JARQ 40 (3), 277 – 282 (2006) http://www.jircas.affrc.go.jp

Biomass Recovery of Naturally Regenerated Vegetation after the 1998 Forest Fire in East Kalimantan, Indonesia

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Abstract

After the 1998 forest fire in East Kalimantan, Indonesia, biomass recovery of naturally regenerated vegetation was estimated in order to evaluate the initial secondary succession patterns of the burned land. We established research plots in naturally regenerated vegetation that included pioneer tree species, and the dominant pioneer species were *Homalanthus populneus*, *Macaranga gigantea* and *M. hypoleuca*, *Mallotus paniculatus*, *Melastoma malabathricum*, *Piper aduncum*, or *Trema cannabina* and *T. orietalis*. Annual tree censuses over 4 years (from 2000 to 2003) showed that on plots where the initially dominant tree species were *M. malabathricum* and *T. cannabina* and *T. orietalis*, they tended to disappear, and were replaced with *M. gigantea* and *M. hypoleuca*. In contrast, on plots where the initially dominant species were *M. gigantea* and *M. hypoleuca*, *M. paniculatus*, or *P. aduncum*, they continued to dominate 5 years after the fire. We classified tree species that were initially dominant but disappeared within 5 years after the fire as extremely short-lived tree species. The aboveground biomass of trees (AGB) averaged 12.3 Mg ha^{-1} (ranging from 9.2 to 17.0 Mg ha^{-1}) in 2000 and 15.9 Mg ha^{-1} (ranging from 7.4 to 25.0 Mg ha^{-1}) in 2003. Between 2000 and 2003, some plots exhibited an increase in AGB and some a decrease in AGB. In the plots dominated by *M. gigantea* and *M. hypoleuca*, the AGB increased to over 20 Mg ha^{-1}, but other plots accumulated significantly less AGB in the 5 years following the fire. These results suggest that the pattern of AGB accumulation in secondary forests is strongly dependent on the dominant pioneer tree species.

Discipline: Forestry and forest products
Additional key words: aboveground biomass, pioneer tree species, short-lived tree species

Introduction

During the last two decades of the 20th century, a large area of East Kalimantan, Indonesia was burned twice, by forest fires that occurred in 1982–1983 and 1997–1998 after prolonged dry spells caused by strong El Niño Southern Oscillation (ENSO) events[8]. A total of 5.2×10^6 ha including 2.6×10^6 ha of forest was burned in East Kalimantan in 1997–1998[14]. Forest degradation and/or fragmentation after the fires affected many organisms[2,7,11] and the fires resulted in significant emissions of carbon into the atmosphere[1,13].

Recent concerns about global warning and the carbon sequestration potential of tropical rainforests highlight the importance of regenerated secondary forests and their role as a carbon sink. In the humid tropics, however, if fire kills large primary tree species and the burned area becomes dominated by a few pioneer tree species, the lost biomass is unlikely to be completely restored[18]. In addition, degraded lands without parent trees may not have the potential for succession leading to replacement[15,21]. Therefore, biomass recovery in such areas is quite slow[6] and there may be limits to the potential aboveground biomass of trees (AGB) accumulation in secondary forest composed of pioneer tree species.

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Received 15 July 2005; accepted 21 November 2005.

Evaluations of forest ecosystems after the fires have been undertaken by some research projects[3]. There are also some reports of forest structure and species composition in such areas[20]. However, information on naturally regenerated vegetation at an early stage after fires, in relation to biomass recovery, is still limited[4,9].

In the study reported here, we focused on the early biomass recovery in several types of secondary forest. Our aim was to acquire information on initial secondary succession patterns in the area of East Kalimantan, Indonesia, that had been affected by several forest fires and was subsequently dominated by pioneer tree species.

Study site

This study was conducted in the Bukit Soeharto Education Forest (BSEF), Mulawarman University (0°52′S, 117°01′E, alt. 10–100 m) (Fig. 1). The area was originally covered by a lowland dipterocarp forest. The mean annual rainfall is approximately 2,000 mm; the annual mean daily maximum and minimum temperatures are 29.9 and 21.4ºC, respectively[16]; and the dominated soils are Ultisols[10]. This area was subjected to selective logging prior to 1978[17]. During the dry period in 1982–1983, a large-scale forest fire occurred in East Kalimantan and the BSEF was affected by it. A prolonged dry spell in 1997–1998 also resulted in a large-scale forest fire in 1998. As a result of the two forest fires within just 15 years, some patches formed of pioneer tree species without any canopy species above them[8].

