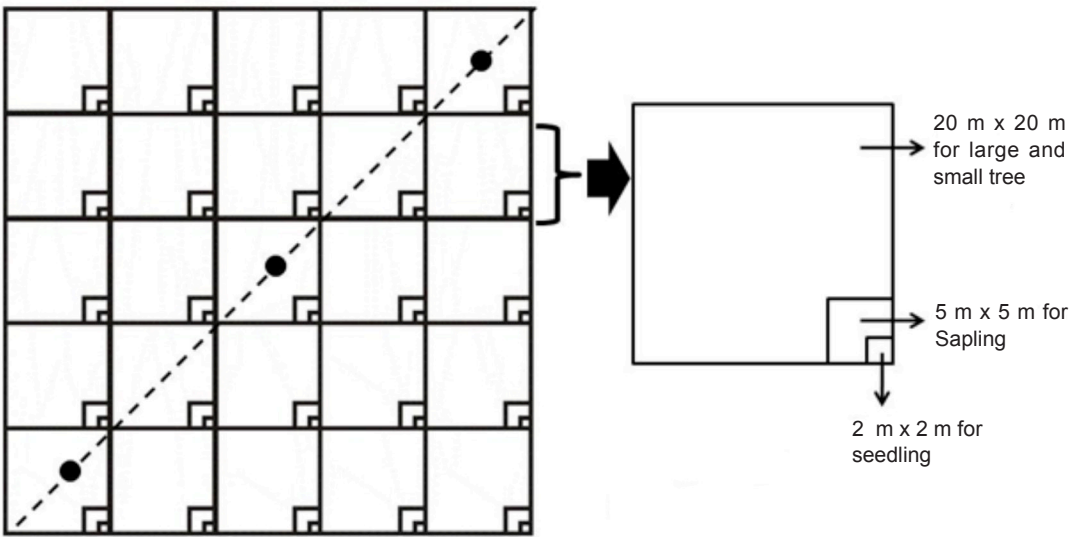

Figure 2 Locations of subplots for vegetation and soil surveys within each permanent plot; ● = the point of soil sampling

for multiple comparisons between the means of each plot.

Soil nutrients

The quantity of SOC, TN and P_2O_5 were compared between the plots using one-way ANOVA for the combined soil depth. When the effect was significant ($p \leq 0.05$), Tukey's HSD test was used to examine the differences between the means of each plot.

RESULTS

Vegetation structure

The surveys of the fallow plots and primary forest plot yielded a combined total of 167 seedlings comprising 26 species in 18 families (Table 1), 848 saplings comprising 89 species in 36 families (Table 2), 664 small trees comprising 44 species in 23 families (Table 3) and 349 large trees comprising 59 species in 29 families (Table 4). The species of eight saplings could not be identified. Among the small trees, four species were identified to genus level while one species remained unidentified. Among the large trees, 21 species were identified to genus level while 3 species remained unidentified.

Abundance

The number of individuals was significantly different among plots for all growth stages (seedling: $F = 3.21$, $df = 3$, $p = 0.04$; sapling: $F = 20.01$, $df = 3$, $p < 0.001$, small tree: $F = 15.72$, $df = 3$, $p < 0.001$ and large tree: $F = 44.58$, $df = 3$, $p < 0.001$) (Table 5). The number of seedlings and saplings was highest in A1, the number of small trees was highest in A10 and the number of large trees showed an increasing trend with fallow years (Table 5).

Number of species and diversity indices

The numbers of species of seedlings ($F = 3.00$, $df = 3$, $p = 0.05$) and saplings ($F = 14.99$, $df = 3$, $p < 0.001$) also differed significantly among plots. The number of species of seedlings and saplings was highest in A10, followed by A1, primary forest and A5 (Table 1). H' differed significantly among plots for all growth stages (seedlings: F =

Table 1 List of species, families and number of individuals for seedlings in plots 1 year (A1), 5 years (A5) and 10 years (A10) after abandonment, and in primary forest

Family	Species	A1	A5	A10	Primary forest
Moraceae	*Ficus uncinulata*	27	3	3	-
Lamiaceae	*Vitex pinnata*	9	-	-	-
Myrtaceae	*Syzygium* sp.	5	3	8	-
Euphorbiaceae	*Macaranga pruinosa*	5	-	-	-
Sapindaceae	*Nephelium uncinatum*	3	3	4	-
Melastomataceae	*Pternandra cordata*	3	-	6	-
Myristicaceae	*Knema* cf.*latifolia*	3	-	3	-
Aquifoliaceae	*Ilex cissoidea*	2	-	2	-
Phyllanthaceae	*Antidesma montanum*	1	1	10	-
Lauraceae	*Actinodaphne glomerata*	1	1	10	-
Dipterocarpaceae	*Shorea leprosula*	1	-	3	4
Annonaceae	*Goniothalamus malayanus*	-	-	15	-
Phyllanthaceae	*Antidesma neurocarpum*	-	-	3	-
Clusiaceae	*Garcinia parvifolia*	-	-	1	1
Myrtaceae	*Eugenia* sp.	-	-	-	**7**
Dipterocarpaceae	*Shorea laevis*	-	-	-	1
Fabaceae	*Kingiodendron* sp.	-	-	-	1
Aquifoliaceae	*Ilex cissoidea*	-	-	2	-
Lamiaceae	*Geunsia pentandra*	-	-	2	-
Others		3	-	7	-

