Forest Ecology and Management 314 (2014) 1–8

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Estimation of fuel mass and its loss during a forest fire in peat swamp forests of Central Kalimantan, Indonesia

Jumpei Toriyama [a,*], Tomoaki Takahashi [b], Sen Nishimura [a,c], Tamotsu Sato [a], Yukako Monda [a], Hideki Saito [a], Yoshio Awaya [d], Suwido H. Limin [e], Agung R. Susanto [e], Fetria Darma [e], Krisyoyo [e], Yoshiyuki Kiyono [a]

[a] Bureau of Climate Change, Forestry and Forest Products Research Institute (FFPRI), 1 Matsunosato, Tsukuba, Ibaraki 305-8687, Japan
[b] Kyushu Research Center, FFPRI, Kurokami, Kumamoto, Kumamoto 860-0862, Japan
[c] Matsushiro, Tsukuba, Ibaraki 305-0035, Japan
[d] River Basin Research Center, Gifu University, Yanagito, Gifu, Gifu 501-1193, Japan
[e] Center for International Cooperation in Sustainable Management of Tropical Peatland, University of Palangka Raya, Palangka Raya, Central Kalimantan 73111, Indonesia

A R T I C L E I N F O

Article history:
Received 11 June 2013
Received in revised form 11 October 2013
Accepted 26 November 2013
Available online 15 December 2013

Keywords:
Peat swamp forest
Forest fire
Fuel mass
Tree biomass
Deadwood

A B S T R A C T

Tropical swamp forests growing on peatlands are exposed to various risks of deforestation. To assess the greenhouse gases (GHG) emission from the deforested tropical peatlands, the amount of carbon released during a forest fire needs to be accounted for. The establishment of a fuel mass data set based on a field-based approach is essential to reduce the uncertainty in estimating GHG emissions during forest fires. We estimated the fuel mass (both living and deadwood) in tropical peat swamp forests and its loss during the fire event in 2009 in Central Kalimantan, Indonesia. We also examined the relationship between the forest structure and the burning process by comparing the distribution of stem diameter in burnt and unburnt areas using a fallen wood simulation. We selected two types of peat swamp forests, mature forest and regenerated forest following a fire in 1997/98, and their neighboring burnt areas. The mean fuel mass values in mature and regenerated forest were 319.7 and 131.5 Mg ha^{-1}, respectively. In burnt areas of mature and regenerated forest, the mean fuel mass values were 235.8 and 89.0 Mg ha^{-1}, respectively, which corresponded to 73.8% and 67.7% of the values of unburnt areas, respectively. The fuel mass in burnt area comprised mainly solid deadwood. Due to the large amount of deadwood left on the ground, the estimated GHG emissions after the forest fire were larger than those during the forest fire in both forest types. The regenerated forest, which was dominated by small trees and contained a small stock of deadwood, was considered to produce a large amount of solid deadwood during the forest fire. In contrast, the mature forest, which contained many large standing trees and large amounts of deadwood, experienced a high-intensity fire over a long duration time, resulting in surface or deeply burnt deadwood. The development of a simple method to tally the surviving large trees in the burnt area (i.e., designing a study plot with a nested structure for different-sized trees) might reduce uncertainties in the estimation of fuel mass and GHG emissions in future forest fires.

1. Introduction

Tropical swamp forests growing on peatlands are exposed to various risks of deforestation (Murdiyarso et al., 2010; Page et al., 2009a). Tropical peatlands cover an estimated 27 million ha in Southeast Asia, being distributed in the Malaysia and Indonesian lowlands, especially in Kalimantan, Sumatra, West Papua, and Malay Peninsula, of which over 12 million ha had been deforested and mostly drained by 2006 (Hooijer et al., 2010; Rieley et al., 1996). Once drainage canals are dug in tropical peatland, in case the canals are devoid of the control function of groundwater levels, the risk of forest fire increases and uncontrolled forest fires occur, associated with El Niño events (Langner and Siegert, 2009; Wooster et al., 2012; Wösten et al., 2006; Yulianti et al., 2012). These forest fires cause the loss of carbon stored in tropical peatlands. For example, an estimated 0.81–2.57 Pg of carbon was released into the atmosphere in 1997 by peatland fires in Indonesia alone, which was equivalent to 13–40% of the mean annual global carbon emissions from fossil fuels (Page et al., 2002). The subsequent forest fires also damaged the tropical peat swamp forests (Takakai et al., 2006; Usup et al., 2004; Yulianti et al., 2012). Accordingly, to assess greenhouse gases (GHG) emission from the deforested tropical peatlands, the amount of carbon released during the forest fire needs to be taken into account (Langner and Siegert, 2009; Page et al., 2009a).

