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High stocks of coarse woody debris in a tropical rainforest, East Kalimantan: Coupled impact of forest fires and selective logging

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ABSTRACT

Forest fires coupled with logging have now become one of the most extensive causes of forest degradation, affecting the balance between carbon emissions and sequestration in lowland tropical forests in Southeast Asia. Being transient pools of disturbance-killed trees, coarse woody debris (CWD) stocks play a key role in the carbon budget of such disturbed forests. Here, we investigated for the first time how logging affects the CWD input during and following a fire and, consequently, post-fire CWD stocks. Measurements were made at a permanent site in Bukit Soeharto Education Forest (BSEF) in East Kalimantan, Indonesia. This site consisted of plots that had been subjected to three different logging intensities (HF: heavily felled, trees with diameter at breast height (DBH) $\geqslant$30 cm were felled; LF: lightly felled, trees with DBH $\geqslant$50 cm were felled; UF: unfelled), all of which were burned by a fire that occurred during a drought associated with the El Niño Southern Oscillation in 1998, shortly after logging. CWD mass were measured in 2012, following 14 years of monitoring the CWD inputs. The average CWD mass across the three logging treatments was 89 Mg ha^{-1}, which is higher than the reported values for undisturbed forests but within the recorded range for recently disturbed forests. The amount of CWD inputs due to tree death during the fire was similar among the three treatments. However, there was a large difference in the CWD input in the post-fire period. In UF plots, large CWD inputs lasted for 2 years following the fire due to delayed tree death, whereas in HF and LF plots, where the above-ground biomass had greatly reduced by selective logging, no further large CWD inputs occurred after the fire. Consequently, the CWD stocks in the HF and LF plots were 50–60% lower than those in the UF plots. A simulation predicted that these CWD inputs during and shortly after the fire still constitute a large proportion of the CWD stocks in 2012, suggesting that the CWD pool is a rather durable carbon store in BSEF. In the HF and LF plots, there was few large diameter CWD pieces, reflecting the selective logging of large diameter trees, whereas, in the UF plots, there were large standing dead and uprooted trees. Since the larger diameter CWD pieces are persist in the forest for a longer time continuing to store carbon and to provide habitats for diverse wild life, selective logging could have large impacts on forest ecology and function not only by decreasing the total CWD inputs and stocks but also by decreasing the large diameter CWD pieces.

1. Introduction

Coarse woody debris (CWD) is an important component of carbon storage in tropical forests (Chambers et al., 2000; Rice et al., 2004; Palace et al., 2012). In undisturbed moist forests, it may account for approximately 10% of the total carbon storage (Pregitzer and Euskirchen, 2004) and can constitute up to 33% of the forests' above-ground biomass (AGB) (Baker et al., 2007). A disturbance event usually causes large changes in CWD stocks and fluxes. Increased mortality due to disturbance promotes carbon flux from the living mass to the CWD pool (Rice et al., 2004), and the subsequent decomposition of the dead trees increases total carbon emission of the stand. Therefore, quantifying the stocks and fluxes of CWD helps our understanding of the carbon balance of the disturbed forests.

Undisturbed tropical rainforests are generally highly resistant to fires because of the moist microclimate and low fuel loads that create low-flammability conditions (Kauffman et al., 1988; Cochrane and Schulze, 1999). However, recent changes in land use, increased human activity, and drought associated with the El Niño Southern Oscillation (ENSO) have increased the probability of

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catastrophic fires occurring in rainforest regions (Woods, 1989; Cochrane, 2003; Barlow and Peres, 2004; Peres et al., 2006; Toma et al., 2005; Brando et al., 2014). For instance, approximately 6 million hectares of forested land were burned during two ENSO events (1982–1983 and 1997–1998) in East Kalimantan (Malingreau et al., 1985; Siegert et al., 2001). Studies suggested that CWD stocks are generally high in the forest known to be affected by fire (Harmon et al., 1986; Cochrane and Schulze, 1999; Gerwing, 2002). However, most of these studies did not measure tree mortality and carbon flows to the CWD pool during the fire; therefore, links between forest burning and CWD stocks remain unclear. Furthermore, fire does not always kill forest trees immediately but could cause delayed death that lasts several years after the fire (Van Nieuwstadt and Sheil, 2005). Therefore, to accurately evaluate the effects of fire on the CWD pool, CWD inputs need to be monitored for several years during and following the fire.