Table 2 List of species, families and number of individuals for saplings in plots 1 year (A1), 5 years (A5) and 10 years (A10) after abandonment, and in primary forest

No	Family	Species	A1	A5	A10	Primary forest
1	Lamiaceae	*Geunsia pentandra*	84	12	6	-
2	Moraceae	*Ficus uncinulata*	81	15	32	3
3	Cannabaceae	*Trema tomentosa*	79	2	-	-
4	Euphorbiaceae	*Mallotus paniculatus*	60	2	1	-
5	Euphorbiaceae	*Macaranga pruinosa*	41	10	34	-
6	Moraceae	*Ficus aurata*	15	1	7	-
7	Lamiaceae	*Vitex pinnata*	8	4	1	-
8	Lauraceae	*Actinodaphne glomerata*	2	4	21	-
9	Actinidiaceae	*Saurauia nudiflora*	1	1	17	-
10	Myristicaceae	*Knema* cf. *latifolia*	1	1	10	1
11	Euphorbiaceae	*Macaranga conifera*	1	1	3	-
12	Rubiaceae	*Nauclea macrophylla*	1	-	4	1
13	Dipterocarpaceae	*Shorea hopeifolia*	-	2	1	8
14	Dipterocarpaceae	*Shorea leprosula*	-	-	17	3
15	Dipterocarpaceae	*Shorea seminis*	-	-	2	-
16	Fabaceae	*Fordia splendidissima*	-	-	10	-
17	Myrtaceae	*Eugenia* sp.	-	-	-	28
18	Lauraceae	*Litsea firma*	-	-	-	23
19	Malvaceae	*Microcos* cf. *pyriformis*	-	-	-	12
20	Others		19	20	61	74

Table 3 List of species, families and number of individuals for small trees in plots 1 year (A1), 5 years (A5) and 10 years (A10) after abandonment, and in primary forest

No	Family	Species	A1	A5	A10	Primary forest
1	Cannabaceae	*Trema tomentosa*	72	23	10	-
2	Euphorbiaceae	*Mallotus paniculatus*	1	2	8	-
3	Lamiaceae	*Geunsia pentandra*	1	12	30	-
4	Euphorbiaceae	*Macaranga pruinosa*	-	9	183	1
5	Moraceae	*Ficus lepicarpa*	-	1	4	-
6	Lamiaceae	*Vitex pinnata*	-	1	7	-
7	Euphorbiaceae	*Macaranga gigantea*	-	2	70	-
8	Phyllanthaceae	*Glochidion celastroides*	-	1	11	1
9	Annonaceae	*Cananga odorata*	-	19	-	-
10	Aquifoliaceae	*Ilex cissoidea*	-	-	34	-
11	Moraceae	*Ficus aurata*	-	-	31	-
12	Dipterocarpaceae	*Shorea leprosula*	-	-	9	2
13	Rubiaceae	*Nauclea macrophylla*	-	-	13	-
14	Euphorbiaceae	*Macaranga* sp.	-	-	-	4
15	Thymelaeaceae	*Gonystylus brunnescens*	-	-	-	1
16	*Euphorbiaceae*	*Aporusa nitida*	-	-	-	1
17	Dipterocarpaceae	*Shorea dasiphylla*	-	-	-	4
18	Dipterocarpaceae	*Shorea parvifolia*	-	-	-	1
19	Dipterocarpaceae	*Shorea falax*	-	-	-	1
20	Others		-	12	74	8

Table 4 List of species, families and number of individuals for the large tree stage in plots 1 year (A1), 5 years (A5) and 10 years (A10) after abandonment, and in primary forest

