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Sixteen years changes in tree density and aboveground biomass of a logged and burned dipterocarp forest in East Kalimantan, Indonesia

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Abstract. *Toma T, Warsudi, Osone Y, Sutedjo, Sato T, Sukartiningsih. 2017. Sixteen years changes in tree density and aboveground biomass of a logged and burned dipterocarp forest in East Kalimantan, Indonesia. Biodiversitas 18: 1159-1167.* Changes in tree density and aboveground biomass (AGB) of a logged and burned lowland dipterocarp forest were monitored in Bukit Soeharto Research and Education Forest (BSREF) of Mulawarman University, East Kalimantan, Indonesia. A 9-ha plot was established in 1997 to investigate the effect of second felling and the subsequent recovery. Experimental felling was conducted in October 1997, and the plot was burned by uncontrolled fires between February and April 1998. Stem diameter of living trees (diameter at breast height ≥ 10 cm) in the plot was recorded annually. Allometric functions and the annual tree inventory were used to estimate changes in AGB. Tree density in the 9-ha plot was 429 trees ha^{-1} before the experimental felling.This decreased to 76 trees ha^{-1} in 2000 because of the felling and fires. Tree density increased to 515 trees ha^{-1} until 2008 and then decreased to 408 trees ha^{-1} in 2014. AGB of the 9-ha plot was 279 Mg ha^{-1} in 1997,which decreased to 96 Mg ha^{-1} in 2000 and then increased to 139 Mg ha^{-1} in 2014. After 16 years of the 1998 fires, in 2014, BSREF consists of a mosaic of forest stands that are dominated by either large late successional tree species or small pioneer trees. The former stands consisted of numerous late successional tree species that survived the felling and fires. The latter stands were dominated by a few pioneer species. In 2016, 16 years after the fire, these pioneer dominating stands are now undergoing a transitional stage from pioneer to late successional trees that grow longer and larger than the pioneer trees. Logged and burned forest stands may recover their AGB comparable to that of the original forest (≥400 Mg ha^{-1}), if these stands are saved from further logging and fires in the longterm.

Keywords: Aboveground biomass, Bukit Soeharto, logging and fire, recovery

Abbreviations: AGB = Aboveground biomass,BSREF = Bukit Soeharto Research and Education Forest, DBH = diameter at breast height, ENSO = El Niño Southern Oscillation, LF = light felling, HF = heavy felling, UF = unfelled, CWD = coarse wood debris

INTRODUCTION

Logging and fires are major disturbing factors in tropical forests. However, logged and burned forests should be considered as worthy of conservation or at least not necessary to be regarded as deforested. Because selectively logged forests maintain high biodiversity as well as high carbon stock, logged forests are expected to provide various ecosystem services compared to other land uses, but there is still a lack of basic understanding on the long-term effects of logging (Edward et al. 2013). Burned forests have the potential to recover naturally; however, there are no detailed published accounts of long-term recovery of tropical forests after fire (Chazdon 2014). Apparently, tropical rain forests can recover from fire, but little is known about the timescales involved and the pathways along which this recovery takes place (Slik et al. 2008).

Lowland forests in East Kalimantan, Indonesia, have been disappearing at a rapid rate since the 1960s because of commercial logging and agricultural development. Forests in East Kalimantan have also been damaged by uncontrolled fires repeatedly, including the world largest-scale forest fires that occurred in 1982-83 and 1997-98 (Mori 2000). Compared to the 1982-83 fires, damage by the 1997-98 fires and early recovery after the fires have been well described (Mori 2000, Hiratsuka et al. 2006, Slik et al. 2008, Toma et al. 2000b, 2005, Van Nieuwstadt and Sheil 2005). However, these studies were conducted only until several years after the fires using temporal sampling plots. Here we report about forest recovery after the 1997-98 fires observed in a long-term monitoring plot for a 16-year period.

In the present article, we highlight the following points from the long-term monitoring: (i) pioneer trees, established after the fire, dominate the logged and burned stands in terms of number of trees; (ii) large late successional trees, which survived the logging and fires, dominate the stands in terms of aboveground biomass (AGB); and (iii) the logged and burned stands are undergoing a transitional stage from pioneer to late successional trees that grow longer and larger than the pioneer trees; and (iv) the stands may recover their biomass comparable to that before disturbances, if they are saved from further disturbances in the long term.

MATERIALS AND METHODS

Study site and methods

This study was conducted in Bukit Soeharto Research and Education Forest (BSREF) of Mulawarman University. BSREF is situated in between Samarinda and Balikpapan in the lowland coastal area of East Kalimantan (Figure 1.A), which was originally covered with a lowland dipterocarp forest. The mean annual rainfall in BSREF is approximately 2000 mm; the mean annual daily maximum and minimum temperatures are 29.9°C and 21.4°C, respectively (Toma et al. 2000a); and the soils are Ultisols (Ohta and Effendi 1992). Rainfall type belongs to Type B (slightly seasonal), according to Whitomore (1984), and to the tropical wet type (relatively frequent short dry period or short dry season), according to Walsh (1996). Unusually prolonged and severe droughts related to extremely strong El Niño Southern Oscillation (ENSO) events occurred in 1982-1983 and 1997-1998, and the forests in East Kalimantan were damaged by the droughts and drought-related fires (Mori 2000).

