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CARBON BALANCE OF TROPICAL PEAT SWAMP FOREST

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SUMMARY

The features of the carbon balance of tropical peat swamp forest, such as seasonal variation, environmental controls and distrubance effects, are described based on long-term field monitoring of CO_2 flux at three tropical peat ecosystems with different disturbance degrees in Central Kalimantan, Indonesia.

Keywords: *Disturbance, ecosystem, groundwater level, photosynthesis, respiration*

INTRODUCTION

Tropical peat swamp forest (PSF) is a unique ecosystem rich in carbon and water, which is widely distributed in Southeast Asia's coastal lowlands, mainly in Indonesia and Malaysia. The ecosystem has accumulated a huge amount of organic carbon as peat soil over millennia under the condition of high groundwater level (GWL). However, the PSF has been degraded by logging and drainage, and many of PSFs were converted into oil palm and pulpwood plantations during the last two decades. Such human disturbances potentially increase carbon dioxide (CO_2) emissions to the atmosphere through enhanced oxidative peat decomposition and raised risk of peat fires. Moreover, PSF suffers from drought of El Niño-Southern Oscilation (ENSO) quasi-periodically. Therefore, PSF is recognized as a “hot spot” for vulnerable carbon pool in this century. It is essential to quantify the current carbon status of PSF to assess the role of PSF in the regional and global carbon balances. Thus, we have measured net ecosystem CO_2 exchange (NEE) between the atmosphere and PSF using the eddy covariance technique and soil CO_2 efflux (soil respiration: RS) using the chamber technique at three tropical peat ecosystems with different disturbance degrees (almost undrained PSF (UF), drained PSF (DF) and burnt ex-PSF (DB)) (Figure 1) in Central Kalimantan, Indonesia (Hirano et al., 2012) for more than 10 years. Based on the long-term field data from the three sites, the features of the carbon balance of PSF, such as seasonal variation, environmental controls and the effect of disturbance due to human activities and ENSO drought. Although the outflow of dissolved organic carbon (DOC) and methane (CH_4) should be considered for full carbon accounting (Hirano et al., 2009), here the focus is on two large CO_2 fluxes with opposite directions: gross primary production (GPP, ecosystem photosynthesis) and ecosystem respiration (RE). GPP and RE can be partitioned from NEE (= RE – GPP) using an empirical technique. Conventionally, NEE is positive when the ecosystem functions as a net CO_2 source, and vice versa.

a) b) c) d)