* Corresponding author. Tel.: +81 29 829 8330; fax: +81 29 874 3720.
E-mail address: jtori@affrc.go.jp (J. Toriyama).

0378-1127/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.foreco.2013.11.034

There is an increasing need to develop a monitoring system for the emission and removal of GHG in tropical peat swamp forests to meet the needs of international frameworks such as Reducing Emissions from Deforestation and forest Degradation (REDD; Hirata et al., 2012). When considering the feasibility of a monitoring system, a simple formula has been suggested to estimate the amount of carbon released during a forest fire (GOFC-GOLD, 2012; IPCC, 2006; Levine, 1999),

$$L_{\text{fire}} = A \times M_{\text{FL}} \times C_{\text{f}} \times G_{\text{ef}} \times 10^{-3}, \tag{1}$$

where L_{fire} is the GHG emission from the fire (the total of each GHG, e.g., CH_4, N_2O); A is the burnt area (ha); M_{FL} is the fuel mass (Mg ha^{-1}) available for combustion and includes biomass, necromass, and peat, C_{f} is a combustion factor (dimensionless); and G_{ef} is an emission factor (g kg^{-1}). The burnt area and emission factor can be estimated by remote sensing techniques (Hirata et al., 2012; Langner and Siegert, 2009; Langner et al., 2007; Yulianti et al., 2012) and a combustion test (Akagi et al., 2011), respectively. To reduce the uncertainty of the GHG emission from the fire in a tropical peat swamp forest, the establishment of a fuel mass and combustion factor data set based on a field-based approach is essential because the existing data set is mainly based on slash-and-burn studies in tropical forests (Akagi et al., 2011; IPCC, 2006). As noted in a previous study, the contribution of peat to fuel mass is high compared to living and deadwood (Murdiyarso et al., 2010). However, the monitoring of forest biomass remains a key issue from a perspective of environmental safeguards (i.e., the conservation of biodiversity; Chokkalingam et al., 2009; Hirata et al., 2012; Shimamura and Momose, 2007). The amount of deadwood should also be monitored because it affects the intensity of future forest fires (Siegert et al., 2001) and the resprouting of some tree species (van Eijk and Leenman, 2004). For monitoring the mass of living and deadwood, stratified sampling of different forest types (i.e., primary and secondary forests) may be the best option to reduce the uncertainty of the GHG emission from the fire because the fuel mass, survival rate, and the burning process are affected by forest structure and tree-size distribution (Slik and Eichhorn, 2003; Uhl and Kauffman, 1990).

Our research group began investigations on the mass of living and deadwood in peat swamp forests in Central Kalimantan, Indonesia, in January 2009. However, in early 2009, an uncontrolled forest fire (Yulianti et al., 2012) burned the area surrounding our study plots. We used the opportunity to conduct an additional investigation of the fuel mass in the burnt area and the combustion factor shortly after the forest fire. The objective of the present study was to estimate the fuel mass (both living and deadwood) in a tropical peat swamp forest and its loss during the fire event in 2009, based on a comparison of burnt and unburnt areas. We also examined the relationship between the forest structure and the burning process in tropical peat swamp forest.

