Impact of peat-fire disturbance to forest structure in tropical peat forest in Central Kalimantan, Indonesia

Center for Sustainability science, Hokkaido University, Japan — Satomi SHIODERA
Faculty of Environmental Earth Science, Hokkaido University, Japan — Tika Dewi Atikah
Research Center for Biology-LIPI, Indonesia — Joeni Setijo Rahajoe・Ismail Apandi
Tsukuba Experimental Forest, Agricultural and Forestry Research Center, Faculty of Life and Environmental Sciences, Tsukuba University, Japan — Tatsuyuki SEINO
Faculty of Environmental Engineering, The University of Kitakyushu, Japan — Akira HARAGUCHI
Faculty of Agriculture, University of Palangka Raya, Indonesia — Afentina S. Hut
Graduate School of Environmental Science, Hokkaido University, Japan — Takashi KOHYAMA

Introduction

In the world, 11 % (44.1 million hectares (Mha)) of global peatland area is located in tropical regions. Most of the tropical peatlands (24.8 Mha, 56 %) are found in the Southeast Asia region (47 % in Indonesia, 6 % in Malaysia, 3 % in Papua New Guinea, with small pockets and remnants in Brunei, Myanmar, the Philippines, Thailand and Vietnam) (*3*). However, all regional peatlands are threatened by either logging, drainage, agricultural conversion (mostly to oil palm, as well as rice, rubber, coconut and pineapple), fire or other human activities.

Tropical peat swamp forests are unique ecosystems, because of their extreme acidic, anaerobic and nutrient poor conditions. They support diverse forms of flora, fauna and microbes with many endemic and endangered species. Anderson (*1*) recorded 927 species of flowering plants and ferns in the peat swamp forests of Borneo. Most of the tree families that are present in lowland dipterocarp forests are also presented in peat swamp forests, but many of the species in peat swamp forests are specific to this habitat (*8*). They are also an important refuge for many endangered species including orangutan.

At the same time, tropical peatlands are one of the largest sink of organic carbon. The carbon is stored not only in the living biomass, but also in the peat soil. In Southeast Asia, their high carbon density results in a large regional peat carbon store of 68.5 Gt, equivalent to 77 % of the tropical and 11 – 13 % of the global peat carbon pools (*3*). Indonesia has the largest stock of tropical peat carbon (57.4 Gt, 65%). This data is used to provide revised estimates for Indonesian forest soil carbon pools of 77 Gt, and total forest carbon pools (biomass plus soil) of 97 Gt. Peat carbon contributes 74 % to the total forest soil carbon pools in Indonesia. However, Indonesia is also the third largest emitter of greenhouse gases. Page et al. (*5*) estimated that, under the 1997 El Nino event, 32 % (0.79 Mha) had burnt in the 2.5 Mha study area in Central Kalimantan and which of 91.5 % (0.73 Mha) was peatland. According to their estimation, 0.19 – 0.23 Gt of carbon was released to the atmosphere through peat combustion and 0.05 Gt of carbon was released from burning of the overlying vegetation. They emphasized that, as a result of burning peat and vegetation, between 0.81 and 2.57 Gt of carbon was released to the atmosphere in 1997 in Indonesia. It is almost 13 – 40% of the mean annual global carbon emissions from fossil fuels.

In Central Kalimantan, peat fire has been a serious problem since the last decade. Peat fire is a major cause of peatland degradation that leads to loss of biodiversity and carbon stock in peat swamp forests. When peat is ignited, fire will develop underground slowly and may spread vertically and horizontally dominated by smoldering process. Finally, peat fire will destroy ecosystem completely and change the environment drastically. Because, peat swamp forests are sustained in the sensitive balance among deep water table, canopy cover and leaf litter inputs (*8*), forest recovery would be difficult after a fire.

In this study, we evaluated the impact of fire disturbance to forest structure and reforestation after peat fire from the comparison among peat swamp forests with differences on disturbance severity.

