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Factors affecting oxidative peat decomposition due to land use in tropical peat swamp forests in Indonesia

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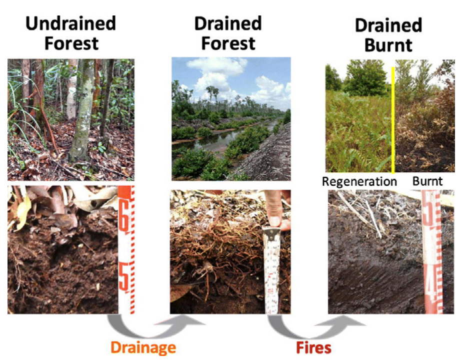
HIGHLIGHTS

- Change in oxidative peat decomposition (PD) was surveyed.
- Change was monitored as a function of drainage and fire.
- The groundwater level (GWL) explained PD and was used to predict the annual PD.
- Predicted annual PD was in drained forest > undrained forest and a drained, burned site.
- Change in peat conditions with drainage and fire resulted in different responses.

GRAPHICAL ABSTRACT



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ABSTRACT

The increasing frequency of fire due to drainage of tropical peatland has become a major environmental problem in Southeast Asia. To clarify the effects of changes in land use on carbon dioxide emissions, we measured oxidative peat decomposition (PD) at different stages of disturbance at three sites in Central Kalimantan, Indonesia: an undrained peat swamp forest (UF), a heavily drained peat swamp forest (DF), and a drained and burned ex-forest (DB).

PD exhibited seasonality, being less in the wet season and greater in the dry season. From February 2014 to December 2015, mean PD (±SE) were 1.90 ± 0.19, 2.30 ± 0.33, and 1.97 ± 0.25 μmol m^{-2} s^{-1} at UF, DF, and DB, respectively. The groundwater level (GWL) was a major controlling factor of PD at all sites. At UF and DF, PD and GWL showed significant quadratic relationships. At DB, PD and GWL showed significant positive and negative relationships during the dry and wet seasons, respectively. Using these relationships, we estimated annual PD from GWL data for 2014 and 2015 as 698 and 745 g C m^{-2} yr^{-1} at UF (mean GWL: −0.23 and −0.39 m), 775 and 825 g C m^{-2} yr^{-1} at DF (−0.55 and −0.59 m), and 646 and 748 g C m^{-2} yr^{-1} at DB (−0.22 and −0.62 m), respectively. The annual PD was significantly higher in DF than in UF or DB, in both years. Despite the very dry conditions, the annual PD values at these sites were much lower than those reported for tropical peat at plantations (e.g., oil palm, rubber, and acacia). The differences in the relationship between PD and GWL indicate that separate estimations are required for each type of land. Moreover, our results suggest that PD can be enhanced by drainage both in forests and at burned sites.

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1. Introduction

Southeast Asia contains an abundance of peat, found as peat swamp forests (Page et al., 2004), which are distributed predominantly in Indonesia and Malaysia. Indonesia has the largest area of tropical peat in the world, over 2.48×10^5 km^2, accounting for about 56% of global tropical peatland area; Indonesia's peatland stores up to 68.5 Gt of soil carbon (C), or 77% of soil C in global tropical peatlands (Page et al., 2011). However, vulnerable peat swamp forest ecosystems have been devastated by extensive logging and land development involving deforestation and drainage since the 1970s (Sorensen, 1993). As a result, large areas of peat swamp forest have been converted into secondary forests, plantations, and abandoned open shrub and fern lands due to repeated peat fires. For example, the amount of open land has increased from 7% to 15% of total land area over the last two decades (Miettinen et al., 2012, 2016). Deforestation can raise soil temperatures (Sano et al., 2010), and drainage directly lowers the groundwater level (GWL). Land conversion with deforestation and drainage accelerates oxidative peat decomposition (PD), because of increases in temperature and aeration (Couwenberg et al., 2010; Hooijer et al., 2012). Extensive forest exploitation following peat drainage for agricultural expansion (e.g., the creation of oil palm and acacia plantations) can lead to catastrophic peat fires (Langner and Siegert, 2009; Yulianti et al., 2012). The frequency of fires may explain why the area of abandoned and unused peatland has increased threefold from 1.2 to 3.5 Mha since 1990, as landowners have given up on managing their land (Miettinen and Liew, 2010).

Conversion of peatland inevitably leads to aeration and consequent PD, resulting in substantial carbon dioxide (CO_2) emissions into the atmosphere (e.g., Melling et al., 2005; Couwenberg et al., 2010, 2011; Hooijer et al., 2014; Hirano et al., 2014; Könönen et al., 2015). Annual C losses through peat drainage and fires are on average 28 times greater than pre-disturbance rates (Dommain et al., 2014). According to the Wetland Supplement (IPCC, 2014), default CO_2 emissions from tropical peatlands (i.e., emission factors [EFs]) range from 150 to 2000 g C m^{-2} y^{-1}, although this was determined using limited data from fewer than 50 peer-reviewed papers.