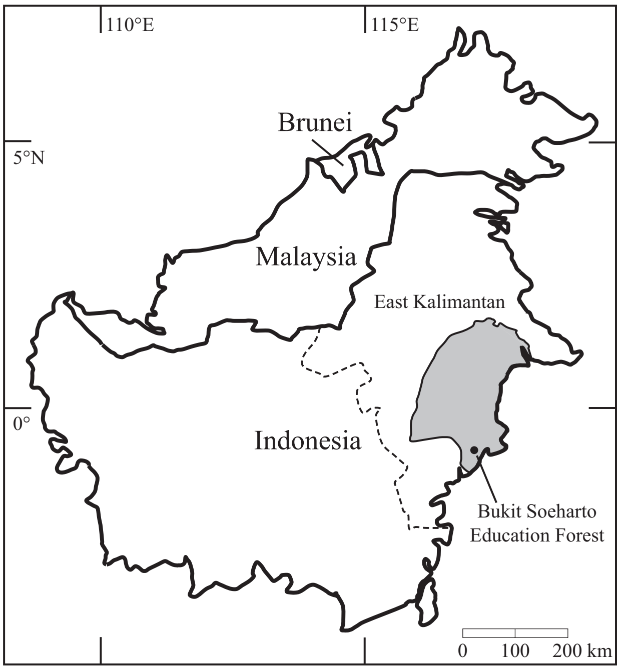

Fig. 1. Map of Kalimantan Island including the area which was burned at least two times in 1982–83 and 1998 (modified from published map[3])

: Burned area in 1982-1983 and 1998.

Field measurements

In September 2000, we established 8 research plots (100 m^2, 10 × 10 m each) in areas dominated by the pioneer tree species *Homalanthus populneus* (Hom), *Macaranga gigantea* and *M. hypoleuca* (Mac), *Mallotus paniculatus* (Mal), *Melastoma malabathricum* (Mel), *Piper aduncum* (Pip), or *Trema cannabina* and *T. orietalis* (Tre) by tree number base in each plot. Other pioneer tree species within, but not dominating, the plots included *Ficus* sp., *Geunsia pentandra*, and *Vernonia arborea*, which are common colonizers following forest fires in this area[5,8].

Condition in the area where we established each of the plots in September 2000 was similar. The area of established plots had no primary trees because of repeated forest fires. In addition, the area was clearly burned in the 1998 fire and there were no standing plants that were alive in April 1998. All plants were regenerated in natural after the fire. Site conditions were considered to be similar among plots.

We conducted an annual tree census in September of each year from 2000 to 2003. All trees over 1.3 m in height were labeled and identified to at least genus level. The trunk diameter at 1.3 m aboveground (*D*, cm) of all labeled trees in each plot was measured and recorded. In each tree census, new trees that just exceeded 1.3 m in height were labeled, identified and their *D* was measured and recorded.

Biomass estimation

Aboveground tree dry mass was estimated using allometric equations. For *Ficus* sp., *Geunsia pentandra*, and *Piper aduncum*, aboveground dry mass was estimated using empirical allometric equations[5] as follows:
for *Ficus* sp.;

$$M = 7.50 \times 10^{-2}(D)^{2.60}, \ r^2 = 0.95, \ n = 26 \quad (1)$$

for *G. pentandra*;

$$M = 5.56 \times 10^{-2}(D)^{2.62}, \ r^2 = 0.91, \ n = 20 \quad (2)$$

for *P. aduncum*;

$$M = 8.89 \times 10^{-2}(D)^{2.39}, \ r^2 = 0.92, \ n = 37 \quad (3)$$

where *M* is the total aboveground dry mass of an individual tree (kg) and *D* is the trunk diameter at 1.3 m aboveground of the tree (cm). For *M. gigantea* and *M.*

hypoleuca, and other pioneer species, we drew allometric equations from inventory data[5] based on destructive sampling as follows:

for *M. gigantea* and *M. hypoleuca*;

$$M = 5.64 \times 10^{-2}(D)^{2.47},\ r^2 = 0.96,\ n = 30 \quad (4)$$

for other pioneer species;

$$M = 1.49 \times 10^{-1}(D)^{2.09},\ r^2 = 0.68,\ n = 77 \quad (5)$$

AGB in each plot is the sum of the aboveground dry mass of all individual trees with over 1.3 m height.