Family	Species	A1	A5	A10	Primary forest
Cannabaceae	*Trema tomentosa*	-	27	4	-
Lamiaceae	*Geunsia pentandra*	-	1	-	1
Magnoliaceae	*Elmerilia* sp.	-	1	-	-
Aquifoliaceae	*Ilex cissoidea*	-	-	37	-
Euphorbiaceae	*Macaranga pruinosa*	-	-	23	-
Moraceae	*Ficus aurata*	-	-	19	-
Euphorbiaceae	*Macaranga gigantea*	-	-	15	
Rubiaceae	*Anthocephalus chinensis*	-	-	4	17
Lythraceae	*Duabanga moluccana*	-	-	4	3
Euphorbiaceae	*Macaranga hypoleuca*	-	-	-	24
Dipterocarpaceae	*Shorea stenoptera*	-	-	-	17
Dipterocarpaceae	*Shorea leprosula*	-	-	-	16
Dipterocarpaceae	*Shorea dasiphylla*	-	-	-	14
Dipterocarpaceae	*Shorea fallax*	-	-	-	8
Dipterocarpaceae	*Vatica* sp.	-	-	-	5
Dipterocarpaceae	*Dipterocarpus* sp.	-	-	-	4
Dipterocarpaceae	*Hopea* sp.	-	-	-	2
Dipterocarpaceae	*Shorea leavis*	-	-	-	2
Dipterocarpaceae	*Shorea ovalis*	-	-	-	1
Dipterocarpaceae	*Dryobalanops* sp.	-	-	-	1
Dipterocarpaceae	*Shorea johorensis*	-	-	-	1
Dipterocarpaceae	*Shorea parvifolia*	-	-	-	1
Dipterocarpaceae	*Shorea gibbosa*	-	-	-	1
Others		-	-	-	96

Table 5 Number of individuals, species, Shannon index and evenness of seedlings, saplings, small trees and large trees in plots 1 year (A1), 5 years (A5) and 10 years (A10) after abandonment, and in primary forest

Sample	Plot	Number of individuals	Number of species	Shannon index	Evenness
Seedling (per 4 m^2)	A1	3.75(3.89) a	1.94(1.34) ab	0.42(0.54) ab	0.45(0.45) ab
	A5	1.29(0.76) b	1.14(0.38) b	0.09(0.24) b	0.13(0.35) b
	A10	3.71(1.27) a	2.86(1.15) a	0.91(0.44) a	0.84(0.31) a
	Primary forest	1.56(0.53) ab	1.56(0.53) ab	0.39(0.37) ab	0.56(0.53) ab
Sapling (per 25 m^2)	A1	18.56(11.09) a	5.60(1.71) a	1.46(0.4) ab	0.89(0.11)
	A5	4.68(3.15) b	3.05(1.93) b	0.83(0.62) c	0.90(0.23)
	A10	10.36(4.76) b	6.80(1.98) a	1.69(0.38) a	0.90(0.12)
	Primary forest	5.80(1.53) b	4.16(0.94) b	1.29(0.24) bc	0.93(0.09)
Small tree (per 400 m^2)	A1	5.29(4.97) b	1.21(0.58) bc	0.05(0.17) d	0.07(0.25) b
	A5	4.16(2.91) b	2.95(1.27) b	0.96(0.49) b	0.91(0.24) a
	A10	19.36(8.69) a	7.56(2.69) a	1.67(0.32) a	0.86(0.08) a
	Primary forest	1.14(0.53) c	1.14(0.53) c	0.47(0.38) c	0.09(0.30) b
Large tree (per 400 m^2)	A1	-	-	-	-
	A5	2.07(1.49) c	1.07(0.27) c	0.04(0.27) c	0.72(0.00) b
	A10	4.24(1.94) b	2.64(0.95) b	0.84(0.35) b	0.92(0.10) a
	Primary forest	8.56(2.81) a	8.60(2.81) a	2.09(0.36) a	1.00(0.00) a

Values are means + standard deviation; different letters indicate significant differences between permanent plots (Tukey's HSD)

4.01, df = 3, p = 0.018; saplings: F = 9.00, df = 3, p < 0.001; small trees: F = 9.61, df = 3, p < 0.01; large trees: F = 16.79, df = 3, p < 0.001) (Table 1). The H' was highest in A10 for seedlings, saplings and small trees, while in primary forest it was highest for large trees. The J' values for seedlings, small and large trees also differed significantly among plots (F = 4.56, df = 3, p = 0.011; F = 10.18, df = 3, p < 0.001 and F = 17.29, df = 2, p < 0.001) respectively (Table 1). J' values for saplings were not significantly different among plots (F = 0.91, df = 3, p = 0.442) (Table 1).

Species composition

The most abundant seedling species in A1 and A5 was *Ficus uncinulata* (Moraceae) which comprised 42.9 and 27.3% of total individuals, in the respective plots (Table 1), whereas in A10, the most abundant species was *Goniothalamus malayanus* (Annonaceae, 19.0%). *Eugenia* sp. was the most abundant in the primary forest plot, comprising 50.0% of total individuals. *Antidesma montanum* (Phyllantaceae) and *Actinodaphne glomerata* (Lauraceae) were found in all fallow plots. For the group of other families, three species, *Trichadenia philippinensis* (Flacourtiaceae), *Glochidion celastroides* (Phyllanthaceae) and *Nauclea macrophylla* (Rubiaceae) seedlings were found in A1. Meanwhile four species, *Antidesma cuspidatum* (Phyllanthaceae), *Nauclea excelsa* (Rubiaceae), *Cratoxylum arborescens* (Hypericaceae) and *Melanochyla caesia* (Anacardiaceae) seedlings were found in A10 (Table 1).

