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Effects of burning strength in shifting cultivation on the early stage of secondary succession in Sarawak, Malaysia

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ABSTRACT **The effects of burning strength in shifting cultivation on the early stage of secondary succession in tropical rain forest was investigated at four sites (Sabal, Balai Ringin, Niah, and Bakam) in Sarawak, Malaysia. The number and growth (diameter, height, and biomass) of germinated seedlings were measured in experimental shifting cultivation plots in which the burning strength varied between 0, 100, 200, and 300 t/ha at Sabal, Balai Ringin, and Niah and 0, 20, and 100 t/ha at Bakam. Species composition of germinated tree and herbaceous seedlings was surveyed, and a germination test of buried seed was conducted at Niah and Bakam. The number of germinated seedlings decreased with increasing burning strength, whereas seedling growth was promoted by burning. During the first year, growth was best in the intermediate burning strength plots, whereas during the second year, growth was best in the most strongly burned plots. Species composition differed between unburned and burned sites. Site-specific factors such as original stand biomass, soil properties, and invasion of exotic species also affected germination and growth. Buried seeds in the Ao layer were killed by burning, and nearly all seeds in the 0-5 cm layer were killed in the plots with the highest burning strength (> 100 t/ha). On the basis of our findings, we conclude that in shifting cultivation systems burning promotes vegetation recovery when the burning strength is properly managed.**

Key words: Sarawak, shifting cultivation, vegetation recovery, secondary succession, biomass, buried seeds

INTRODUCTION

Shifting cultivation is the traditional agricultural practice in Sarawak, Malaysia. Shifting cultivation is considered to be in harmony with the forest environment, provided that the fallow period is long enough (Ichikawa, 2004), and increases in waste lands or the degradation of tropical rain forest has never occurred in a traditional shifting cultivation system with a sufficiently long fallow duration (Kleinman et al. 1995). However, a recent surge in population density and involvement in global commercial activities have caused farmers in Malaysia to use shorter fallow periods and to increase the degraded land area (Brady, 1996).

In Sarawak, Malaysia, between 1963 and 1991 the area of forested land converted to cultivated land doubled (from 28,000 to 57,000 ha) and the total forested area decreased from 9,100,000 to 8,000,000 ha (Keong, 1998). According to Teng (1993), the rate of land conversion to shifting cultivation was 75,000–150,000 ha/year (0.6–1.2% of the total land area), and 2,700,000 ha (22% of the total land area) was either under use or had been used at least once for shifting cultivation. The present land-rotation system consists of continuous rice cropping for 2 years or more with a shorter fallow period of about 5 years, compared to the historical fallow period (Kendawang et al. 2004). The shorter fallow period accelerates land degradation, and the area of degraded land in Malaysia has increased with these changes in agricultural practice. Once degraded area is formed, recovery or rehabilitation of the area is very difficult owing to the violent runoff associated with heavy rains and the extremely dry and hot soil surface caused by strong sunshine. Consequently, degraded lands in need of rehabilitation are now widespread in Sarawak.

In order to rehabilitate the degraded land, it is important to understand the vegetation recovery process after burning. Numerous studies have investigated vegetation recovery after shifting cultivation or forest burning in tropical rain forests (East Kalimantan, Indonesia: Okimori and Matius, 1991; Hashimoto et al. 2000; Sabah, Malaysia: Nykvist, 1996; Ohtsuka, 1999, 2001; Solomon Islands: Nakano, 1992; Amazonia, Venezuela: Uhl, 1984, 1987; Costa Rica: Ewel et al. 1981), tropical seasonal forests (northern Thailand: Nakano, 1978; eastern India: Prasad et al. 2001; northeastern India: Toky and Ramakrishnan, 1983), and temperate forest (Kamada et al. 1987). In Sarawak, Ewel et al. (1983) performed an intensive study of biomass and woody-plant floristic composition of forests regenerated after logging followed by shifting cultivation, and Chai (1997) estimated the aboveground biomass of a secondary forest established after shifting cultivation.

None of these studies, however, analyzed the effect of burning strength on the vegetation recovery process after shifting cultivation, although the burning strength must affect essential functions in the process such as germination and growth. In shifting cultivation, the burning strength depends on the amount of slashed plant material (biomass) of the existing forest. Burning strength can be controlled, however, and may represent a key factor in the proper management of shifting cultivation systems. The purpose of this study was to clarify the effects of burning strength on the early stage of secondary succession in a shifting cultivation system.

This study was carried out as a part of a larger investigation of shifting cultivation conducted in Sarawak, Malaysia (Kendawang et al. 2004, 2005; Tanaka et al. 2004, 2005). To analyze the effect of burning strength on vegetation recovery, we conducted experimental shifting cultivation in which particular amounts of vegetation biomass were burned as fuel. Four study sites were selected to compare the site-specific effects on vegetation recovery. We focused on the early stage of secondary succession (1 or 2 years after burning) because the early stage is the most important phase not only in vegetation recovery but also in rice cropping, which is carried out for 1 or 2 years after burning. Understanding the suitable burning strength for optimal vegetation recovery is necessary for the appropriate management of shifting cultivation systems in the tropics.

RESEARCH SITES

To compare site-specific effects on vegetation recovery, the experiments were carried out at four sites in Sarawak, Malaysia (Fig. 1): Sabal Forest Reserve (01°03'N, 110°55'E), Balai Ringin Protected Forest (00°55'N, 110°43'E), Niah Forest Reserve (03°39'N, 113°42'E), and Bakam Experimental Reserve (04°16'N, 113°60'E). Mean annual temperature in these areas was about 25 °C from 1991 to