Results and discussion

Total tree numbers averaged 67.0 trees 100 m^{-2} in the 8 plots (ranging from 43.0 to 97.0 trees 100 m^{-2}) in 2000 and 40.1 trees 100 m^{-2} (ranging from 28.0 to 52.0 trees 100 m^{-2}) in 2003 (Fig. 2 & Table 1). Thus, the mean values of total tree number in each plot decreased between these two dates, but in plot Tre-1, there was evidently an increase from 2002 onwards as *M. gigantea* invaded. Changes in the dominant tree species in each plot differed. Where the initially dominant tree species were *H. populneus*, *M. malabathricum*, or *T. cannabina*

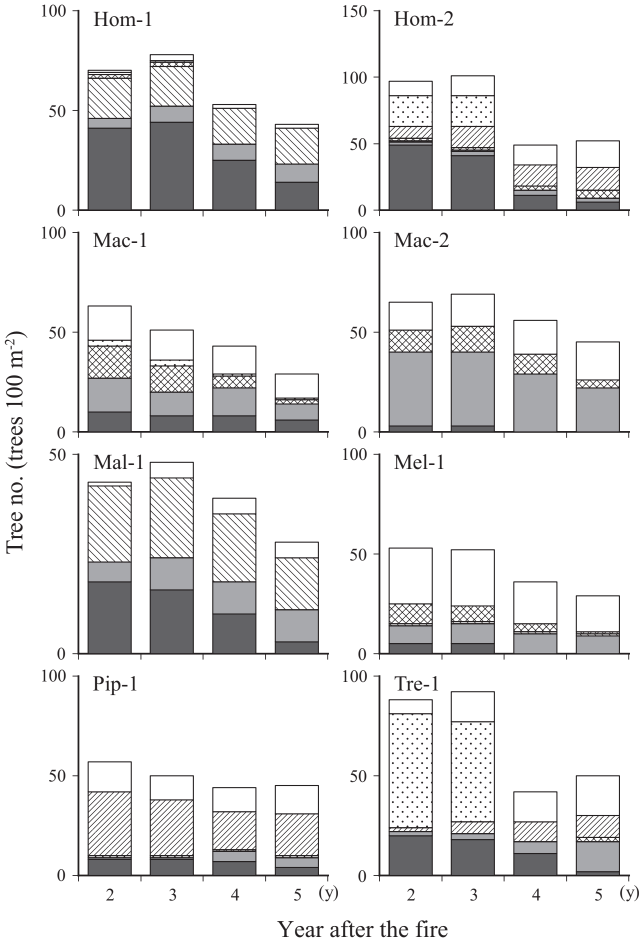

Fig. 2. Tree population changes after the forest fire in each plot

The designation of each plot refers to the species that dominated at the beginning of the survey, namely *Homalanthus populneus* (Hom), *Macaranga gigantea* and *M. hypoleuca* (Mac), *Mallotus paniculatus* (Mal), *Melastoma melabathricum* (Mel), *Piper aduncum* (Pip), and *Trema cannabina* and *T. orietalis* (Tre).

■ : Hom trees, ■ : Mac trees, ▧ : Mal trees, ▩ : Mel trees, ▨ : Pip trees, ⁘ : Tre trees, □ : Other pioneer trees.