Majority of the forest stands in BSREF were subjected to selective cutting by local people and commercial logging companies, until the area was designated as a protected forest in 1978 (Matius and Okimori 1991). BSREF was affected by the 1982-83 fires, and the severity of fire damage in the burned stands was related to past logging intensity; the most heavily damaged sites in 1988 were dominated by pioneer *Macaranga* species, and the lightly damaged sites were dominated by surviving dipterocarp species (Matius and Okimori 1991). Thus, by 1997, BSREF had become a mosaic of forest stands dominated by surviving dipterocarp trees and pioneer *Macaranga* trees as a result of selective logging and the 1982-1983 forest fires (Toma et al. 2000b).

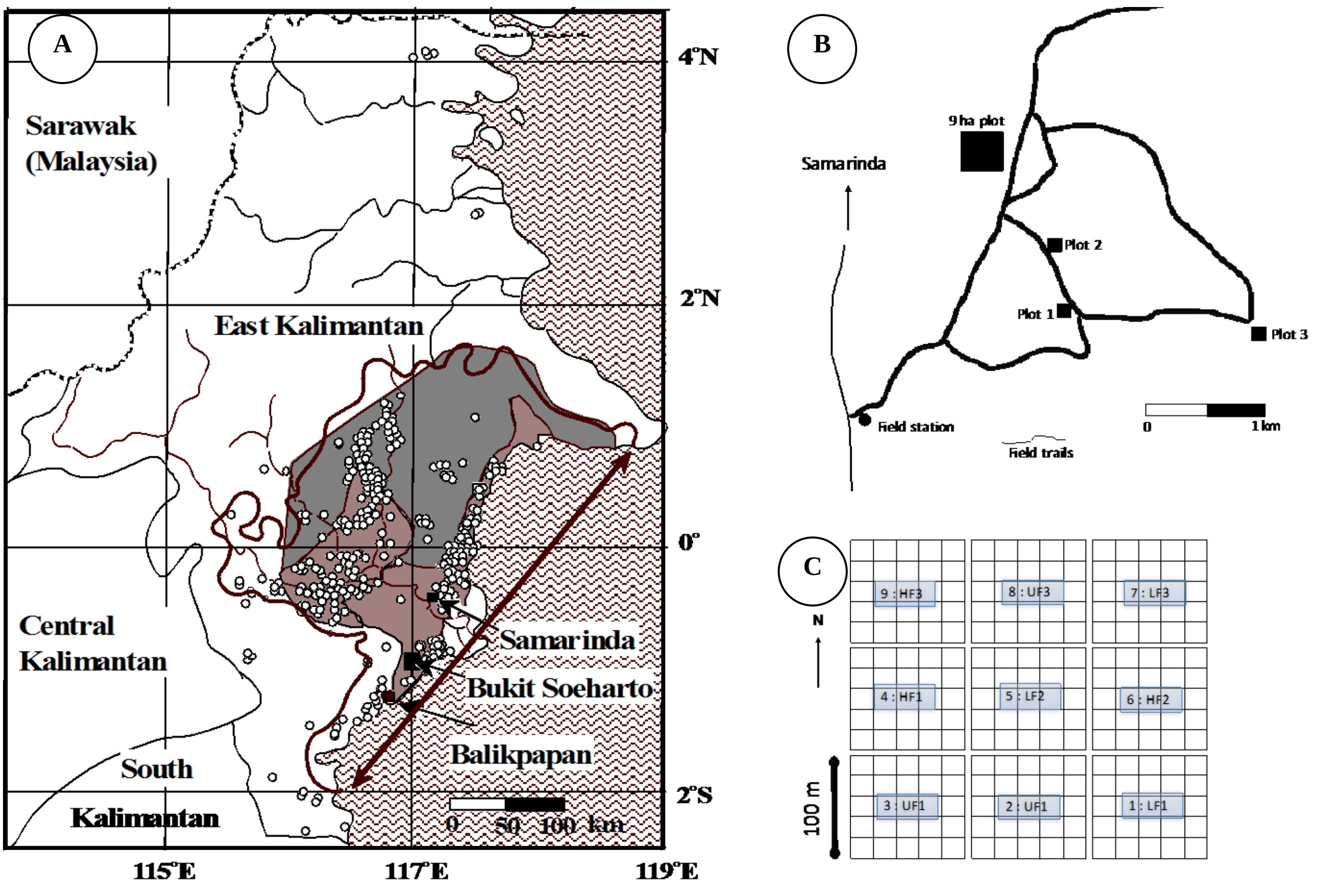

Figure 1. A. Location and, B. Monitoring plots of Bukit SoehartoResearch and Education Forest, and C. Layout of the 9-ha plot. Shaded area in A were affected by the 1982-83 fires. The area surronded by curves and arrows in A were affected by the 1998 fires. Open circles are hot spots observed on 14 February 1998. Plots 1, 2, and 3 correspond to LDS, MDS, and HDS in Toma et al. (2000b, 2005), respectively. HF, LF, and UF represent heavily felled, lightly felled, and unfelled, respectively (Ruslim et al. 2000)