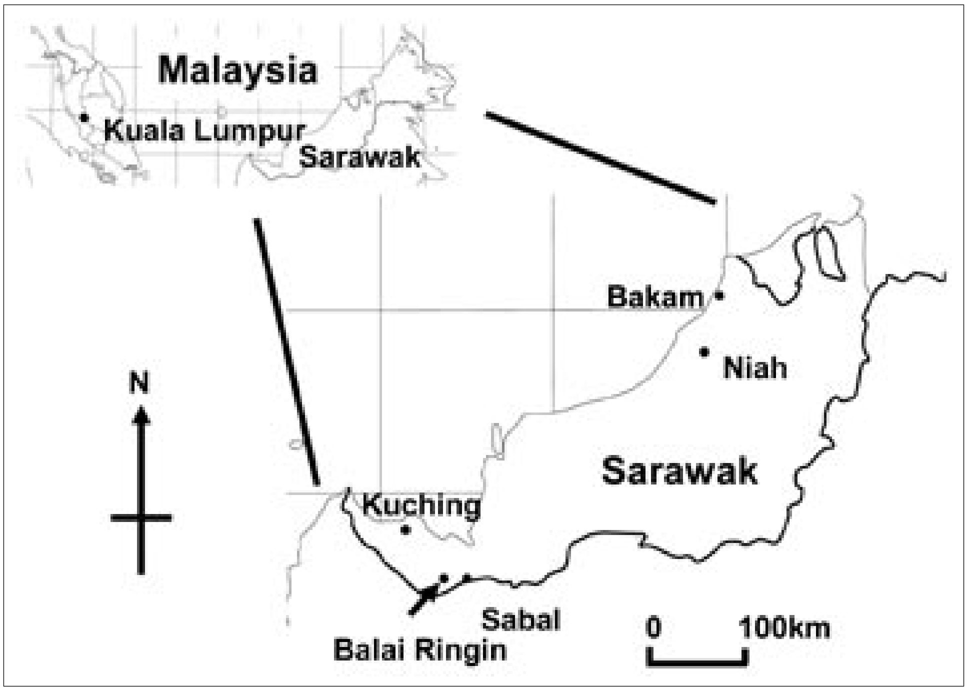

Fig. 1. Map of the study sites.

2001, with negligible monthly variations (Meteorological Department, 2001). From 1991 to 2001, the average annual precipitation was 4010 mm at the Sungai Pinang rainfall station near Sabal Forest Reserve, 3500 mm at the Balai Ringin rainfall station, 2880 mm at the Sungai Lebai rainfall station near Niah Forest Reserve, and 2900 mm at Bukit Lambir Micro rainfall station near Bakam Experimental Reserve (Department of Irrigation and Drainage, 2001). Based on these data, all the sites belong to a humid tropical climate.

One-hectare experimental plots were established within these forests (Table 1). The original vegetation at Balai Ringin and Niah was mixed dipterocarp forest, and at Sabal and Bakam mixed dipterocarp forest with kerangas forest. The present vegetation at Sabal, Balai Ringin, and Niah is secondary forest after previous selective cutting, whereas that at Bakam is in the early stage of secondary secession after shifting cultivation. Estimates based on biomass surveys for the aboveground biomasses, including undergrowth, were 201.2, 241.1, 144.7, and 57.2 t/ha at Sabal, Balai Ringin, Niah, and Bakam, respectively (Ninomiya et al. unpublished data).

The slope at the Sabal site was gentler (mean 7.8°) than at Balai Ringin (25.5°) and Bakam (25.4°), while at Niah the slope was intermediate (14.4°). The soil was sandy and nutrient poor at Sabal, clayey at Balai Ringin and Niah, and nutrient poor at Bakam. The major soil types were Oxyaquic or Spodic Quartzipsamments at Sabal, Oxic Dystrudepts at Balai Ringin, Typic Kandihumults or Typic Kanhaplohumults at Niah, and Typic Dystrudepts or Typic Udorthents at Bakam, according to the USDA classification system (Soil Survey Staff, 1999).

RESEARCH METHODS

Burning experiments

The burning experiments were performed in August 2001 at Sabal, September 2001 at Balai Ringin, July 2002 at Niah, and August 2002 at Bakam. All the plants in each 1-ha experimental site were slashed and kept *in situ* for more than 1 month to dry. Tree trunks and branches with a diameter larger than about 20 cm were cut into fragments of about 1 m. Twelve 10-m × 10-m experimental plots at Sabal, Balai Ringin, and Niah and nine 10-m × 10-m plots at Bakam were carefully chosen to exclude irregular microtopographic features such as rock outcrops and large tree stumps.

The field-dried plant materials (0, 100, 200, and 300 t/ha at Sabal, Balai Ringin, and Niah; 0, 20, and 100 t/ha at Bakam) were heaped up on each experimental plot to serve as fuel for triplicate burning experiments. In 0-t/ha plots, all of the aboveground plant materials were removed. Amount of the argest burning materials in each plot may correspond to the aboveground biomass of each experimental site (Table 1) when the difference between field and oven drying is considered. In traditional shifting cultivation, when mature secondary or primary forests are burned, large trees usually remained unburned or are only charred (Freeman, 1955). Therefore, the burning strengths adopted in this study can be considered to reflect the burning conditions of traditional shifting cultivation to some extent. These plots were randomly arranged in the sites at a distance of at least 10 m from each other to minimize the influence from the adjoining plots. Fire-breaks with a width of 1 to 2 m were prepared around the plots by removing all dried plant materials.

Table 1. Characteristics of the study sites.

Site	Vegetation	Aboveground biomass[a]	Altitude	Slope	Soil type	Soil texture[b]
		[t/ha]	[m a.s.l]	[Ave. gradient]	USDA Classification system	
Sabal	Mixed Dipterocarp & Kerangas	201.2	60	7.8	Oxyaquic Quartzipsamments Spodic Quartzipsamments	SL
Balai Ringin	Mixed Dipterocarp	241.7	90–120	25.5	Oxic Dystrudepts	HC
Niah	Mixed Dipteroparp	144.7	40	14.4	Typic Kandihumults Typic Kanhaplohumults	LiC
Bakam	Mixed Dipterocarp & Kerangas	57.2	70–100	25.4	Typic Dystrudepts Typic Udorthents	SL-SCL

[a] The aboveground biomass inculdes that of undergrowth.
[b] Textural class proposed by International Society of Soil Science.

Except for 0-t/ha plots (control), the plots were burned in the afternoon. The fuel was ignited from the lower end of the slope. Although the fires were nearly extinguished within about 1 to 2 hours, some fuel continued to smolder into the following day.

After the burning was completed, large, unburned, or partially charred fuel was weighed and removed. The combustion efficiency, calculated as the ratio of the amount of burned fuel to heaped fuel, ranged from 72% to 88% at Sabal, 86% to 99% at Balai Ringin, 84% to 94% at Niah, and 80% to 90% at Bakam. The efficiency tended to increase with larger amounts of fuel (Kendawang et al. 2004, 2005).