The 2006 Intergovernmental Panel on Climate Change Guidelines (IPCC, 2006) generally provides methods for the estimation of greenhouse gases at three levels of detail, from Tier 1 (the default method) to Tier 3 (the most detailed method). The IPCC offers accurate EFs, but deriving EFs from tropical peatlands is a scientific challenge. The Tier 3 approach is not yet feasible due to a lack of accurate data (Couwenberg and Hooijer, 2013); thus, more field data are required from various types of land use in tropical peatlands (Krisnawati et al., 2015). Therefore, this study included sites representing three types of land use, with different levels of disturbance (minimal, moderate, and intensive) due to drainage and repeated forest fires in an edaphically similar area.

Direct chamber measurements have been made to obtain accurate C loss data from tropical peatland (e.g., Couwenberg et al., 2010; Hooijer et al., 2010, 2012; Jauhiainen et al., 2012; Couwenberg and Hooijer, 2013). However, few studies have reported PD by heterotrophic respiration alone (Jauhiainen et al., 2012; Hirano et al., 2014), separate from peat total soil respiration (SR), including litter decomposition and root respiration (RR). RR may be responsible for various amounts of total SR, from <10% to 90%, so SR measurements alone are inadequate for determining CO_2 emissions from PD (Couwenberg et al., 2010). Few studies have directly measured PD using the chamber technique; these measurements have been taken for tropical peat in an acacia plantation (Jauhiainen et al., 2012), oil palm plantation (Dariah et al., 2014; Husnain et al., 2014), mixed forest (Melling et al., 2013), and drained and burned ex-forest (Hirano et al., 2014).

Therefore, we measured PD in three types of tropical peatlands using the closed-chamber method with trenching, to exclude root respiration (RR). Then, to understand how the environmental factors affects CO_2 fluxes, we compared the results from different types of land use under the same geophysical conditions. Wakhid et al. (2017) recently reported both PD and SR for compacted peat in a rubber plantation only 25 km from our observation sites, enabling us to compare our results with data from a plantation. Finally, seasonal variation and annual CO_2 emissions were estimated using empirical models.

2. Materials and methods

2.1. Study site

This study was conducted in tropical peatland at the upper Sebangau River Catchment, located about 20 km south of the city of Palangka Raya, Central Kalimantan province, Indonesia (Fig. 1). A large peatland

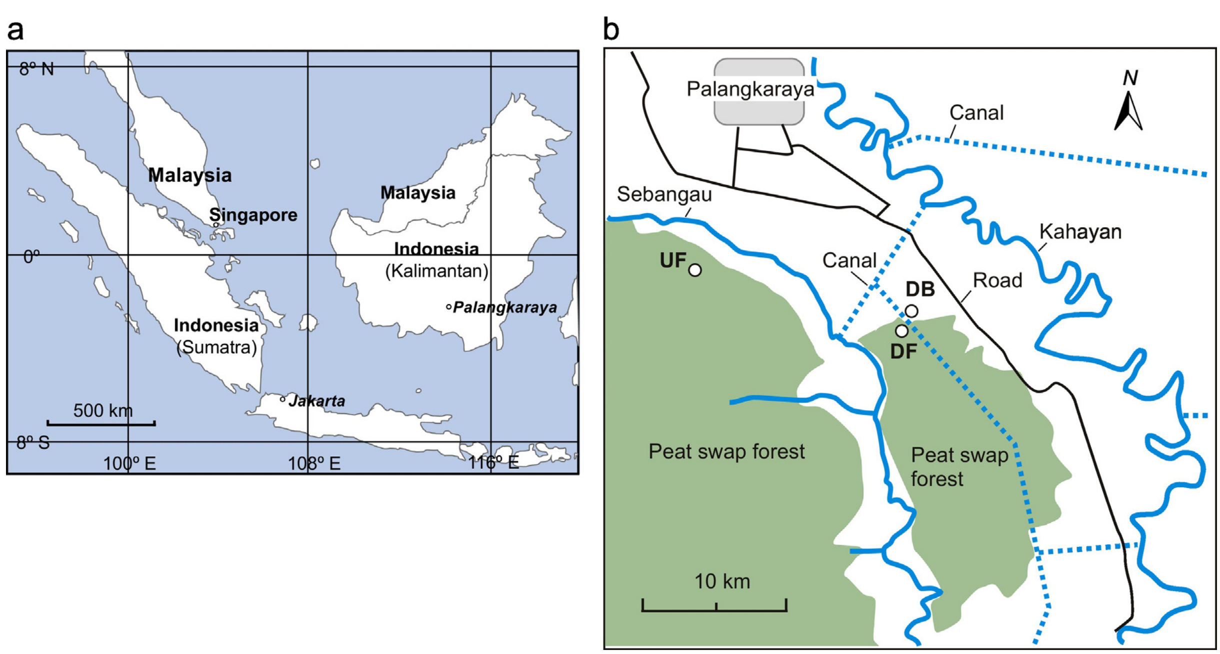

Fig. 1. Locations of Palangkaraya in Central Kalimantan, Indonesia and the research sites.