For saplings, *Geunsia pentandra* (Lamiaceae) and *F. uncinulata* were the most numerous species in A1 and A5, comprising 21.4 and 20.0% of the total individuals, respectively. A10 was dominated by *Macaranga pruinosa* (Euphorbiaceae) (15.0% of saplings) while *Eugenia* sp. (Myrtaceae) comprised 18.3% of saplings in the primary forest plot. The primary forest and fallow plots A1, A5 and A10, differed markedly in species composition of seedlings and saplings. The primary forest plot recorded 5 seedling species (19.2% of the 26 species identified across all plots) and 49 sapling species (54.4% of the 90 species identified across all plots). Among saplings of the group of others, Euphorbiaceae was the most abundant in the fallow plots, while Dipterocarpaceae was the most abundant in primary forest plot (Table 2)

The numbers of small and large tree species also differed significantly between the fallow and primary forest plots (F = 11.96, df = 3, p < 0.001, and F = 29.71, df = 3, p < 0.001) respectively (Table 5). A10 was the most dominated by small trees (Table 3), whereas in the primary forest plot, large trees were more abundant than in other plots (Table 4). For small trees, *Trema tomentosa* dominated (97.3% of individuals) in plot A1, followed by *Mallotus paniculatus* (1.4%) and *G. pentandra* (1.4%). The species composition in A5 was dominated by *T. tomentosa* (28%), *Cananga odorata* (23.1%) and *G. pentandra* (14.6%). The number of species was greater in A10 than in A1 and A5. The dominant species in A10 was *M. pruinosa* (37.8%) followed by *M. gigantea* (14.4%) and *Ilex cissoidea* (7%) (Table 3). At the family level, the levels of dominance between fallow year plots and the primary forest plot differed slightly. The richest family in A1 and A5 was Cannabaceae, of which small trees comprised 97.3% (Table 1) and 28.1% (Table 2), respectively. For small trees in A10, Euphorbiaceae was the dominant family (55.6%), while in the primary forest plot, 33.3% of the small trees were in the family Dipterocarpaceae. For the group of other families, Rutaceae, Moraceae, Rubiceae and Sonneratiaceae, as small trees, were found in all plots, less than 8 individuals per ha (Table 3). The number of species of large trees increased with increasing fallow years (Table 5). The most abundant species in A5, A10 and primary forest plot was *T. tomentosa* (93.1% of the total number of species), *I. cissoidea* (34.9%), and *M. hypoleuca* (11.2%), respectively. Large trees abundant in primary forest plot were from the families Dipterocarpaceae (34.1%), Euphorbiaceae (12.1%) Lauraceae (7.9%), Rubiaceae (7.9%) and Myrtaceae (5.6%), while the other families had less than 8 individuals per ha (Table 4).

Dipterocarp species

Dipeterocarp species were also found growing in the fallow plots. Seedlings of *S. leprosula* were found at A1 and A10 (Table 6). Saplings of *S. hopeifolia* were found at A5 and A10, and those of *S. leprosula* and *S. seminis* at A10. Additionally, small trees of *S. leprosula* were found at A10. *Shorea* sp., especially *S. leprosula* and *S. stenoptera,* were prevalent species of Dipterocarpaceae, which dominated in the primary forest plot (Table 4).

Soil nutrients

SOC and TN were not significantly different among plots for combined soil depth (SOC: F

Table 6 The number of species and individuals of dipterocarps in A1, A5 A10 and primary forest

Species	A1	A5	A10	Primary forest
	a/b/c/d	a/b/c/d	a/b/c/d	a/b/c/d
Dipterocarpus sp.	-	-	-	0/0/0/4
Dryobalanops sp.	-	-	-	0/0/0/1
Hopea sp.	-	-	-	0/0/0/2
Shorea dasiphylla	-	-	-	0/0/4/14
Shorea fallax	-	-		0/0/1/8
Shorea gibbosa	-	-	-	0/0/0/1
Shorea hopeifolia	-	0/2/0/0	0/1/0/0	0/8/0/0
Shorea johorensis	-	-	-	0/0/0/1
Shorea leavis	-	-	-	1/0/0/2
Shorea leprosula	1/0/0/0	-	3/17/9/0	4/3/2/16
Shorea ovalis	-	-	-	0/0/0/1
Shorea parvifolia	-	-	-	0/0/1/1
Shorea seminis	-	-	0/2/0/0	-
Shorea stenoptera	-	-	-	0/0/0/17
Vatica sp.	-	-	-	0/0/0/5
Total	1/0/0/0	0/2/0/0	3/20/9/0	5/11/8/73

a = seedling, b = saplings, c = small trees, d = large trees

= 0.138, df = 3, p = 0.937; N: F = 0.584, df = 3, p = 0.629), whereas P_2O_5 content in A1 was higher than the other plots for combined soil depth (F = 8.435, df = 3, p<0.001) (Table 7).