Vegetation surveys

At each site, the burning experimental plot (10 m × 10 m) was divided into four subplots (5 m × 5 m) and one of them was used for the vegetation survey (the other subplots were used for soil and cropping surveys; see Kendawang et al. 2004, 2005; Tanaka et al. 2004, 2005). A vegetation survey plot (3 m × 3 m) was established in the subplot and divided again into nine quadrats (1 m × 1 m). A tree survey was conducted in all nine quadrats and a herbaceous survey was conducted in three randomly selected quadrats.

The date, number of germinated seedlings, genus/species (except for Sabal), height, and diameter at the base of the seedlings were recorded in the tree surveys, and the date and number of germinated seedlings were noted in the herbaceous surveys. The vegetation surveys were begun 1–2 weeks after burning and continued daily at Sabal and Balai Ringin and two times each week at Niah and Bakam until 3 months after burning. Triplicate surveys were conducted in each burning strength plot.

Harvesting survey

The harvesting surveys were carried out 1 and 2 years after burning at each site. Two quadrats were randomly selected from the vegetation survey plot. The height and base diameter of the plants were recorded before harvesting. Aboveground parts of the vegetation were harvested and fresh weights were measured on site. The dry weight was estimated based on the ratio of dry/fresh weight of samples obtained from each site.

Germination experiment of buried seeds

The germination of buried seeds was tested in soil samples gathered from the Niah and Bakam sites in August, 2002. The 470-cc soil samples were collected from the Ao layer and from 0–5 cm depth after burning, with two to six samples collected for each burning strength plot. Each sample was spread over river sand in a round tray (25-cm diameter, 3 cm depth). Control trays (sand only) were also prepared to discriminate the effects of the seed contained in the sand. The trays were covered with cloth (c.a. 30% of light was cut) to protect seed from wind and strong sunshine. The photon flux density and air temperature during the experiment were less than 500 μmol photon/m^2/s and 40 °C, respectively. The trays were checked daily and watered if the surfaces were dry. The number of germinated seedlings, including herbaceous and tree species,

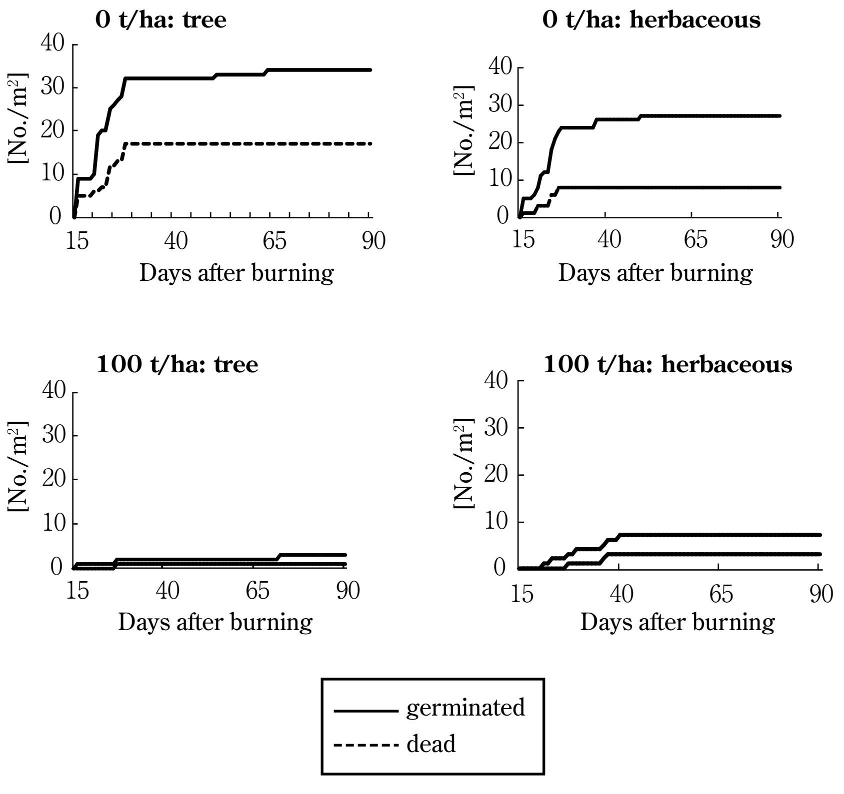

Fig. 2. Changes in the number of germinated and dead seedlings with days after burning in the 0- and 100-t/ha plots at the Sabal site.

was recorded weekly.

RESULTS

Vegetation recovery in terms of germination

Figure 2 shows result of the vegetation survey in the 0- and 100-t/ha plots at Sabal. The germination of both herbaceous and tree species started 15 to 20 days after burning. The some germinated seedlings died soon after germination, however, and germination stopped at about 30 days for herbaceous plants and continued longer (about 60 days) for tree species. These trends were observed for all plots within all sites.

The germination patterns of both herbaceous and tree seedlings with regard to burning strength were nearly the same, so in our analyses we combine the two life forms. The number of germinated and dead seedlings at 3 months after burning is shown in Figure 3. The number of germinated seedlings was the largest at Balai Ringin in almost all burning strength plots. The average mortalities were 42.5%, 22.7%, 36.1%, and 38.3% for Sabal, Balai Ringin, Niah, and Bakam, respectively, with the lowest rate at Balai Ringin. Thus, Balai Ringin was the most recoverable site in terms of the germination and mortality rates.

At Sabal and Balai Ringin, the number of germinated seedlings was the highest in unburned plots and low in burned plots. At Sabal, however, the number of germinated seedlings was not significantly different among burned plots, while the number decreased with burning strength at Balai Ringin. At Niah the number of germinated seedlings tended to be highest in the 100-t/ha plots and was very small in the plots of greater burning strength. At Bakam the number of germinated seedlings was the highest in unburned plots and decreased with burning strength, but the difference was not as significant as seen at Balai Ringin. Across all sites, higher burning strength tended to depress the number of germinated seedlings.