Materials and Methods

The study was conducted in Hampangen Educational Forest (HEF) of University of Palangka Raya, Kabupaten Kasongan, Central Kalimantan, Indonesia. HEF is situated at 1°53′S, 113 °28′ E, at 42 m above sea level. The entire area of 5,000 ha HEF is covered by about 4 – 6 m shallow peat soil. Palangka Raya, the provincial capital of Central Kalimantan, is located about *ca*. 70 km south-southeast of the study site. An average annual precipitation was *ca*. 2,800 mm (1993 – 1997) at Palangka Raya, with monthly averages ranging from 80 mm in

---

Satomi SHIODERA, Tika Dewi Atikah, Takashi KOHYAMA (Hokkaido Univ., Sapporo, Japan), Joeni Setijo Rahajoe, Ismail Apandi (Research Center for Biology-LIPI, Indonesia), Tatsuyuki SEINO (Tsukuba Univ., Tsukuba, Japan), Akira HARAGUCHI (The University of Kitakyushu, Kitakyushu, Japan), Afentina S. Hut (University of Palangka Raya, Indonesia)
Impact of peat-fire disturbance to forest structure in tropical peat forest in Central Kalimantan, Indonesia

August to 370 mm in January. The dry season occurs from July to October, when mean monthly rainfall is < 130 mm. In rainy season, some parts of HEF will be flooded by long spell rain. On the other hand, in dry season, some parts of HEF will suffer severe damage by peat fire. In consequence, the mixed distribution of un-burnt and burnt forests is created in the HEF.

Three 0.2 ha (20 m × 100 m) transects (P1, P2 and P3) were established in the peat swamp forest in December 2010. To identify the impact of peat fire to the forest recovery, the plots were set up according to disturbance severity by peat fire. P1, P2 and P3 were located in un-burnt forest, burnt forest in 1997, and burnt forest in 1997/2009, respectively. The topography of the study site was generally flat. All trees with GBH (girth at breast height) more than 15 cm within the plots were identified to species and recorded. Tree height (H) was also measured for all trees. For trees measured in the plots, herbarium specimens were collected, treated with alcohol, then, sent to Herbarium Bogoriense, Research Center for Biology-LIPI in Cibinong for further identification. Based on GBH, DBH (diameter at breast height) and tree basal area were calculated, and converted into per ha in each plot. Shannon's diversity (*H'*) was calculated to obtain the overall vegetation characteristics (*9*). To estimate dry mass of the trunk, trunk volume index (D^2H; m^3) was calculated. Allometric relationships between DBH and H were regressed by the following equation:

$$\mathrm{Log}\,(H) = a + b\,\mathrm{Log}\,(DBH),$$

where *a* and *b* are the regression parameters. Analysis of covariance was used for comparison of regression coefficients for linier allometric relationships. All statistical analyses were performed using R 2.10.0.

Results

Results of our plot survey indicated that forest structure among three plots had changed in consequence of peat fire and showed different characteristics. We found 47 species (29 families) in P2 (Table 1). The species number was close to 61 species (31 families) in P1. However, there were only 5 species (5 families) in P3. The largest value of tree density was 3,730 ha^{-1} in P2. It was followed by 2,330 ha^{-1} in P1 and 1,820 ha^{-1} in P3. Tree basal area displayed different tendency. P1 had largest basal area (28.55 m^2ha^{-1}) among the three plots. The values of P2 and P3 were 18.73 m^2ha^{-1} and 18.43 m^2ha^{-1}, respectively. The mean DBH and tree height were 5.25 cm and 14.8 m in P1, 3.79 cm and 10.6 m in P2, and 5.11 cm and 10.2 m in P3. Trunk volume index of P1 (236.5) was about three times and twenty five times larger than those of P2 (72.3) and P3 (8.8), respectively. The lowest *H'* was obtained from plot P3 (0.72), which was burnt in 1997 and 2009. Contrary to our expectations, P1 and P2 showed similar *H'* values (5.13 and 4.55). In P1, the dominant species were *Palaquium leiocarpus* Boerl and *Syzygium creaghii* (Ridl.) Merr. & Perry. Then, dominants were *Combretocarpus rotundatus* (Miq.) Danser and *Cratoxylum glaucum* Korth in P2 and P3. In P3, almost individuals were *Combretocarpus rotuodatus*.

The frequency distributions of tree diameter size indicated unimodal distributions in P1 and P3 (Figure 1). From these results, we found that the small individuals are scarce in these plots. On the other hand, a steep L-shaped distribution of P2 implied that many small trees have been recruiting there. The panels also displayed that the tree number of P2 is larger than P1 and P3 in small size classes. Trees in P2 plot demonstrated a high frequency of small trees (3 ≤ DBH < 5 cm), especially for the class 3 – 4 cm (> 250 trees). Meanwhile, few trees had > 10 cm DBH in P1 and P3; maximum observed DBH was 23 and 37 cm for P1 and P3, respectively.