DISCUSSION

Vegetation structure

We found that the family composition of seedlings and saplings in the early stages of forest recovery differed from that in primary forest. Seedlings and saplings found in the primary forest plot were predominantly *Eugenia* sp. (Myrtaceae), which was also found in the understorey of a tropical forest in Sumatra, Indonesia (Hadi et al. 2009). It implied that *Eugenia* sp. was a shade tolerant species (Cid-Liccardi et al. 2012). The domination of *F. uncinulata* in A1, *N. unicnatum* in A5 and *G. malayanus* in A10 depicts an early species composition that is different from that reported in the East (Hashimoto et al. 2007) and West Kalimantan (Lawrence et al. 2005). The differences in species at seedling stage among plots in the study may be due to seed inputs from the surrounding secondary forest. *Ficus* sp., which was the dominant seedling species in A1, could have been dispersed to that fallow plot by animals such as birds and bats which feed on the drupe fruits (Galindo-Gonzalez et al. 2000)

For small trees, the number of species was highest in the fallow plot 10 years after abandonment, and the species composition also differed among plots. For example, *T. tomentosa* (Cannabaceae), a dominant species in A1, is known as a fast-growing pioneer species, from which seeds germinate successfully in open areas but do not germinate well in the understorey (Raich & Khoon 1990). The dominant small trees in A10, i.e. *M. pruinosa*, was not found in a previous study (Lawrence et al. 2005). This may be because seeds of this species can germinate in the forest understorey with lower light intensity. The density of large trees increased with time after abandonment, but remained markedly lower than that in the primary forest plot, even in A10. The density of each species differed between A5 and A10, e.g. *T. tomentosa* was most abundant in A5 but less abundant in A10, being replaced by *I. cissoidea* in A10. The dominance by *S. leprosula* in the present study, and also in Pasoh Forest Reserve in Malaysia (Davies et al. 2003) indicates that *S. leprosula* has a wider distribution than other dipterocarp species. The results also showed that the pioneer species in fallow plots were replaced overtime by both

Table 7 Contents of SOC (A), TN (B) and P_2O_5 (C) in plots 1 year (A1), 5 years (A5) and 10 years (A10) after abandonment, and in primary forest

Plot	SOC	TN	P_2O_5
A1	2.66(0.85)	0.22(0.07)	38.17(1.87) a
A5	2.49(0.85)	0.23(0.08)	11.53(2.73) b
A10	2.27(0.64)	0.17(0.05)	14.17(1.13) b
Primary forest	2.68(0.76)	0.18(0.05)	18.25(4.02) b

Values are means + standard deviatio; different letters indicate significant differences between permanent plot (Tukey's HSD)

light-demanding and shade-tolerant species, as observed in Singapore (Chua et al. 2013), Bolivia (Peña-Claros 2003) and Vietnam (Van Do et al. 2010, 2011). The species number, evenness and Shannon indices of large trees increased with time after abandonment. Only 1.8% in A5 and 3.8% in A10 of the total occupied species were found in the primary forest plot, e.g. *G. pentandra* in A5, and *A. chinensis* and *Duabanga moluccana* in A10. This indicated that the fallow plots required more time to recover and attain a number of species comparable to primary forest.

Emergence of dipterocarp species

Succession in the young fallow plots after cessation of shifting cultivation was illustrated by the development of vegetation overtime and the increasing number of individuals and species of large trees. Large trees change the micro-climate and allow late succession species to survive under the shade of pioneer species (Breugel et al. 2007, Teegalapalli & Datta 2016). Our discovery of late-succession dipterocarp forest species, i.e. *S. leprosula, S. hopeifolia* and *S. seminis* (Dipterocarpaceae), recolonising young fallows, has not been previously reported. The existence of dipterocarps in young fallows is probably because these plots were surrounded by seed sources of dipterocarps.