Table 2 lists the tree species that germinated within 3 month after burning. We identified 91–96% of seedlings to the genus level at Balai Ringin, 82–100% at Niah, and 80–95% at Bakam. Nearly all of the germinated seedlings were pioneer species. More than 50% of germinated seedlings in unburned plots at Balai Ringin were *Glochidion* spp. (Euphorbiaceae), and this genus also germinated abundantly in burned plots. *Trema* spp. (Ulmaceae) and *Macaranga* spp. (Euphorbiaceae) germinated only in burned plots, whereas *Ficus* spp. (Moraceae) and *Artocarpus elasticus* (Moraceae) did not germinate in burned plots at Balai Ringin. At Niah the most abundantly germinated genus was *Trema*. The genus accounted for 100% and 73% of germinated species in the 200- and 300-t/ha plots, respectively, whereas *Macaranga* spp. were the most abundant in 100-t/ha plots. *Alstonia angustifolia* (Apocynaceae) and *Ficus* spp. were not found in burned plots at Niah. At Bakam *Trema* was also the most abundant germinated genus. Compared to unburned plots, the proportion of *Macaranga* spp. was lower in burned plots and that of *A. angustifolia* was higher.

Vegetation recovery in terms of growth

Figure 4 shows the mean diameter of germinated trees

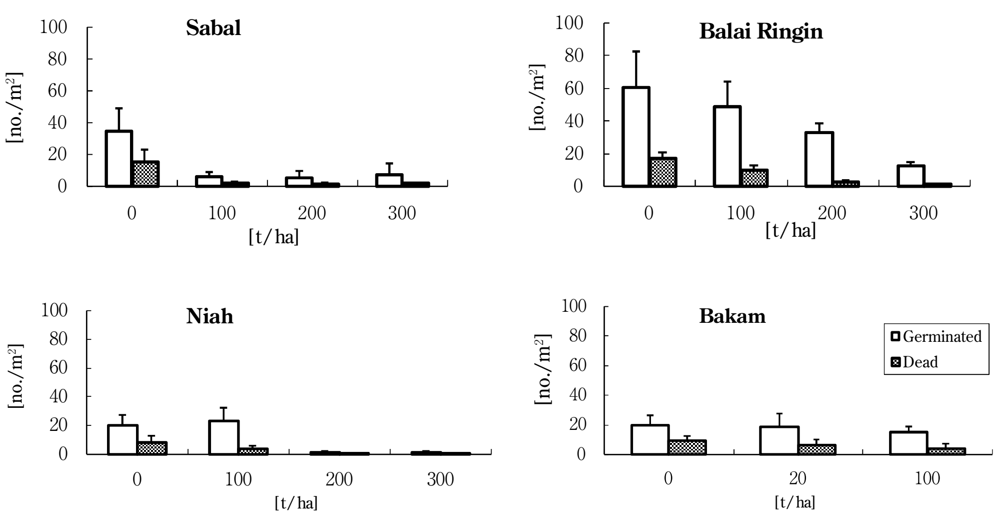

Fig. 3. The number of germinated and dead seedlings with regard to burning strength at 3 months after burning (mean ± SE).

Table 2. Germinated species (%) after burning *in situ*.

Balai Ringin

	0 [t/ha]	100 [t/ha]	200 [t/ha]	300 [t/ha]
Glochidion spp. (Euphorbiaceae)	58.0	30.6	36.6	50.0
Trema spp. (Ulmaceae)		32.9	41.0	29.9
Musa spp. (Musaceae)	13.9	25.4	10.6	9.0
Octomeles sumatrana (Datiscaceae)	18.9			
Macaranga spp. (Euphorbiaceae)		3.5	2.6	7.5
Ficus spp. (Moraceae)	2.1			
Artocarpus elasticus (Moraceae)	1.0			
Others	6.0	7.8	9.2	3.7
Total	100.0	100.0	100.0	100.0

Niah

	0 [t/ha]	100 [t/ha]	200 [t/ha]	300 [t/ha]
Macaranga spp. (Euphorbiaceae)	19.0	56.7		20.0
Trema spp. (Ulmaceae)	34.3	29.9	100.0	73.3
Alstonia angustifolia (Apocynaceae)	19.7	0.8		
Ficus spp. (Moraceae)	3.6	0.8		
Others	18.3	11.8		6.7
Toal	100.0	100.0	100.0	100.0

Bakam

	0 [t/ha]	20 [t/ha]	100 [t/ha]
Macaranga spp. (Euphorbiaceae)	12.7	3.9	4.0
Trema spp. (Ulmaceae)	75.9	70.6	44.0
Alstonia angustifolia (Apocynaceae)	5.7	9.8	32.0
Anthocephalus cadamba (Rubiaceae)	0.6	2.0	
Others	5.1	13.7	20.0
Total	100.0	100.0	100.0

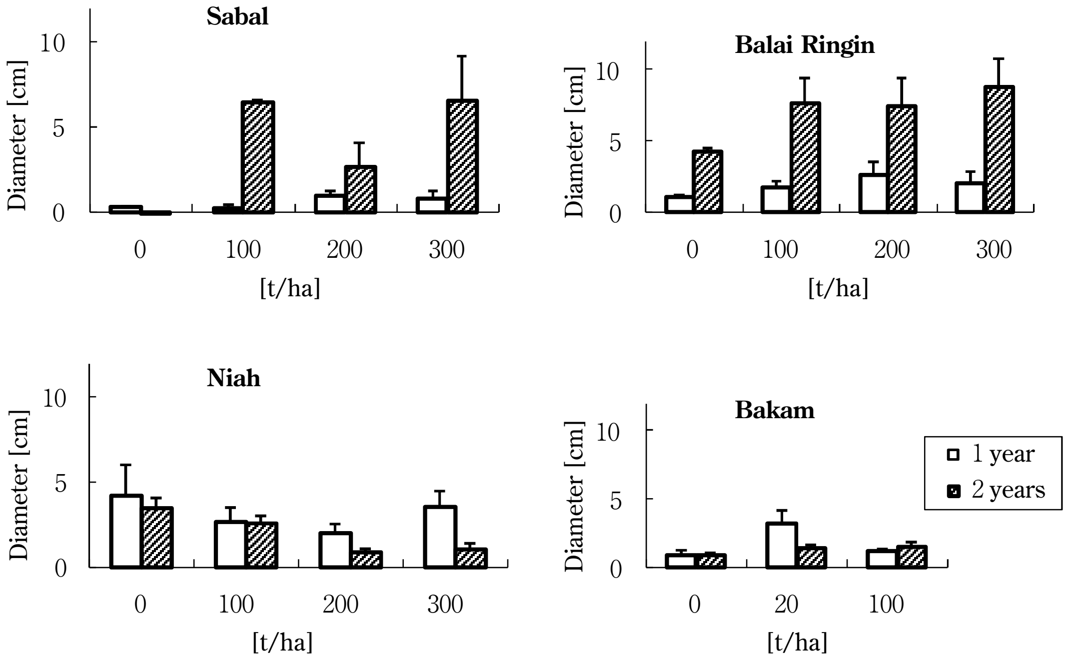

Fig. 4. Mean (± SE) stem diameter at the base at 1 and 2 years after burning.