The 9-ha plot and tree censuses

A 9-ha permanent plot was established in May 1997 to investigate the effects of second felling on a logged-over dipterocarp forest and the subsequent recovery from the felling (Ruslimet al., 2000). The 9-ha plot consisted of nine 1-ha subplots of 100 × 100 m, each arranged in 3 × 3square plots (Figure 1.C). Tree censuses in the 9-ha plot have been conducted repeatedly since 1997 at least once a year, except in 2001, 2002, and 2004. All trees ≥ 10 cm in diameter at breast height (DBH) were identified, tagged, and their DBH was measured. Trees were felled in six of the nine plots in October 1997 at two different felling intensities. Light felling (LF) is the conventional method used in forest concessions, in which trees with a diameter of at least 50 cm are harvested for merchantable timber. Trees with a diameter of at least 30 cm were harvested during heavy felling (HF) operations. Three replicates of each felling treatment and untreated (unfelled, UF) plots were used. The effects of the second felling on the forest structure, tree damage, traffic area, and soil damage and the trees remaining for the next felling have been reported by Ruslim et al. (2000). BSREF suffered a forest fire during the 1998 drought, and the 9-ha plot was also burned between February and April 1998. Consequently, BSREF consists of a mosaic of forest stands that are dominated by surviving late successional tree species (e.g., Dipterocarpaceae and *Eusideroxylon zwageri*) and pioneer species (e.g., *Macaranga gigantea*, *Euodia alba*, and *Vernonia arborea*), which rapidly increased in abundance following the forest fires.

Tree censuses and AGB estimation in the 9-ha plot

The annual tree inventory and allometric functions were used to estimate changes in aboveground biomass (AGB). Based on the known characteristics of tree species, we divided all trees into two ecological groups, pioneer and late successional tree species. Unidentified trees and tree species without known ecological characteristics are treated as late successional trees.

Aboveground mass (M_T) of late successional species was calculated by the following equations taken in BSREF (Eq.(1); Toma et al. (2005)) and in Sebulu (Eqs. (2)-(4); Yamakura et al. (1986)):

$$1/H = 1/(1.444D) + 1/62.5 \quad (1)$$
$$M_S = 0.0290\cdot(D^2H)^{0.981} \quad (2)$$
$$M_B = 0.119\cdot M_S^{1.059} \quad (3)$$
$$M_L = 0.0942\cdot(M_S + M_B)^{0.727} \quad (4)$$
$$M_T = M_S + M_B + M_L \quad (5)$$

where H is height (m), D is DBH (cm), M_S is trunk biomass (kg), M_B is branch biomass (kg), and M_L is leaf biomass (kg). The following equations from Toma et al. (2005) taken in BSREF were used for estimating AGB of the pioneer tree species:

$$1/H = 1/(0.0116D^{3.09}) + 1/20.4 \quad (6)$$
$$M_S = 0.0132\cdot(D^2H)^{0.976} \quad (7)$$
$$M_B = 0.0494\cdot M_S^{1.351} \quad (8)$$
$$M_L = 0.1443\cdot(M_S + M_B)^{0.778} \quad (9)$$
$$M_T = M_S + M_B + M_L \quad (5)$$

RESULTS AND DISCUSSION

Results

Overall trend

Tree density and AGB of the 9-ha plot decreased by the experimental felling and the 1998 fires (Figure 2). The decreasing trend continued until 2000 and then both tree density and AGB started to increase. Tree density in the 9-ha plot increased until 2008 and then started to decrease (Figure 2.A). Tree density in 2008 was higher than that in May 1997, before the felling and fires. AGB of the 9-ha plot increased until 2013, and the increment was primarily due to rapid increase in AGB of pioneer trees (Figure 2.B, upper panel). Although the density of pioneer trees started to decrease after 2008, AGB of pioneer trees increased until 2013 (Figure 2, upper panels). AGB of late successional trees was stable compared to that of pioneer trees and increased gradually since 2000 (Figure 2, middle panels). Although tree density in the 9-ha plots once became higher than that before the felling and fires, AGB of the 9-ha plot was maintained lower than that before the felling and fires (Figure 2, lower panels). In 2014, AGB of the 9-ha plot was only about 50% of that before the felling and fires.

Impact of experimental felling and the 1998 fires until 2000

At the first census in May 1997, the mean (±SD) tree density and AGB of the 9-ha plot were 429±51 ha^{-1} and 279±49 Mg ha^{-1}, respectively. No significant difference was observed before treatment. Experimental felling harvested commercial trees and killed the trees near the harvested trees. As a result, tree density and AGB of HF (326±50 ha^{-1} and 152±19 Mg ha^{-1}, respectively) and LF (316±35 ha^{-1} and 170±7 Mg ha^{-1}, respectively) plots became significantly smaller than those of UF (456±35 ha^{-1} and 308±79 Mg ha^{-1}, respectively) plots. Tree density and AGB in the 9-ha plot were decreased by the 1998 fires, and the decreasing trend continued until 2000, 2 years after the fires. In 2000, tree densities in the HF, LF, and UF plots were 57±48 ha^{-1},44±20 ha^{-1}, and 129±28 ha^{-1}, respectively, and the respective AGB values were 52±23 Mg ha^{-1},60±16 Mg ha^{-1}, and 178±47 Mg ha^{-1}. While no significant difference was observed in tree density among the treatments, AGB in the UF plots was significantly larger than the AGB in the HF and LF plots. Majority (97%) of the trees that survived the fires included late successional trees,whereas nearly no pioneer trees existed in the 9-ha plot in 2000.