Selective logging, a common land-use change process in tropical regions (Lambin et al., 2003), may increase the susceptibility of forests to fire. Logging facilitates the spread of the fire probably by disrupting the canopy cover, thereby producing warmer and drier conditions on the forest floor (Uhl and Kauffman, 1990; Cochrane and Schulze, 1999; Siegert et al., 2001), and by providing large quantities of fuel in the form of logging debris (Pereira et al., 2002; Palace et al., 2007, 2008; Saner et al., 2012). In tropical forests, deforestation and forest degradation often begin with one or more logging episodes followed by burning (Cochrane and Schulze, 1999). However, information on the quantity and dynamics of CWD in logged and burned forests remains sparse, although individual effects of fire or logging on CWD stocks have been well documented (Harmon et al., 1986; Cochrane and Schulze, 1999; Gerwing, 2002; Pereira et al., 2002; Palace et al., 2007, 2008; Saner et al., 2012).

Here, we investigated the combined effects of fire and logging intensity on CWD stocks in Bukit Soeharto Education Forest (BSEF), East Kalimantan, which is a forest known to have experienced large forest fires in the past (Toma et al., 2000b, 2005). In October 1997, our research group established nine 1-ha plots in areas that had been subjected to three different logging intensities [heavily felled (HF), lightly felled (LF), and unfelled (UF)], with the original aim of investigating how logging affects the forest structure and species composition (Ruslim et al., 2000). However, during February–April 1998, a large forest fire burned the entire area, including our study site. Taking advantage of this, we began to monitor the regeneration process of the burned forests, logged and unlogged, at this site. After monitoring tree death (≈CWD input) for 14 years, we measured CWD stocks in 2012, with the aim of answering the following questions:

1. How large is the CWD stock in a logged and burned lowland tropical forest?
2. How does pre-fire logging affect 14 years of CWD inputs, CWD stocks, and CWD quality (size and form)?
3. Which period of tree mortality (i.e., during vs. after the fire) contributed to the CWD stock of 2012?

To answer the third question, we performed a simulation predicting how much each of the annual CWD inputs from the year of the fire to the year 2012 contributed to CWD stocks in 2012.

2. Materials and methods

2.1. Study site

The study site was located in BSEF of Mulawarman University, which is situated in the lowland and coastal part of East Kalimantan (Borneo), Indonesia (Fig. 1, 0°52′S, 117°01′E, 10–100 m above sea level). BSEF was originally covered with lowland dipterocarp forest but has been subjected to human and natural disturbances for several decades. This forest was selectively logged for dipterocarp trees by timber companies and local people until the area was designated

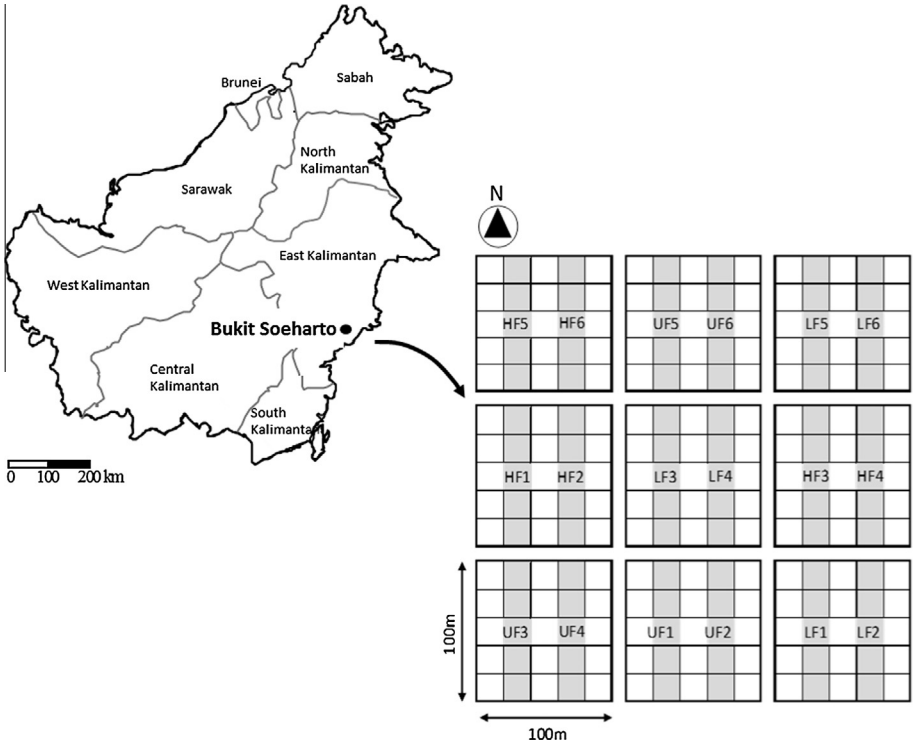

Fig. 1. Location and layout of study sites. HF, LF and UF represents heavily felled, lightly felled and unfelled plots, respectively. Shaded areas show 20 m × 100 m strips for CWD mass measurements. The numbers after HF, LF and UF represent replicates.