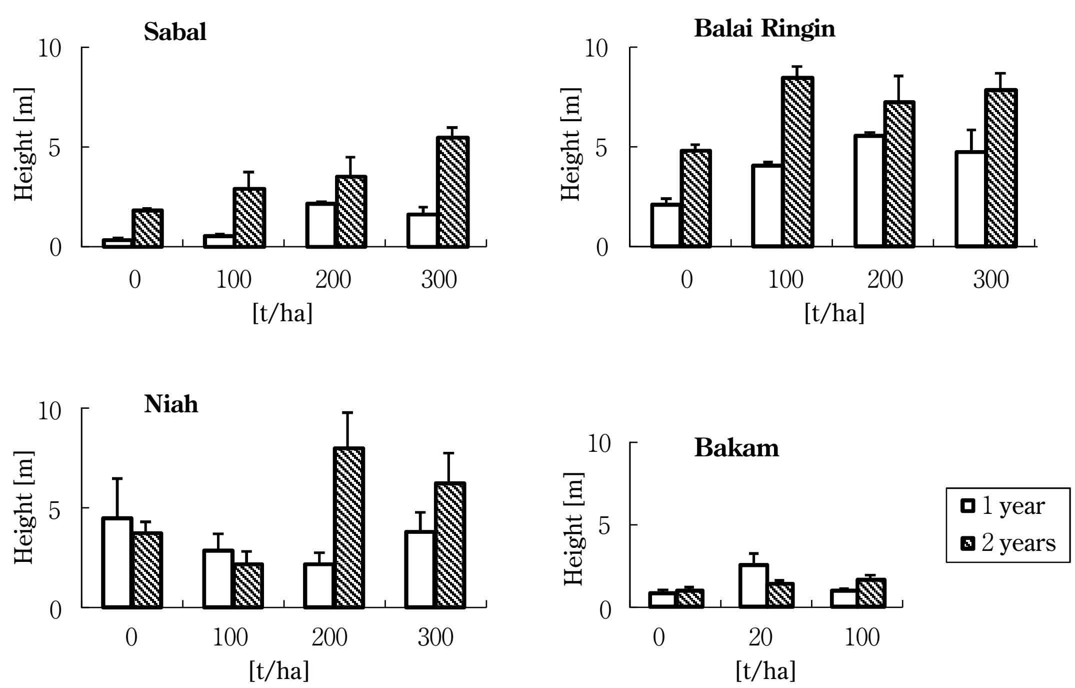

Fig. 5. Mean (± SE) tree height at 1 and 2 years after burning.

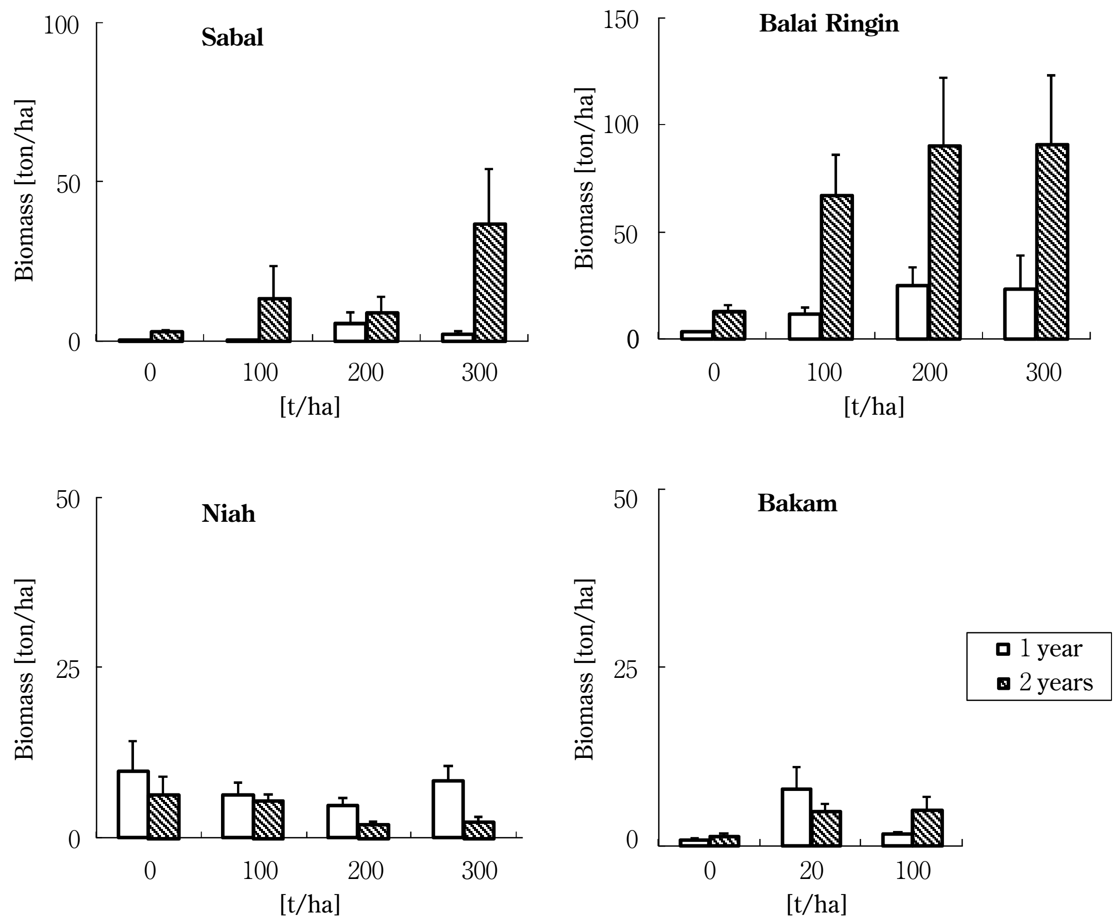

Fig. 6. Mean (± SE) aboveground biomass at 1 and 2 years after burning.