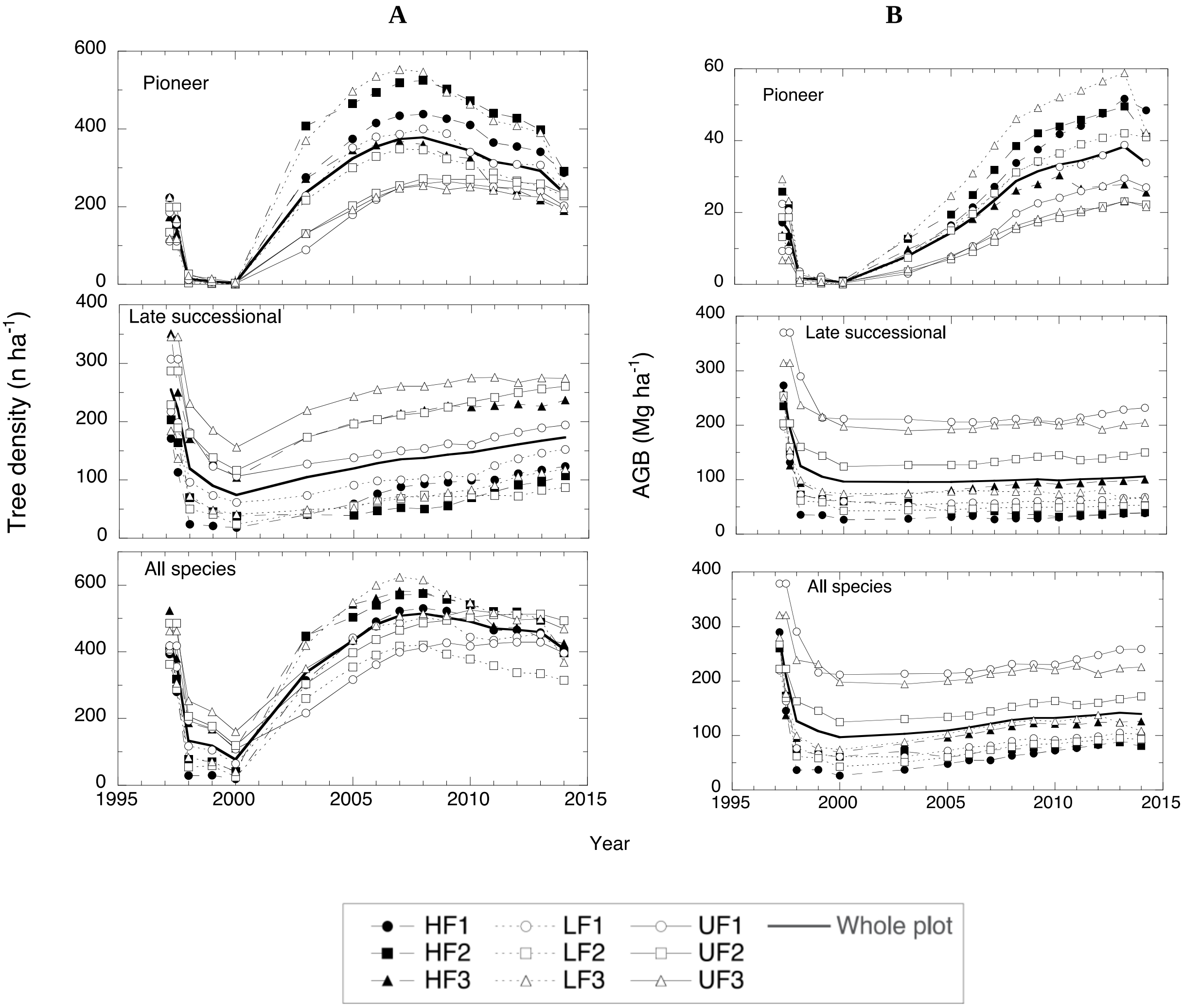

Figure 2. Changes in tree density and aboveground biomass (AGB) in the 9-ha plot. Note the variation in Y scale. A. Tree density, B. Aboveground biomass (AGB)

Changes in tree density after 2000

Tree density in the 9-ha plot increased from 76±50 ha^{-1}in 2000 to 515±70 ha^{-1}in 2008 (Figure 2.A). Thereafter, it decreased to 408±52 ha^{-1} in 2014. These changes were primarily induced by the pioneer trees that established after the fires. In 2000, nearly no pioneer trees (DBH ≥ 10 cm) existed in the 9-ha plot. However, in 2008, pioneer trees accounted for 73% of the total number of trees. The ratio of pioneer trees also decreased since 2008 and it was 60% in 2014. Tree density of late successional trees in the 9-ha plot was much smaller than that of pioneer trees, but it kept increasing after 2000.