2. Materials and methods

2.1. Study site

The study area was located near Palangka Raya City in Central Kalimantan, Indonesia, extending 25 km east to west by 15 km north to south (2°16′2–2°22′4S, 113°52′0–114°04′9E). The mean precipitation in this area is 2331 mm year^{-1} with a dry season from June to October and a mean air temperature of 26.3 °C (2002–2005; Hirano et al., 2009). The study area contains both drained and relatively non-drained forested areas. The drained forested area is distributed between the Kahayan River and Sebangau River (Block C in the Mega Rice Project), where drainage canals were constructed in the mid-1990s. The relatively non-drained forested area is distributed west of the Sebangau River (Sebangau) though it is also affected by the hand-dug small canals for the log transport. The mean thickness of peat domes in Block C and Sebangau are estimated to be 3.65 and 5.40 m, respectively (Jaenicke et al., 2008). The peat swamp forest occupied 59.6% of Block C in 1973, gradually decreased to 42.7% by 1997, and dropped to 16.2% in 2000 because of an uncontrolled forest fire in 1997/98 (Page et al., 2002, 2009b). In addition, further forest fires in 2002, 2004, and 2006 also damaged the peat swamp forest in Block C (Takakai et al., 2006; Usup et al., 2004; Yulianti et al., 2012). The increase in fire experience raises the ratio of *Combretocarpus rotundatus* and the coverage of ferns in post-fire vegetation succession in this area (Page et al., 2009b). The mean monthly depth of the groundwater table in the drained forested area is less than 40 cm and it drops to nearly 100 cm during the El Niño years (Usup et al., 2004). In Sebangau, the forested area was zoned as production forest, and it was managed and logged under logging concessions from 1976 to 1997, followed by the illegal logging, though most disturbance has ceased at present (Page et al., 2009b).

We established plots in two different types of peat swamp forest based on their fire history. Mature forest, having no experience of forest fire, was distributed in both drained and non-drained forested areas. The condition of mature forest was influenced by selective logging, but it remained as a valuable forest resource for local people and provides wildlife habitats. Though "the logged over and partly drained mature forest" is more appropriate to describe the forest type, we use the term "mature forest" only in this paper. Regenerated forest was distributed only in the drained area and was burned in 1997/98. As with the mature forest, regenerated forest might be degraded by the local use before 1997, because it was in a readily accessible location due to the road system. In regenerated forest, fire resistant tree species such as *C. rotundatus* and *Cratoxylum arborescens* were frequently observed (Page et al., 2009b; Saito et al., 2005; Yulianto and Hirakawa, 2006). The "unburnt forest" in the mature and regenerated forest zones was located next to the "burnt area", which originated from the forest fire in early 2009. The burnt area was generally distributed on the edges of the unburnt forest (see supplemental file for more information on land cover; USGS, 2013). Considering the number of hotspots of forest fire (Yulianti et al., 2012), the activity of 2009 forest fire was comparable to those in 2002, 2004 and 2006 in Central Kalimantan. During 2009 fire, the mean height of peat surface was measured in regenerated forest and showed a decrease of 20 cm (Kiyono, 2013). We estimated the loss of fuel during the 2009 fire from the difference in fuel mass between the burnt and unburnt areas.

2.2. Plot setting and tree census

We established study plots in unburnt forest, which were monitored from January to December 2009, and in the burnt area from November to December 2009. Eleven mature forest plots and 10 regenerated forest plots were established in unburnt forest zone, and three burnt mature forest plots and four burnt regenerated forest plots were established in the burnt area. Five mature forest plots were located in the non-drained area and the other six were located in the drained area. All of the unburnt regenerated forest and the burnt mature and regenerated forest plots were located in the drained area. All plots (except for burnt mature forest) were rectangular (30 m × 40 m; Fig. 1). Each plot contained 12 grids with an area of 100 m^2 and each grid contained four quadrats (5 m × 5 m; Fig. 1). Within each quadrat, the species and the diameter at breast height (D) of all living trees ($D \geqslant 5$ cm) were recorded. The size of standing deadwood was also recorded for the calculation of the mass of deadwood. For burnt mature forest, a belt transect plot (10 m × 100 m) was used because the piles of