Allometric relationship between DBH and H demonstrated difference among three sites (Figure 2). The slope of P1 was steeper than that of P2 and P3. On the other hand, no significant difference was found between P2 and P3. This means that trees of P1 have a larger height than the trees of P2 and P3 in the same DBH.

Discussion

Result from current research, we found that the forest burnt only in 1997 (once-burnt forest) recovered beyond our expectation. In the forest, tree density was the highest among three forests that the disturbance severity was different (Table 1). The values of numbers of species and *H'* in P2 were sufficiently high compared to those of un-burnt forest. The comparison of DBH distributions indicated that many small individuals were included in the once-burnt forest, although the other forests didn't show such tendency (Table 2). Because, it seems that the small individuals in the once-burnt forest recruited after peat fire in 1997, the high recruit rate would contribute to forest recovery there. However, in terms of carbon storage, the once-burnt forest is estimated to be only one third of un-burnt forest (Table 1).

The dominant species in two-type burnt forests are the same and it was very different from un-burnt forest (Figure 1). *Combretocarpus rotundatus* and *Cratoxylum glaucum* are the specific species that dominate after-burnt forest. After peat fire, these two species survive or sprout from the base of burnt stems. Moreover, *Combretocarpus rotundatus* can produce flowers and fruits throughout the year. The seeds have wings and can float on water. In the rainy season, the seeds are carried to everywhere in the flooded forest floor. As result, the burnt forest will change into pure forest of *Combretocarpus rotundatus*. However, the species cannot survive under the dark closed canopy, because they are light-demanding species. So, according to progress of succession, they would decline in the dark forest floor (personal communiction).

In terms of stand-level allometry for multiple species, marked differences among un-bernt and burnt forests were observed in DBH-H relationship (Figure 2). The DBH-H relationship indicated that trees in burnt forest had short stature compared to un-burnt forest trees. In other words, trees in un-burnt forest are heigher than trees in burnt forests of same DBH. Then, it is indicated that after-burnt forests have different forest structure from un-burnt forest.

From the results of dominant species composition and allometry regression between DBH and H, we concluded that after-burnt forests have similar forest structure. They are very different from un-burnt forest and need to spend a long time to recover.

It is indicated that the tallest forest (canopy up to 45 m) developed on the thickest and oldest peat in a forest in Central Kalimantan, and the low pole forest (up to 20 m) and mixed swamp forest (upper canopy 35 m) developed on the thinner and younger peat (*4*). Simbolon et al. (*6*) compared the dominant species in peat swamp forest among three sites in Central Kalimantan and represented that their species compositions were very different. They suggested that the differences in the dominant tree species among sites might be related to the degree of forest disturbance, intensity of logging, peat depth and other edaphic factors. Variation in the species composition and forest structure of peat swamp forests are related with hydrology, nutrient status and thickness of the peat (*1, 7, 4*). Gunawan et al. (*2*) indicated that tree regeneration is controlled by the degree of disturbance severity, peat depth, seed availability, predation of seeds and seedlings, and also competition with other plant species. If there are no mother trees and suitable water table, the forest cannot regenerate for a long time. In current study, we revealed that if burnt forest could avoid peat fire damage for only ten years, they could reforestate at some level in our sites. To prevent forest degradation, we need to prevent forest from suffering serious damage by peat fire .

Acknowledgements

This work was supported by "Wild fire and carbon management in peat-forest in Indonesia", SATREPS, JST-JICA.

References

(*1*) Anderson JAR (1963) The flora of the peat swamp forests of Sarawak and Brunei. Including a catalogue of all recorded species of flowering plants, ferns and fern allies. Gard Bull Singap **29**: 131-228.

(*2*) Gunawan H, Page S, Muhammad A, Qomar N, Helentina A, Hakim A, Yanti MM, Darmasanti (2008) Peat swamp forest regeneration using green belts in a timber estate in Riau, Sumatra, Indonesia. Paper presented at the international seminar on the role of biology in sustainable utilization of local natural resources for environmentally friendly industrial purposes. North Sumatra.

(*3*) Page SE, Rieley JO, Banks CJ (2011) Global and regional importance of the tropical peatland carbon pool. Global Change Biol. **17**: 798-818

(*4*) Page SE, Rieley JO, Shotyk W, Weiss D (1999) Interdependence of peat and vegetation in a tropical swamp forest. Philos Trans R Soc B Biol Sci **354**: 1885-1897.