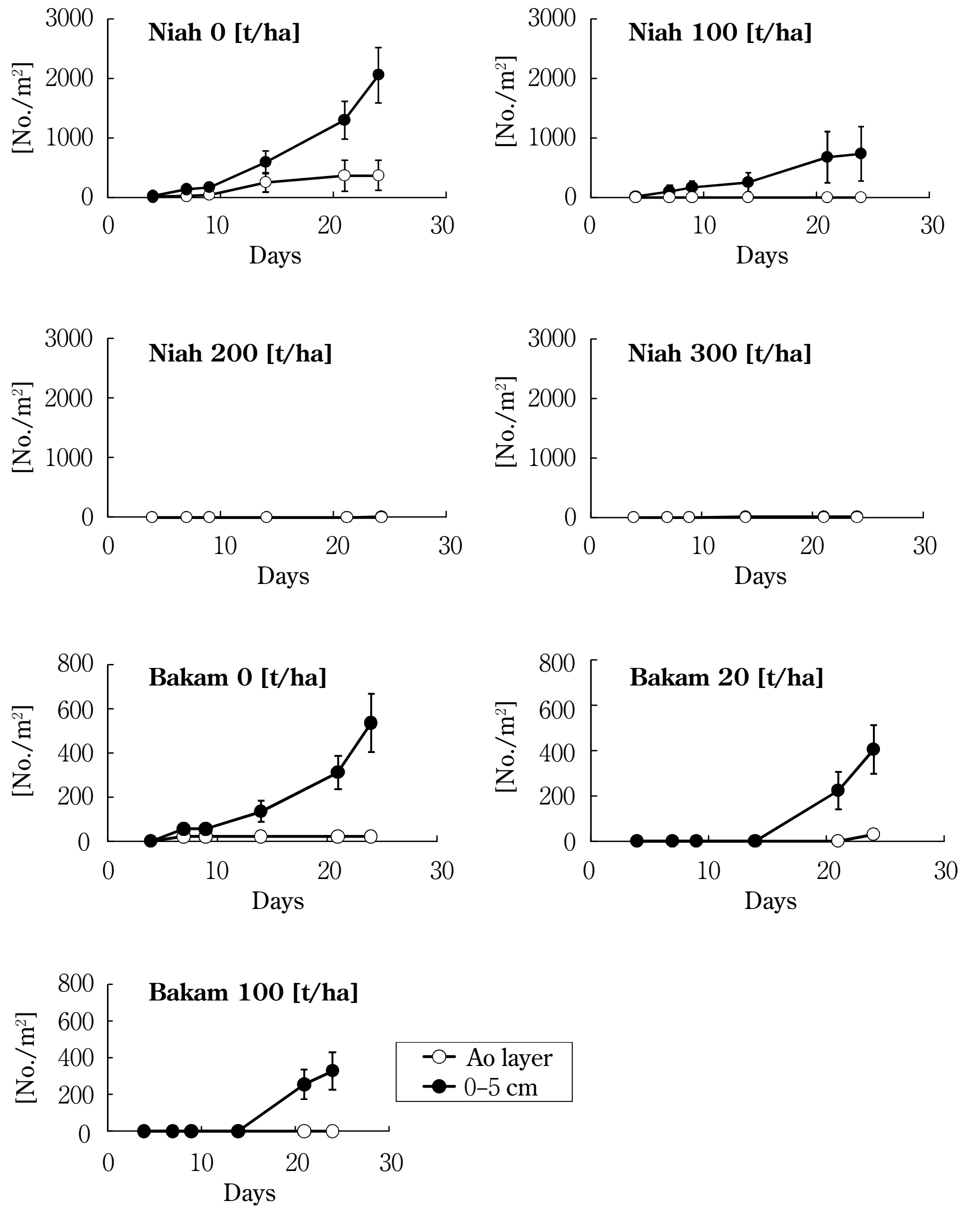

Fig. 7. Germination from buried seeds gathered from the Ao and 0- to 5-cm layers with days after sowing at Niah and Bakam. Data are mean ± SE.

at 1 and 2 years after burning. Diameter growth was best at Balai Ringin, where the number of germinated tree seedlings was also the highest. Overall, the diameter growth in burned areas was larger than or almost equivalent to that in unburned areas. For the first year, the diameter was largest in the intermediate burning strength plots (except for Niah), 200 t/ha at Sabal and Balai Ringin and 20 t/ha at Bakam. This tendency was no longer apparent in the second year after burning, when it was confirmed that the diameter growth was better in burned areas (except for Niah).

The same results were obtained for height growth (Fig. 5); that is, in the first year after burning the height growth was better in burned areas than in unburned areas, and it was highest in intermediate burning strength plots (except for Niah). In the second year, greater height growth was observed in burned areas and the difference between burned and unburned areas became more prominent.

In terms of biomass, vegetation recovery was also best at Balai Ringin (Fig. 6). In the first year, the biomass at the other three sites was less than 10 t/ha, whereas that at Balai Ringin was more than 20 t/ha in the more strongly burned plots. The plots of intermediate burning strength (200 t/ha for Sabal and Balai Ringin, 20 t/ha for Bakam) showed the best recovery in terms of biomass. The biomass in burned areas was greater than in unburned areas, except for Niah, in which no significant difference was detected.

In the second year after burning, the difference of biomass between burned and unburned became clearer at Sabal and Balai Ringin (Fig. 6). At Sabal the most strongly burned plot (300 t/ha) showed the most recovered biomass, 36.7 t/ha, which accounted for 18.2% of the original biomass of 201.2 t/ha. In contrast, the biomass in unburned plots was 2.8 t/ha, or 1.4% of the original. At Balai Ringin the best recovery was observed in the 200- and 300-t/ha plots, with 37.4% (90.2 t/ha) and 37.7% (90.8 t/ha) of the original stand biomass of 241.1 t/ha. The biomass in unburned plots at Balai Ringin was 5.2 t/ha, or 12.6% of the original. At Niah the biomass in more strongly burned plots became smaller during the second year, and unburned plots contained the largest biomass, 6.5 t/ha, or 4.5% of the original. At Bakam the largest biomass during the second year was found in the 100-t/ha plot, 5.0 t/ha, or 8.7% of the original biomass.