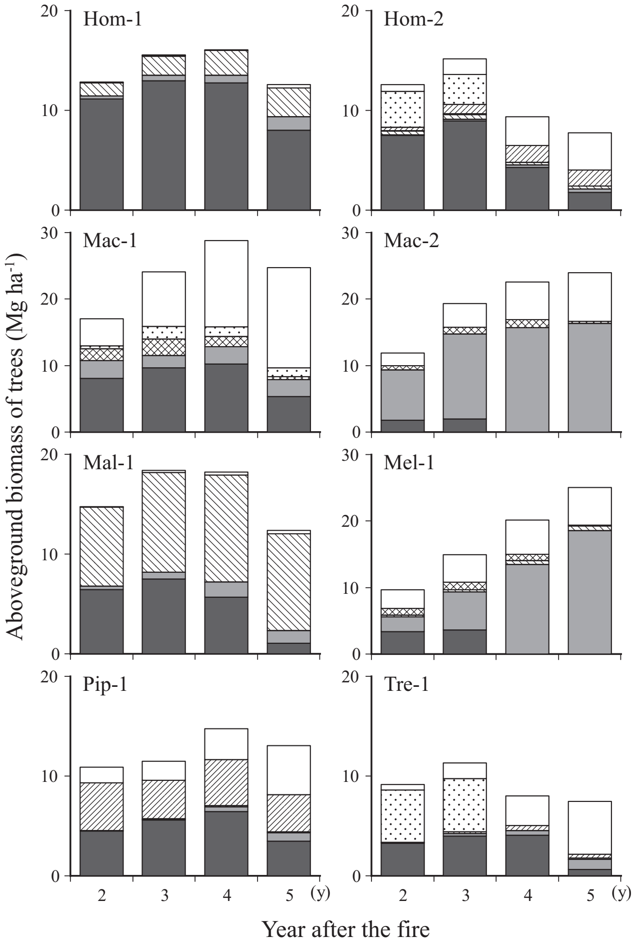

Fig. 3. Dynamics of aboveground biomass of trees (AGB) after the forest fire

The designation of each plot refers to the species that dominated at the beginning of the survey, namely *Homalanthus populneus* (Hom), *Macaranga gigantea* and *M. hypoleuca* (Mac), *Mallotus paniculatus* (Mal), *Melastoma melabathricum* (Mel), *Piper aduncum* (Pip), and *Trema cannabina* and *T. orietalis* (Tre).

■ : Hom trees, ■ : Mac trees, ▧ : Mal trees, ▩ : Mel trees, ▨ : Pip trees, ⁘ : Tre trees, □ : Other pioneer trees.

and *T. orietalis*, they tended to disappear from the plot, to be replaced by *M. gigantea* and *M. hypoleuca*. Where the initially dominant tree species were *M. gigantea* and *M. hypoleuca*, *M. paniculatus*, or *P. aduncum*, especially the former, they continued to dominate in the plot. They also became dominant in plots Hom-1, Hom-2, Mel-1, and Tre-1.

In 2000, AGB averaged 12.3 Mg ha^{-1} in the 8 plots (ranging from 9.2 to 17.0 Mg ha^{-1}) and in 2003 it averaged 15.9 Mg ha^{-1} (ranging from 7.4 to 25.0 Mg ha^{-1}) (Fig. 3 & Table 1). There were both increases and decreases in AGB between 2000 and 2003. In the plots dominated by *M. gigantea* and *M. hypoleuca*, in the 5 years after the fire, AGB increased and reached to be over 20 Mg ha^{-1}. In plot Mel-1, AGB also increased to over 20 Mg ha^{-1} onwards as the proportion of *M. gigantea* and *M. hypoleuca* increased. The trends in this plot may be similar to the AGB dynamics of plot Mac-2 where initially dominated by *M. gigantea* and *M. hypoleuca*. The AGB dynamics for 5 years after the fire

Table 1. Dominated tree species in each year, tree density (trees 100 m^{-2}), average trunk diameter (*D*, cm) with S.D., basal area (BA, m^2 ha^{-2}), and aboveground biomass of trees (AGB, Mg ha^{-2}) in each plot

Plot		Year after the fire (y)			
		2	3	4	5
Hom-1	Tree density (trees 100 m^{-2})	70	78	53	43
	Mean *D* (cm) with S.D.	2.8 (1.9)	2.8 (2.0)	3.6 (2.3)	3.6 (2.2)
	BA (m^2 ha^{-2})	6.0	7.3	7.5	6.0
	AGB (Mg ha^{-2})	12.8	15.5	16.1	12.6
Hom-2	Tree density (trees 100 m^{-2})	97	101	49	52
	Mean *D* (cm) with S.D.	2.5 (1.3)	2.7 (1.4)	3.1 (1.5)	2.7 (1.5)
	BA (m^2 ha^{-2})	6.0	7.3	4.6	3.9
	AGB (Mg ha^{-2})	12.6	15.1	9.4	7.8
Mac-1	Tree density (trees 100 m^{-2})	63	51	43	29
	Mean *D* (cm) with S.D.	3.6 (2.1)	4.6 (2.6)	5.4 (3.2)	5.9 (3.8)
	BA (m^2 ha^{-2})	8.3	11.2	13.2	11.2
	AGB (Mg ha^{-2})	17.0	24.1	28.8	24.7
Mac-2	Tree density (trees 100 m^{-2})	65	69	56	45
	Mean *D* (cm) with S.D.	3.0 (2.1)	3.5 (2.5)	4.3 (2.8)	4.8 (3.2)
	BA (m^2 ha^{-2})	6.7	10.2	11.4	11.6
	AGB (Mg ha^{-2})	11.8	19.3	22.6	23.9
Mal-1	Tree density (trees 100 m^{-2})	43	48	39	28
	Mean *D* (cm) with S.D.	4.1 (1.9)	4.2 (2.2)	4.7 (2.4)	4.6 (2.4)
	BA (m^2 ha^{-2})	6.8	8.5	8.4	5.8
	AGB (Mg ha^{-2})	14.7	18.4	18.2	12.3
Mel-1	Tree density (trees 100 m^{-2})	53	52	36	29
	Mean *D* (cm) with S.D.	2.9 (1.8)	3.5 (2.3)	4.8 (3.1)	5.7 (3.9)
	BA (m^2 ha^{-2})	4.9	7.2	9.1	10.8
	AGB (Mg ha^{-2})	9.6	14.9	20.2	25.0
Pip-1	Tree density (trees 100 m^{-2})	57	50	44	45
	Mean *D* (cm) with S.D.	3.0 (1.7)	3.3 (1.8)	4.1 (1.9)	3.8 (1.7)
	BA (m^2 ha^{-2})	5.3	5.6	6.9	6.2
	AGB (Mg ha^{-2})	10.9	11.5	14.7	13.0
Tre-1	Tree density (trees 100 m^{-2})	88	92	42	50
	Mean *D* (cm) with S.D.	2.3 (1.1)	2.4 (1.3)	3.1 (1.6)	2.4 (2.0)
	BA (m^2 ha^{-2})	4.4	5.5	3.9	3.8
	AGB (Mg ha^{-2})	9.2	11.3	8.0	7.4