The rate of tree recruitment decreased from 89 (number of recruited trees ha^{-1} yr^{-1}) between 2000 and 2003 to 14 (trees ha^{-1} yr^{-1}) between 2013 and 2014 (Figure 3.A). The rate of recruitment (number of recruited trees ha^{-1} yr^{-1}) of pioneer trees was higher in the earlier period and then it decreased in the latter period (Figure 3.A, upper panel). An increasing trend of mortality (number of died trees ha^{-1} yr^{-1}) of pioneer trees was observed (Figure 3.B), but it was not so obvious compared to that of recruitment rate. The recruitment rate of pioneer trees was higher than those of late successional trees during the earlier period of monitoring (Figure 3.A, upper and middle panels). Late successional trees did not show a clear trend and variation between the 1-ha subplots, and the measurement periods were large. Between 2000 and 2003, 80% of recruited trees were pioneer trees, but it was only 29% between 2013 and 2014.

The number of pioneer trees that died between the two consecutive censuses increased from 2000 to 2011 with a large year-to-year variation (Figure 3.B, upper panel). Simultaneous death of pioneer trees in the felled plots (HF and LF) was observed in 2011 and 2014. The number of died trees of late successional species was one-tenth of pioneer species, and no synchrony was observed among the subplots (Figure 3.B, middle panel).

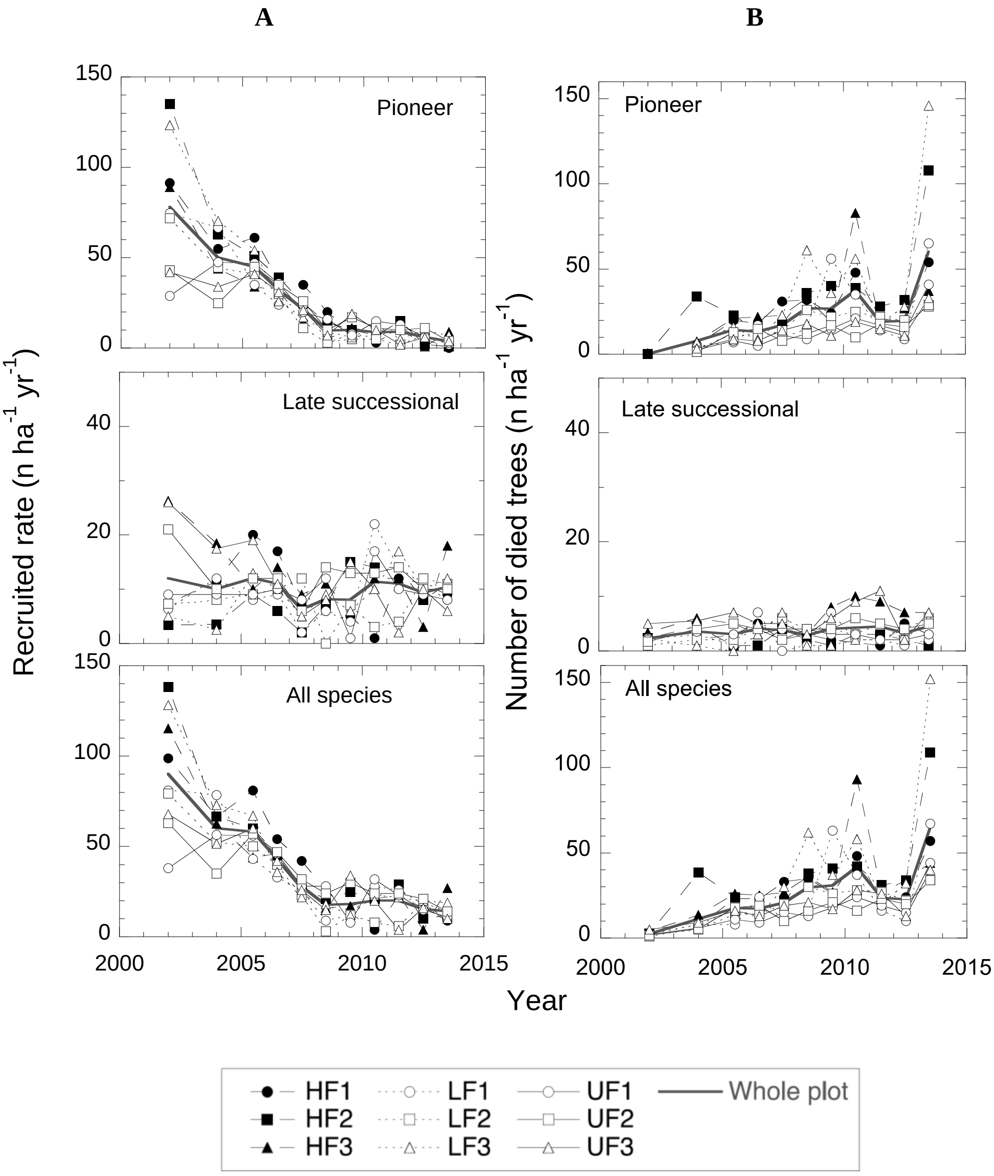

Figure 3. Number of (A) recruited and (B) died trees between enumeration (AGB) in the 9-ha plot. Tree census was not conducted in 2001, 2002, and 2004. Therefore, the number of recruited and died trees between 2000 and 2003 divided by 3 years and are shown at 2002. Values between 2003 and 2005 were obtained by the number of trees recruited and died between 2003 and 2005 divided by 2 years, and then shown at 2004. Note the variation in Y scale.