Germination from buried seeds

Figure 7 illustrates the results of germination tests of buried seeds at Niah and Bakam. The germination in soils from Niah started 1 week after sowing and continued for more than 3 weeks. The total density of germinated seedlings at 3 weeks in soil collected from the Ao layer in the unburned plot was more than 300 per m^2, whereas there was almost no germination from the Ao layer in stronger burned plots (200-t/ha and 300-t/ha). For the 0- to 5-cm layer at Niah, germination occurred only in soils collected from the 0-t/ha plots.

In soils collected from the 0- to 5-cm layer at Bakam, the germination started 1 week after sowing in unburned plots and after 2 weeks in the burned plots. Germination in soil from the Ao layer was negligible in both unburned and burned plots. The number of germinated seeds from the 0- to 5-cm layer in burned plots decreased with burning strength, although the trend was not significant. The density of germinated seedlings in soils gathered from all plots was less than 600 per m^2 at 3 weeks after sowing.

DISCUSSION

Effects of site conditions on the vegetation recovery

Vegetation recovery after burning depends on two essential functions, germination and growth. Although germination is used to refer to both seed germination and sprout germination, we discuss only seed germination because no sprout germination was observed in our experiment. One factor that determines the number of germinated seedlings is seed supply. The seed supply for germination after shifting cultivation comes from two sources, the seed bank (buried seeds) and seed rain (seed falling from the surrounding plants; Whitmore, 1984, 1998).

Our findings suggest that germination from buried seed is affected by burning strength and site factors. According to the germination tests of buried seeds at Niah (Fig. 7), there was almost no germination from Ao layer in the burned areas. This means that the buried seeds (dormant seeds in this case) in the surface layer were killed by heat. In the 0- to 5-cm layer of soil, the buried seeds were killed in 200- and 300-t/ha burning strength plots, and seeds germinated at a higher density in the unburned plots compared to the 100-t/ha plots. These results may reflect a decrease of germination *in situ* in more strongly burned areas (Fig. 3).

Ewel et al. (1981) performed germination tests on buried seeds after slashing and burning in a tropical rain forest in Costa Rica; although the buried seeds (0 to 4 cm depth) were not killed by burning, the number of germinated seedlings was smaller than that in the control plots. Kamada et al. (1987) also reported the survival of buried seeds (0 to 5 cm depth) after shifting cultivation in temperate deciduous forest, and in this case the germination from dormant seed of tree species was promoted by the warming. These results differ from those of our study, in which nearly all of the seeds in the 0- to 5-cm layer were killed at burning strengths over 100 t/ha. These differences may be due to different burning temperatures. Soil temperatures were seldom > 50 °C at 2 cm depth in the experiment in Costa Rica (Ewel et al. 1981), in which larger firewood was removed from the sites. The temperature in the experiment in temperate deciduous forest (Kamada et al. 1987) was less than 55 °C at 2.5 cm depth, and the larger trees were also removed before burning. In contrast, the temperature in our experiment was raised to >100 °C at less than 3 cm depth in the 200- and 300-t/ha plots except at a few points (Kendawang et al. 2004, 2005). Tanaka et al. (2001) performed burning experiments in a drier forest of northern Thailand without removing larger trees; extremely high temperatures in excess of 300 °C were recorded at 2.5 cm depth when 100 t/ha was burned. The results from our study suggest that the buried seeds would have been killed at those temperatures.

In the germination test for buried seeds, the mean density of germination from the 0- to 5-cm layer in unburned plots at Niah and Bakam were 2054 and 533 per m^2, respectively. The density of germinated seedlings at Niah was double of that reported in a primary tropical rain forest in Singapore (about 1000 per m^2; Metcalfe and Turner, 1998), and was nearly equivalent to that in a late-successional mixed dipterocarp forest in Sri Lanka (2273 per m^2; Singhakumara et al. 2000). The differences recorded between Niah and Bakam may depend on the size of the respective seed banks. The formation of a seed bank is affected by factors such as successional stage and forest size. Forests at an earlier successional stage contain more buried seeds, because pioneer species are abundant at this stage and they produce more seeds than late-successional species. Likewise, the more numerous plants in larger forests supply more seeds. Although the successional stages of the Niah and Bakam forests were different, the results of our germination tests suggest that the difference in the size of their seeds banks more strongly depended on forest size (i.e., biomass; Table 1). This can also explain the difference of the number of germinations *in situ* among the sites (Fig. 3).

The other source of seeds available for germination is seed rain, which falls from neighboring sites. The supply from seed rain is related not to burning strength but to site conditions, and among these conditions the size of the surrounding forest may be the most important factor, as in the case of seed bank. When species composition and the successional stage of the surrounding forest are the same, larger forests supply more seed rain. Thus, Balai Ringin likely received more seed rain than Niah, resulting in the larger number of germinated seedlings (Fig. 3), because the original biomass at Balai Ringin was larger than that at Niah, although the species composition was similar in both sites (Table 1). The relatively small number of germinated seedlings at Sabal compared to Balai Ringin (Fig. 3) in spite of small differences in biomass, were likely due to differences in vegetation and successional stage.

Another important factor in vegetation recovery is the growth of germinated seedlings, which may be related to site conditions such as soil properties and topography. In previous studies (Kendawang et al. 2004,

Table 3. Vegetation recovery expressed as aboveground biomass in the early stage of secondary succession after burning in the humid tropics.