The results also suggested that lands abandoned after shifting cultivation could facilitate the regeneration of late-succession species, even though natural regeneration of dipterocarps was still poor, 10 years after abandonment. The limited number of dipterocarps was probably due to a high light intensity in the fallows (Hattori et al. 2013), which causes high mortality for dipterocarp seedlings (Kenzo et al. 2011, Hattori et al. 2013). For instance, the only dipterocarp seedlings found in A1 was *S. leprosula*, whose seedlings and saplings are known to demand relatively high-light conditions (Zipperlen & Press 1996, Kobayashi et al. 2001, Phillips et al. 2002) and are tolerant to moisture stress and open areas in the early stages of development than the other dipterocarps species (Appanah & Weinland 1993). *Shorea hopeifolia* and *S. seminis* were found in A5 and A10. Since they are known as shade tolerant species (Phillips et al. 2002), nurse trees at A5 and A10 may have provided favorable microclimates for the recruitment of these seedlings.

However, overall the number of individuals and species of dipterocarps found in young fallows was small, likely because young fallows, such as A1 and A5, provided micro-environments (e.g. high light intensity and temperature on the forest floor due to direct sunlight) unfavorable for growth of dipterocarp species, especially shade tolerant species (Otsamo et al. 1996). Seedlings and saplings of dipterocarps are known to be intolerant of open environments and need shading under nurse trees (Appanah & Weinland 1993).

Otsamo (1998, 2000) showed that dipterocarps can grow in degraded forest areas under nurse trees of some exotic species, e.g. *Acacia mangium*, *A. crassicarpa*, *Gmelina arborea*, *Paraserianthes falcataria* and *Peronema canescens*. The exotic nurse trees, however, may have negative impacts such as invasion into natural ecosystems (Osunkoya et al. 2005). The results suggest that some native pioneer species, such as *T. tomentosa, C. odorata*, *M. pruinosa*, *M. gigantea*, *F. aurata* and *I. Cissoidea* may be candidates of nurse trees for dipterocarp species. These species were able to adapt to young fallows and may create a suitable microclimate for both light-demanding and shade-tolerant dipterocarp species.

Soil nutrients

The results revealed that the concentrations of SOC and TN did not differ significantly between fallows and primary forest. This is probably because using the slash-and-burn technique to prepare the land for shifting cultivation had only a short-term effect of increasing soil nutrients. The slash-and-burn method used in shifting cultivation was observed to directly increase amounts of SOC and TN by 10.8 and 10.4%, respectively, while afterwards SOC and TN reverted to initial levels due to soil erosion and leaching (Tulaphitak et al. 1985, Tanaka et al. 2001). The results suggested that the concentrations of SOC and TN did not differ significantly between the fallow and primary forest plots, likely because the increase in soil nutrients resulting from the slash-and-burn land preparation was only transient in the nutrient-poor ultisols characteristic of soils in this region. The higher concentration of P_2O_5 in A1 as compared to that in the other fallow and primary forest plots was likely a consequence of deposition of P_2O_5 from vegetation burned during land preparation.

Implications for accelerating recovery of degraded forests

Enrichment planting in the fallows using late succession species such as *Shorea* sp. may be useful to accelerate recovery of species abundance and diversity. Successful natural regeneration of dipterocarps in abandoned areas depends on surrounding conditions, such as the abundance of mother trees in surrounding secondary forests. The main constraints to the natural regeneration of dipterocarp species are irregular flowering (Appanah 1993, Numata et al. 2003) and their recalcitrant seeds (Otsamo et al. 1996). The enrichment planting using dipterocarps with native pioneer species as nurse trees may help accelerate forest recovery by increasing species abundance while avoiding the potential negative effects of using exotic species in forest regeneration (Kartawinata 1994).

Soil nutrient composition was no different in young fallow plots (five years after abandonment) and the primary forest plot, while the species diversity and number of individual large trees increased with fallow age. This implies that the development of vegetation in the early successional stages can increase the total biomass in young fallow areas, which contributes to nutrient availability through litter decomposition (Tanaka et al. 2007).

CONCLUSIONS

The study implied that young fallow areas would be suitable sites for enrichment with native species in terms of facilitating the recovery of soil properties and vegetation. It was observed that the density of large trees increased with time after abandonment, and that species composition of large trees differed greatly between A10 and primary forest plots, where A5 and A10 was dominated by the pioneer species *T. tomentosa* and *I. cissoidea*, respectively. Changes in vegetation structure did not affect the status of soil nutrients in the young fallow plots. Furthermore, the young fallow plots may have created suitable forest micro-environments (e.g. shading) that favored their early colonisation by the typically late-succession forest species, *S. hopeifolia*, *S. seminis* and *S. leprosula*.

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REFERENCES

APG III (Angiosperm Phylogeny Group). 2009. An update of the Angiosperm Phylogeny Group classification of the orders and families of flowering plants: APG III. *Botanical Journal of the Linneah Society* 161: 105–121.

Appanah S. 1993. Mass flowering of dipterocarp forests in the aseasonal tropics. *Journal of Biosciences* 18: 457–474.