Changes in AGB after 2000

The AGB in the 9-ha plot was 96 Mg ha^{-1} in 2000, which increased to 140 Mg ha^{-1} in 2014 (Figure 2.B, lower panel). In 2008, 22.5% of AGB was composed of trees of pioneer species that established after the 1998 fires. The AGB of pioneer trees in the felled plots (LF and HF) was larger than the AGB of the UF plots. The significant difference in AGB between the felled (HF and LF) and UF plots continued to remain until 2014. In 2014, AGB values in the HF, LF, and UF plots were 98±24 Mg ha^{-1}, 101±8 Mg ha^{-1}, and 219±44 Mg ha^{-1}, respectively. Even the number of pioneer trees decreased drastically, while the ratio of pioneer trees to AGB did not change drastically. The AGB of pioneer trees in the 9-ha plot increased from 2000 to 2013 and then decreased from 2013 to 2014, when a large number of pioneer trees died (Figure 2, upper panels). Although AGB of the whole 9-ha plot maintained an increasing trend from 2000 to 2013, AGB of the 1-ha subplot decreased occasionally at various time points (Figure 2.B, lower panel). There was no clear time trend observed in AGB changes of late successional trees. As observed in subplots UF3 in 2009 and 2011, UF2 in 2010, and LF3 in 2012, there was a huge loss in AGB of late successional trees at specific subplots at specific timings that resulted in the fluctuation in AGB loss of the subplots (Figure 4.B).

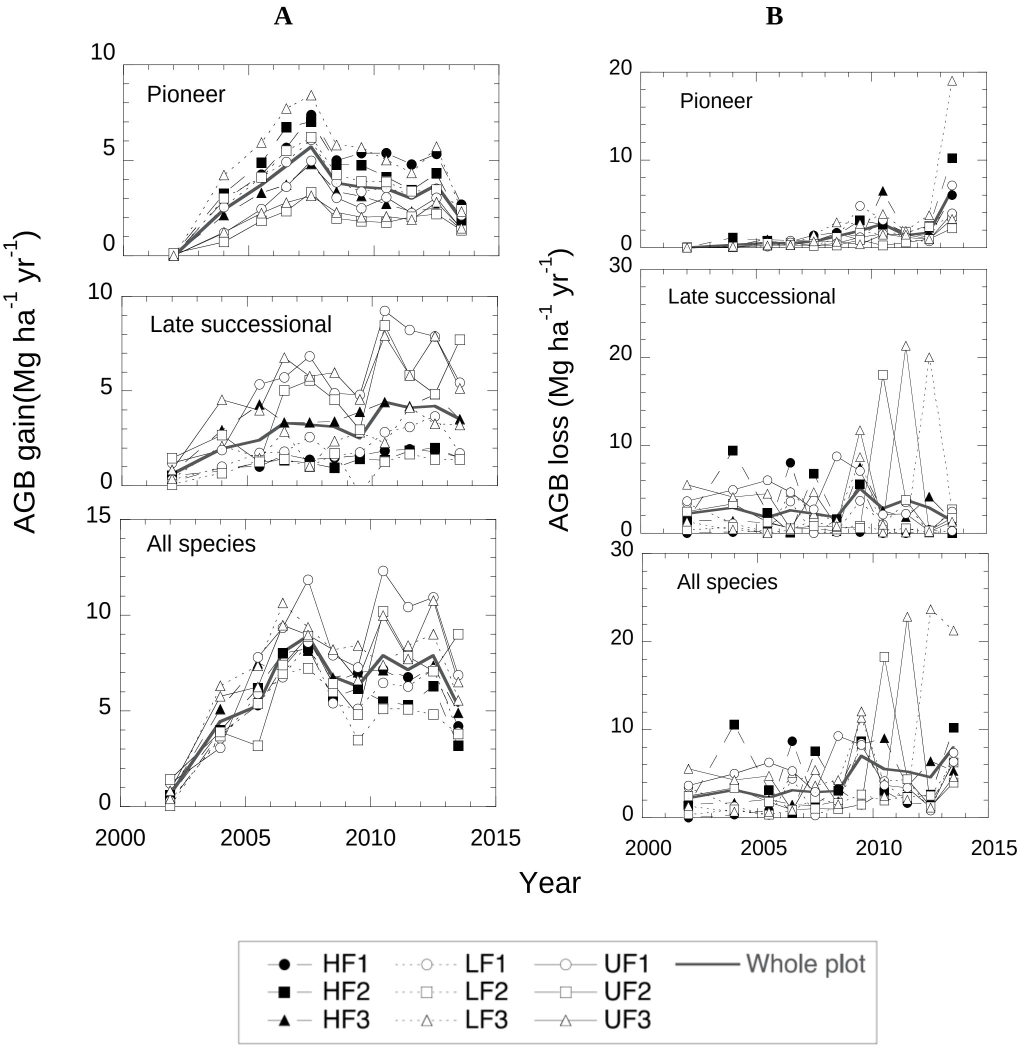

Figure 4. Rate of (A) AGB gain by diameter growth and (B) AGB loss by died trees between enumeration in the 9-ha plot. Tree census was not conducted in 2001, 2002, and 2004. Therefore, the mass of recruited and died trees between 2000 and 2003 divided by 3 years and are shown at 2002. Values between 2003 and 2005 were obtained by the mass of trees recruited and died between 2003 and 2005 divided by 2 years and then shown at 2004.