Location	Original vegetation	Trigger of succession	Succession age [yr]	Biomass [t/ha]	Reference
Sabah, Malaysia	Lowland dipterocarp forest	Forest fire	3	4.7	Nykvist, 1996
			5	26.6	
Sarawak, Mlaysia	Mixed dipterocarp forest	Abandoned	4.5	21.2	Ewel et al., 1983
			4.5	53.6	
Sabah, Malaysia	Lowland and lower montane rain	Abandoned	3	15.0	Ohtsuka, 1999
Sabah, Malaysia		Abandoned	0.3	2.4	Ohtsuka, 2001
			1	6.5	
			3	15.7	
East Kalimantan, Indonesia	Dipterocarp forest	Abandoned	1	7.5	Hashimoto et al., 2000
			1	9.9	
			3	12.1	
			3–4	18.9	
			3–4	23.6	
			4–5	21.7	
			4–5	21.7	
Amazonia, Venezuela	Lowland rain forest	Abandoned	1	7.1	Uhl, 1987
			2	12.8	
			3	20.0	
			4	28.6	
			5	33.9	
					Present study*
Sarawak, Malaysia			1	2.1	
Sabal	Mixed Dipterocarp & Kerangas forest	Burned (300 t/ha)	2	36.7	
			1	22.7	
Balai Ringin	Mixed Dipterocarp forest	Burned (300 t/ha)	2	90.8	
			1	8.4	
Niah	Mixed Dipterocarp forest	Burned (300 t/ha)	2	2.5	
			1	1.5	
Bakam	Mixed Dipterocarp & Kerangas forest	Burned (300 t/ha)	2	5.0	

* Only the results for the highest burning strength are shown.

2005; Tanaka et al. 2004, 2005), we conducted detailed soil surveys at these sites and observed poor soil conditions at Sabal and Bakam, where sandy soil and kerangas vegetation were found (Kendawang et al. 2004, 2005). Although in this study the original biomasses at Sabal and Balai Ringin were nearly the same, germinated seedlings grew faster at Balai Ringin than at Sabal, in terms of diameter (Fig. 4), height (Fig. 5), and biomass (Fig. 6), likely because of the better soil conditions at Balai Ringin (Table 1). The results of intensive soil surveys at the sites also revealed better soil conditions at Balai Ringin in terms of both their physical and chemical properties (Kendawang et al. 2004). As for topography, the slope at Balai Ringin is steeper than that at Sabal, although we did not gather sufficient data to explain the effect of slope on the vegetation recovery.

Vegetation recovery was the best at Balai Ringin in terms of higher germination and growth rates and the low mortality rate of germinated seedlings (Fig. 3). The original biomass at Balai Ringin was the largest among the four studied sites, which may reflect the better soil conditions or the longer recovery period from the damage of previous cutting. The larger original biomass and better soil conditions, in turn, provided better conditions for site recovery from the seed bank and seed rain.

Vegetation recovery at Niah was poor in terms of seedling growth, although the soil properties and original biomass were not so inferior relative to the other site. At this site, however, the exotic climber *Passiflora poetida* (Passifloraceae) from South America is abundant, and thick growth of the climber depressed the growth of other germinated seedlings. Thus, in addition to soil and biomass conditions, interspecific competition and the presence of exotics are also important factors in vegetation recovery.

The aboveground biomass at 1 and 2 years after burning at Balai Ringin was significantly larger than that at the other sites (Fig. 6). Nykvist (1996) reported 4.7 t/ha of biomass at 3 years and 26.6 t/ha at 5 years after a severe forest fire in Borneo. These values are far smaller than the 90.8 t/ha in the 300-t/ha plot at Balai Ringin we recorded at 2 years after burning. Although the burning strength of the Borneo forest fire is unknown, it appears that the vegetation recovery at Balai Ringin occurred very quickly. Based on the results of various studies, Table 3 presents the vegetation recovery during the early stage of secondary succession after shifting cultivation in the humid tropics. These data also highlight the relatively good recovery at Balai Ringin.

Effects of burning on the vegetation recovery

In general, the number of germinated seedlings *in situ* decreased as burning strength increased (Fig. 3). Although these findings seem to indicate that more buried seeds were killed at greater burning strength, a large part of the germination depended on the seed rain, as judged from the germination survey of buried seeds (Fig. 7). A reduction in the number of germinated seedlings retards the initial phase of vegetation recovery. From the viewpoint of agricultural practice, however, burning is effective in controlling the number of weeds in the crop cultivated after burning. Kamada et al. (1987) also noted the effectiveness of burning on weed control in shifting cultivation in a temperate deciduous forest in Japan.

Except for Niah, where the competition effect of the climber was marked, our study showed that burning promotes the growth of germinated seedlings (Figs. 4–6). This effect may have resulted from increased soil nutrients (e.g., N, P, K) from the addition of ash (Tanaka et al. 2004, 2005). For the first year, however, the intermediate burning strength plots (200 t/ha at Sabal and Balai Ringin, 100 t/ha at Niah, and 20 t/ha at Bakam), showed the best growth among burned plots (Figs. 4–6). Thus, although the soil nutrient contents were higher in more strongly burned plots (Tanaka et al. 2004, 2005), too high a burning strength suppressed the first-year growth. This might be caused by fire severity of soil in the more strongly burned plots (Kendawang et al. 2004, 2005). But the degradation of soil caused by the fire severity (Kendawang et al. 2004, 2005) appears to have improved in the second year, when the increases in diameter, height, and biomass were greatest in the most strongly burned plots in which soil nutrients were richest (Tanaka et al. 2004, 2005; Figs. 4–6). Thus, in terms of growth, we conclude that burning promotes vegetation recovery.

The return of nutrients to the soil through burning also promotes the growth of cultivated plants. Rice cultivation experiments performed at the present sites showed that the yield increased with burning strength (Kendawang et al. 2004, 2005). Consequently, in the practice of agricultural, burning is effective both to control the number of weeds and to promote the growth of cultivated plants, which helps to explain the long tradition of shifting cultivation in this region.

The species composition of germinated seedlings differed between burned and unburned plots (Table 2). Some species were absent in burned plots, whereas some species germinated only in burned plots. Buried seeds of the absent species may have been killed by the heat, whereas other species may require fire to germinate or may germinate only after fire. Likewise, fires create openings within forests, providing suitable microhabitats for the dormant seeds of pioneer species that arrived previously in the seed rain as well as new species that arrive after burning. Thus, burning changes the species composition in favor of pioneer species, which disappear in the course of forest succession.

In summary, although the species composition was changed and the number of germinated seedlings was decreased in the burned plots, burning promoted the growth of those seedlings that did germinate. The burning strength was strongly related to the early stage of secondary succession after burning. When the burning strength and the burning area are properly managed, the decrease in the number of germinated seedlings provides good weed control for agriculture and the subsequent increase in growth promotes vegetation recovery and good crops.

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