Appanah S & Weinland G. 1993. *Planting Quality Timber Trees in Peninsular Malaysia: A Review.* Malayan Forest Record No. 38. Forest Research Institute Malaysia and German Agency for Technical Cooperation GTZ, Kuala Lumpur.

Aththorick TA, Setiadi D, Purwanto Y & Guhardja E. 2012. Vegetation stands structure and aboveground biomass after the shifting cultivation practices of Karo People in Leuser Ecosystem, North Sumatra. *Biodiversitas* 13: 92–97.

Biswas S, Swanson ME, Shoaib JUM & Haque SMSS. 2010. Soil chemical properties under modern and traditional farming systems at Khagrachari, Chittagong Hill Tracts, Bangladesh. *Journal of Forestry Research* 21: 451–456.

Breugel MV, Bongers F & Martí´Nez-Ramos M. 2007. Species dynamics during early secondary forest succession: recruitment, mortality and species turnover. *Biotropica* 35: 610–619.

Chesworth W. 2008. *Encyclopedia of Soil Science*. Springer, Dordrecht.

Christanty L. 1986. Shifting cultivation and tropical soils: patterns, problems and possible improvements. Pp 226–240 in Marteen GG (ed) *Traditional Agriculture in Southeast Asia: A Human Ecology Perspective*. West View Press, Boulder.

Chua SC, Ramage BS, Ngo KM, Potts MD & Lum SKY. 2013. Slow recovery of a secondary tropical forest in Southeast Asia. *Forest Ecology and Management* 308: 153–160.

Cid-Liccardi CD, Kramer T, Ashton MS & Griscom B. 2012. Managing carbon sequestration in tropical forests. Pp 183–204 in Ashton MS et al. (eds) *Managing Forest Carbon in a Changing Climate*. Springer Dordrecht Heidelberg, London.

Davies SJ, Nur Supardi MN, Lafrankie JV & Ashton PS. 2003. The trees of Pasoh Forest: stand structure and floristic composition of the 50-ha forest research plot. Pp 35–50 in Okuda T et al. (eds) *Pasoh: Ecology of a Lowland Rain Forest in Southeast Asia*. Springer, Tokyo.

Delang CO. 2007. Ecological succession of usable plants in an eleven-year fallow cycle in Northern Lao P.D.R. *Ethnobotany Research and Applications* 5: 331–350.

FAO (Food and Agriculture Organization). 2006. *Global Forest Resources Assessment 2005: Progress Towards Sustainable Forest Management*. FAO, Rome.

Galindo-Gonzales J, Guevara S & Sosa VJ. 2000. Bat- and bird-generated seed rain at isolated trees in pastures in a tropical rainforest. *Conservation Biology* 14: 1693–1703.

Giardina CP, Sanford JRL, Døckersmith IC & Jaramillo VJ. 2000. The effects of slash burning on ecosystem nutrients during the land preparation phase of shifting cultivation. *Plant and Soil* 220: 247–260.

Hadi S, Ziegler T, Waltert M & Hodges JK. 2009. Tree diversity and forest structure in northern Siberut, Mentawai islands, Indonesia. *Tropical Ecology* 50: 315–327.

Hashimoto T, Tange T, Masumori M, Yagi H & Kojima K. 2007. Early succession process of a fallow forest in East Kalimantan, Indonesia. *TROPICS* 16: 253–259.

Hattori D, Kenzo T, Yamauchi N, Irino Ko, Kendawang JJ, Ninomiya I & Sakurai K. 2013. Effects of environmental factors on growth and mortality of *Parashorea macrophylla* (Dipterocarpaceae) planted on slopes and valleys in a degraded tropical secondary forest in Sarawak, Malaysia. *Soil Science and Plant Nutrition* 59: 218–228.

Kartawinata K. 1994. The use of secondary forest species in rehabilitation of degraded forest lands. *Journal of Tropical Forest Science* 7: 76–86.

Kenzo T, Ichie T, Hattori D, Kendawang JJ, Sakurai K & Ninomiya I. 2010. Changes in above- and belowground biomass in early successional tropical secondary forests after shifting cultivation in Sarawak, Malaysia. *Forest Ecology and Management* 260: 875–882.

Kenzo T, Yoneda R, Matsumoto Y, Azani AM & Majid MN. 2011. Growth and photosynthetic response of four Malaysian indigenous tree species under different light conditions. *Journal of Tropical Forest Science* 23: 271–281.

Kobayashi S, Turnbull JW & Cossalter C. 2001. Rehabilitation of degraded tropical forest ecosystems project. Pp 1–16 in Kobayashi et al. (eds). *Rehabilitation of Degraded Tropical Forest Ecosystems: Workshop Proceedings*. Centre for International Forestry Research (CIFOR), Bogor.

Lamb D, Erskine PD & Parrotta JA. 2005. Restoration of degraded tropical forest landscapes. *SCIENCE* 310: 1628–1632.