Table 2. Years after the fire, recovered aboveground biomass of trees (AGB, Mg ha^{-1}), and mean annual increment of AGB (MAI, Mg ha^{-1} y^{-1}) in secondary forests after disturbance in East Kalimantan of Indonesia and Sabah of Malaysia in Borneo Island

Forest type and regions	Years after the fire (y)	AGB (Mg ha^{-1})	MAI[a)] (Mg ha^{-1} y^{-1})
Bukit Soeharto Education Forest in East Kalimantan, Indonesia (in this study)	2	9.2–17.0	13.1
	3	11.3–24.1	11.8
	4	8.0–28.8	9.2
	5	17.4–25.0	6.5
Sebulu in East Kalimantan, Indonesia[4]	1	7.5–9.9	8.7
	3	12.1	4.0
	3–4	18.9–23.6	6.1
	4–5	22.5–26.6	5.5
	6–8	35.0	5.0
	8–9	33.5–45.5	4.6
	10–12	44.2–55.3	4.5
Sipitang in Sabah, Malaysia[9]	2	1.3	0.7
	5	20.2	4.0
	8	58.0	7.3

a): Median value range of years after the fire and AGB were used for calculating MAI.

depended on the replacement of trees.

A secondary forest composed of *M. gigantea* and *M. hypoleuca* can accumulate AGB up to 40 Mg ha^{-1} in East Kalimantan, Indonesia, and there may be a limit to biomass accumulation in the secondary forests dominated by pioneer tree species[18]. In old secondary forests in East Kalimantan, Indonesia, accumulated AGB values have been found to remain small (Table 2), totaling 44.2 to 55.3 Mg ha^{-1} in approximately 11-year-old forests[4]. The replacement of pioneer tree species with primary tree species will be required for AGB to accumulate to the same level as in a primary forest.

On former study, pioneer trees were divided into two types[19]: short-lived tree species (about 15–30 years) and long-lived tree species (more than 80 years); that also mentioned very short-lived tree species (less than 15 years). The tree population changes during the 5 years after the fire (Fig. 1) indicate that the most short-lived trees account for the greatest population decreases. Initially dominant tree species such as *M. malabathricum* or *T. cannabina* and *T. orietalis*, which almost disappeared from our study area, may be extremely short-lived (surviving less than 5 years).

In this study, the early stage of secondary forest development after forest fire was investigated and the regeneration pattern of secondary forests in the humid tropics was evaluated. Pioneer trees in this area probably include some extremely short-lived trees species (surviving less than 5 years). The results suggest that the AGB dynamics soon after forest fires depends on the type of tree species (short-lived or extremely short-lived) that dominate after the fires at such sites. In addition, such secondary forests consisting of only a few pioneer tree species can not accumulate large quantities of AGB[9,12] which was reported over 500 Mg ha^{-1} in primary forest at about 50 km northwest from the BSEF[22].

Acknowledgments

This study was conducted as a cooperative research project between the Mulawarman University, Indonesia, Center for International Forestry Research (CIFOR) and Waseda University, Japan. This study was supported financially by the Ministry of Environment, Japan (B-60: Development of Evaluation Model for Carbon Sink).

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