AGB gain rate of all species was the lowest between 2000 and 2003 (Figure 4.A). The rate increased to the highest value in 2009 and then tended to decrease afterward with fluctuations between plots and measurement period. AGB gain rates of pioneer trees synchronized between subplots and increased from 2000 to 2008 and then started to decrease (Figure 4.A, upper panel). AGB gain rate was higher in the felled plots (LF and HF) than in the UF plots, because the density of pioneer trees in the felled plots was much higher than that in the UF plots (Figure 2.A, upper panel). AGB gain rate of late successional trees showed an increasing trend, but it was not obvious compared to the pioneer trees during the earlier period of monitoring (Figure 4.A). AGB gain rates of late successional trees were higher in the UF plots than in the LF and HF plots, because of the larger number of late successional trees in the UFplots (Figure 2.A, middle panel).

Size distribution of trees

Figure 5 shows the number of trees (left) and AGB (right) of the 9-ha plot in 2014, according to DBH classes. Regarding the number of trees, small-sized pioneer trees dominated the plot. On the contrary, lesser number of large-sized late successional trees dominated the plot in terms of AGB.

Figure 6 shows the number of died trees (left) and their AGB (right) in the 9-ha plot from 2000 to 2014. Over time, the contribution of pioneer species to the number of died trees increased and it became higher than that of late successional tree species. On the other hand, the contribution of primary species to AGB of died trees had been much higher than that of pioneer species until 2013. Because a lot of pioneer trees died in 2014, the contribution of pioneer trees to AGB loss by died trees became larger than that of late successional trees. However, small-sized trees of pioneer species contributed to the number of died

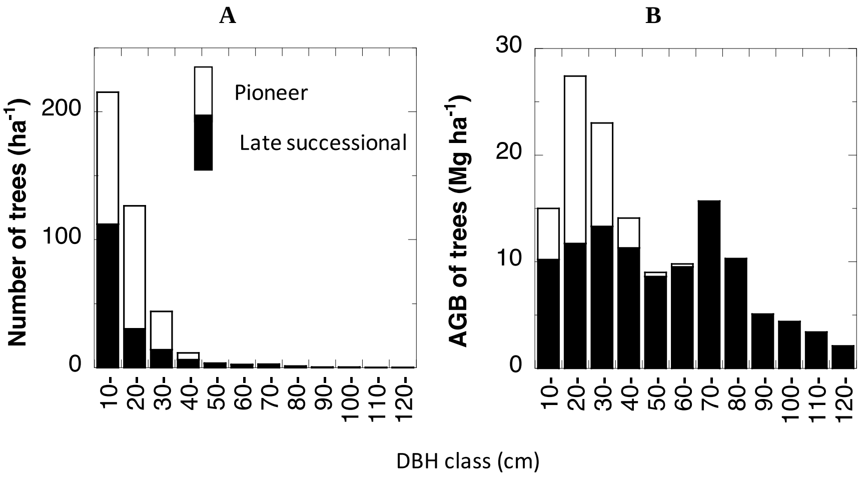

Figure 5. Distribution of trees in the 9-ha plot according to DBH class in 2014. A. Tree density, B. Aboveground biomass (AGB).

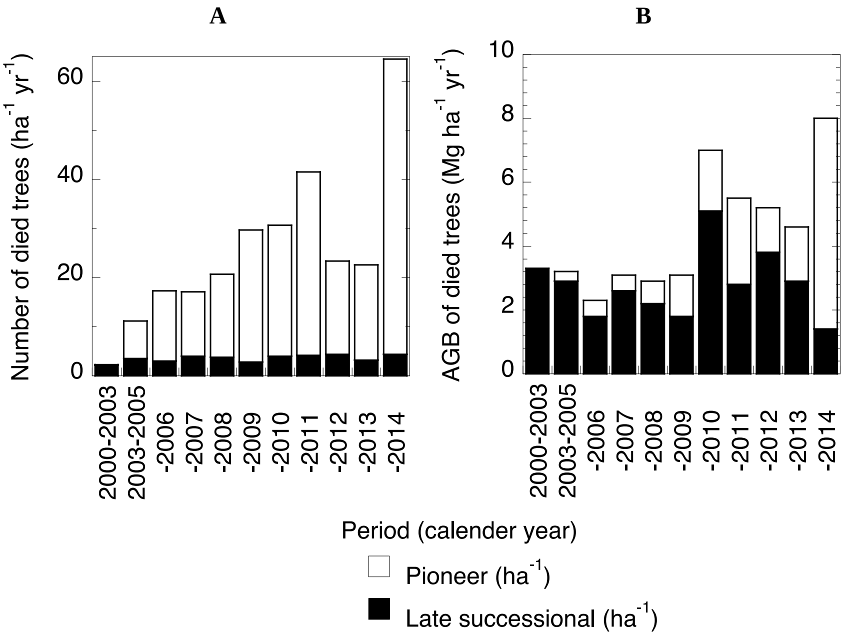

Figure 6. Number and AGB of died trees in the 9-ha plot between 2000 and 2014. A. Tree density, B. Aboveground biomass (AGB). Tree census was not conducted in 2001, 2002, and 2004. Therefore, the number of recruited and died trees between 2000 and 2003 divided by 3 years, and values between 2003 and 2005 were obtained by the number of trees recruited and died between 2003 and 2005 divided by 2 years. Note the variation in Y scale

trees. On the contrary, lesser number of large-sized trees of primary species contributed to AGB loss by died trees.