Lawrence D. 2005. Biomass accumulation after 10–200 years of shifting cultivation in Bornean rainforest. *Ecology* 86: 26–33.

Lawrence D, Suma V & Mogea JP. 2005. Change in species composition with repeated shifting cultivation: limited role of soil nutrients. *Ecological Applications* 15: 1952–1967.

Lawrence D. 2004. Erosion of tree diversity during 200 years of shifting cultivation in Bornean rain forest. *Ecological Applications* 14: 1855–1869.

Magurran AE. 1988. *Ecological Diversity and its Measurement*. Princeton University Press, Princeton.

Numata S, Yasuda M, Okuda T, Kachi N & Nur Supardi MN. 2003. Temporal and spatial patterns of mass flowerings on the Malay Peninsula**.** *American Journal of Botany* 90: 1025–1031.

Osman KS, Jashimuddin M, Sirajul Haque SM & Miah S. 2013. Effect of shifting cultivation on soil physical and chemical properties in Bandarban hill district, Bangladesh. *Journal of Forestry Research* 24: 791–795.

Osunkoya OO, Othman FE & Kahar RS. 2005. Growth and competition between seedlings of an invasive plantation tree, *Acacia mangium,* and those of a native Borneo heath-forest species, *Nelastoma beccarianum*. *Ecological Research* 20: 205–214.

Otsamo R, Otsamo A & Adjers G. 1996. Reforestation experiences with dipterocarps species on grassland. Pp 464–477 in Schulte A & Schone D (eds) *Dipterocarp Forest Ecosystems*. World Scientific, Singapore.

Otsamo R. 1998. Effect of nurse tree species on early growth *of Anisoptera marginata* Korth. (Dipterocarpaceae) on an *Imperata cylindrica* (L.) Beauv. grassland site in South Kalimantan, Indonesia. *Forest Ecology and Management* 105: 303–311.

Otsamo R. 2000. Early development of three planted indigenous tree species and natural understorey vegetation in artificial gaps in an *Acacia mangium* stand on an *Imperata cylindrical* grassland site in South Kalimantan, Indonesia. *New Forests* 19: 51–68.

Peña-Claros M. 2003. Changes in forest structure and species composition during secondary forest succession in the Bolivian Amazon. *Biotropica* 35: 450–461.

Phillips PD, Yasman I, Brash TE & Van Gardingen PR. 2002. Grouping tree species foranalysis of forest data inKalimantan (Indonesian Borneo). *Forest Ecology and Management* 157: 205–216.

Raich JW & Khoon GW. 1990. Effect of canopy opening on tree seed germination in a Malaysian dipterocarpforest. *Journal of Tropical Ecology* 6: 203–217.

Riswan S & Abdulhadi R. 1992. Succession After disturbance of lowland mixed dipterocarp forest by shifting

agriculturein East Kalimantan, Indonesia. Pp 77–84 in Goldammer JG (ed) *Tropical Forests in Transition: Ecology of Natural and Anthropogenic Disturbance Processes*. Birkhäuser-Verlag, Basel.

Sulaeman, Suparto & Eviati. 2005. *Chemistry Analysis Guideline for Soil, Plant, Water and Fertilizer*. Indonesia Soil Research Institute, Indonesia.

Tanaka S, Ando T, Funakawa S et al. 2001. Effect of burning on soil organic matter content and N mineralization under shifting cultivation system of Karen people in Northern Thailand. *Soil Science and Plant Nutrition* 47: 547–558.

Tanaka S, Wasli ME, Kotegawa T et al. 2007. Soil properties of secondary forests under shifting cultivation by the Iban of Sarawak, Malaysia in relation to vegetation condition. *TROPICS* 16: 385–398.

Teegalapalli K & Datta A. 2016. Field to a forest: patterns of forest recovery following shifting cultivation in the Eastern Himalaya. *Forest Ecology and Management* 364: 173–182.

Tropicos. Missouri Botanical Garden, St. Louis. http://www.tropicos.org

Tulaphitak T, Pairintra C & Kyuma K. 1985. Changes in soil fertility and tilth under shifting cultivation II: changes in soil nutrient status. *Soil Science and Plant Nutrients* 31: 239–249.

Van Do T, Osawa A & Thang NT. 2010. Recovery process of a mountain forest after shifting cultivation in Northwestern Vietnam. *Forest Ecology and Management* 259: 1650–1659.

Van Do T, Osawaa, Thang NT et al. 2011. Population changes of early succession forest speciesafter shifting cultivation in Northwestern Vietnam. *New Forests* 41: 247–262.

Zipperlen SW & Press MC. 1996. Photosynthesis in relation to growth and seedling ecology of two dipterocarp rain forest tree species. *Journal of Ecology* 84: 863–876.