(*5*) Page SE, Siegert F, Rieley JO, Boehm HDV, Jaya A, Limin S (2002) The amount of carbon released from peat and forest fires in Indonesia during 1997. Nature **420**: 61-65

(*6*) Simbolon H and Mirmanto E (2000). Checklist of plant species in the peat swamp forests of Central Kalimantan, Indonesia. Proceedings of the International Symposium on TROPICAL PEATLANDS: 179-190.

(*7*) Whitmore TC (1984) Tropical rainforests of the Far East, 2nd edn. Clarendon, Ocford.

(*8*) Yule CM (2010) Loss of biodiversity and ecosystem functioning in Indo-Malayan peat swamp forests. Biodivers. Conserv. **19**: 393-409

(*9*) Zar, JH (1999) Biostatistical analysis (4th ed.). Prentice-Hall, Englewood Cliffs, NJ

Table 1. Tree density, number of species, basal area, mean DBH, mean height, Shannon's diversity (*H'*) and trunk volume index of 0.2 ha plots in three un-burnt and burnt forests.

	Tree density (ha^{-1})	Number of species (0.2 ha^{-1}) (families)	Basal area (m^{2}ha^{-1})	Mean DBH (cm)	Mean tree height (m)	*H'*	Trunk volume index (m^3)
P1	2330	61 (31)	28.55	5.25	14.8	5.13	236.5
P2	3730	47 (29)	18.73	3.79	10.6	4.55	72.3
P3	1820	5 (5)	18.43	5.11	10.2	0.72	8.8

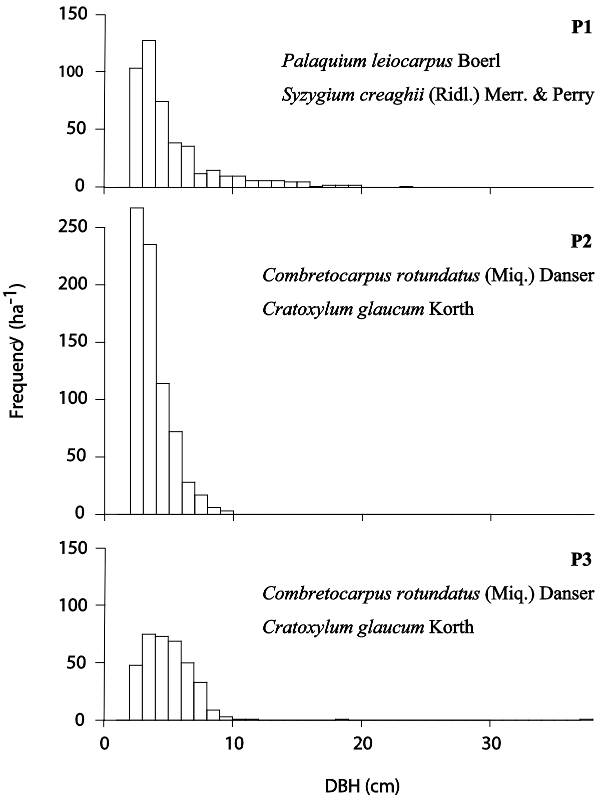

Figure 1. The DBH distributions of each study site. Tree species in each figure are dominant species.

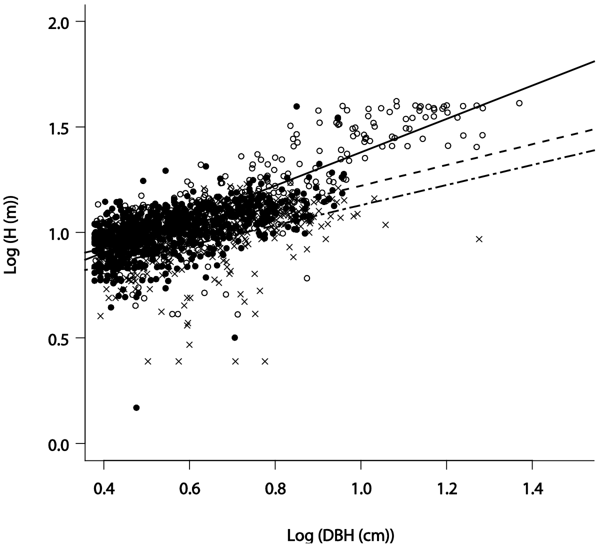

Figure 2. Comparison of the allometric relationship between trunk diameter (DBH) and tree height (H), Log (H) = $a + b$ Log(DBH) in un-burnt and burnt forests. The regression lines of un-burnt (P1) and burnt (P2 and P3) forests are significantly different. Open circle and solid line, P1; closed circle and broken line, P2; cross and dashed-dotted line, P3.