Discussion

Long-lasting effects of logging

Results of our monitoring show that the logged and burned forest is undergoing a recovering process after the recurrent logging and fires. However, the impacts of the disturbances on the forests are still manifest on AGB in the logged stands. The differences in AGB in the felled (HF and LF) and UF plots induced by the experimental felling sustained even after the fire disturbance and then continued to remain until 16 years after the fires.

AGB of large trees

Although AGB of the 9-ha plot has been increasing since 2000 at the whole-plot level, some subplots showed AGB depletion at specific timings. Sporadic death of large-sized trees resulted in AGB loss at the 1-ha subplot level. It is well known that a small number of large-sized trees contain a large share of AGB and its dynamics in tropical forests (Bastin et al. 2015, Slik et al. 2013). As experimental felling removed the large-sized trees from the felled (HF and LF) plots, the dynamics of AGB in the felled plots should have changed from those in the UF plots. In fact, Osone et al. (2016) found that coarse wood debris (CWD) stocks in the HF and LF plots were 50%-60%

lower than those in the UF plots. In 2012, there were few large-diameter CWD pieces in the HF and LF plots, whereas there were large standing dead and uprooted trees in the UF plots (Osone et al. 2016). Due to the persistence of these large died trees of late successional species in the forest as CWD stocks for a longterm (Osone et al. 2016), the loss of AGB does not result in a rapid decrease in the carbon stock of the forest.

Pioneer trees

Tree density that was decreased by felling and fires recovered rapidly by the recruitment of pioneer trees. Although pioneer trees increased their AGB at a rapid rate, maximum AGB stock of pioneer trees was much smaller than those of late successional trees. Successional species change from pioneer to late successional trees is needed to accumulate AGB comparable to that of original forests in the region (Toma et al. 2005).

Hiratsuka et al. (2006) reported that very short-lived pioneer trees that had dominated the severely burned sites in BSREF disappeared within some years after the 1998 fires and were replaced with pioneer species. Warsudi (2012) reported that tree density of pioneer trees in the 9-ha plot started to decrease in 2008 but depletion of biomass of pioneer stands kept increased until 2010. We have been observing a transitional change from pioneer species to late successional trees after around 10 years after the fires. As late successional tree species grow longer and larger than the pioneer trees, the logged and burned stands have a potential to recover their biomass comparable to that before the disturbances. The logged and burned dipterocarp forests can sequestrate carbon and act as carbon stock, if we save them from further disturbances in the longterm.

Variation by time and space

We observed a general trend of tree density and AGB in the entire 9-ha plot. At the same time, we observed variations among plots even under the same felling treatment. These variations may be due to topographic variation and also past disturbance intensities induced by selective logging before 1979 and the fires in 1982-83. A generalized conclusion could not be drawn from the 9-ha plot because the range of disturbance magnitude and the frequency were too large.

In this study, we describe the time trends in tree density and AGB in a logged and burned forest at the 1-ha subplot level. As death of trees due to logging and fires was sporadic, spatial variation of tree density and AGB existed in the subplots. For instance, even in the felled plots (LF and UF), large late successional trees remained at specific sites. On the other hand, patches without surviving trees were observed in the UF plots in 2000. To understand the recovering process after logging and fires, it may be useful to group the stands based on the disturbance intensities or surviving trees and then analyze the changes among the groups. Results of such an analysis as well as changes in tree species composition in the 9-ha plot will be reported in succeeding papers.

The number of recruited trees was higher in the felled plots where trees that survived the experimental felling and fires were scarce. The impact of experimental felling was not even within the felled plots. There were areas with direct impacts of felling and other areas without the impacts. Mortality induced by the 1998 fires also varied within a subplot. As BSREF had been logged selectively in 1978 and was affected by the 1982-83 and 1997-98 fires, the 9-ha plot is not free from past disturbance history and exhibited large special variations in tree density and AGB at a smaller scale. The recovering process may be described clearly by analyzing smaller areas in accordance with trees that survived the past disturbances.

In conclusion, a recent study using satellite imagery showed that the majority of all forests in lowland Kutai have disappeared in the last 40 years (Gaveau et al. 2016). BSREF is one of the remnant forests in the deforested area. Although AGB of BSREF is smaller than AGB of original forests because of logging and fires, the forest is undergoing a recovering process. Long-term monitoring of forest recovery in the 9-ha plot will provide a scientific base for managing, conserving, and restoring logged and burned forests in the region.

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