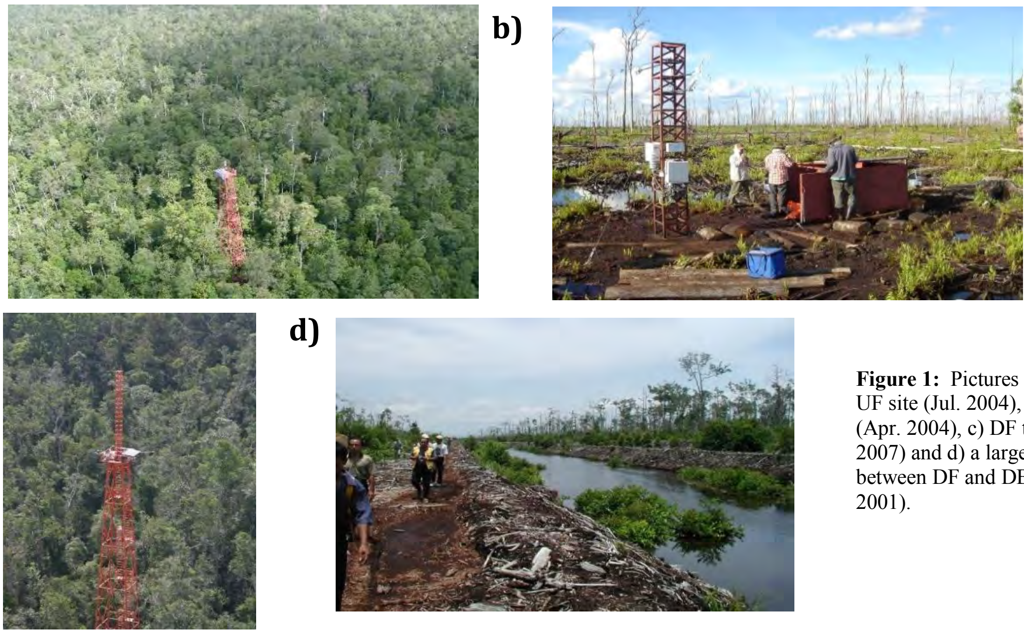

Figure 1: Pictures of study sites. a) UF site (Jul. 2004), b) DB site (Apr. 2004), c) DF tower (Oct. 2007) and d) a large canal running between DF and DB sites (Mar. 2001).

HYDROLOGICAL CONTROLS

The carbon balance is strongly affected by local hydrology. In particular, RE and RS are mainly governed by GWL. RE and RS decreased as GWL increased, but increased slightly at shallow GWL near the ground surface, and then decreased sharply if water level rose aboveground (Hirano *et al.,* 2012; Sundari *et al.,* 2012). Large RE and RS at low GWL were caused by the enhancement of oxidative peat decomposition through oxygen (O_2) supply to deeper peat (Hirano *et al.,* 2014). Increase in RE and RS at shallow GWL was attributable to the enhanced decomposition of leaf litter on the ground through wetting (Sundari *et al.,* 2012). Water-saturated peat by flooding suffered from anoxia, and consequently RS was strongly inhibited. Also, GPP was affected by GWL, though it was mainly governed by solar radiation. GPP showed a convex quadratic curve with GWL (Hirano *et al.,* 2012). GPP decrease at low GWL was chiefly due to lower surface conductance (G_s), which corresponds to stomatal opening of vegetation, because of water stress (Hirano *et al.,* 2015). The decrease was more distinct at DB site, where re-growth of fern plants with shallow root systems dominated the site after fire. In contrast, GPP decrease at high GWL was probably caused by slow nutrient mineralization and consequent slow plant nutrient uptake because of poor aeration in water-saturated peat (Mezbahuddin *et al.,* 2014). As a result, NEE increased sharply as GWL decreased, if GWL was lower than a threshold, at which GPP reached a peak on the quadratic curve. The GWL thresholds were -0.3, -0.7 and -0.3 m, respectively, at UF, DF and DB sites (Hirano *et al.,* 2012). The lower threshold at DF site than UF site suggests the adaptation of tree species to the low GWL environment over five years after canal excavation (Hirano *et al.,* 2015; Mezbahuddin *et al.,* 2016). Annual NEE showed a negative linear relationship with minimum monthly-mean GWL at forest sites (UF and DF) (Hirano *et al.,* 2016). In spite of different drainage conditions of the two sites, the relationships were combined into a single significant line ($r^2 = 0.82$). The linearity suggests that 10-cm drawdown of minimum monthly-mean GWL brings about further net annual CO_2 emissions (NEE) of about 50 gC m^{-2} y^{-1} from PSF. At DB site, although no significant relationship was found for NEE, a significant negative relationship of RS with GWL suggests that every 10-cm drawdown of GWL causes additional oxidative peat decomposition of about 90 gC m^{-2} y^{-1} on an annual basis (Hirano *et al.,* 2014).

DISTURBANCE EFFECTS

Recently, tropical PSF has been threatened by several kinds of disturbances due to logging, drainage, fire and ENSO drought. The conversion of PSF into plantations usually accompanies logging and drainage, and frequent fire for land clearing. In ENSO years, the dry season is prolonged, and consequently peat becomes dry to be easily ignited, especially in disturbed PSF with lower GWL. The resultant peat fire frequently becomes out of control and spreads. During large-scale fires, the ground is covered with dense smoke emitted through peat/biomass combustion, and solar radiation is attenuated, but the diffused fraction of solar radiation increases rapidly (Marpaung and Hirano, 2014).

Annual NEE was all positive at the three sites for four years (2004-2008); mean annual values were 174, 328 and 499 gC m^{-2} y^{-1}, respectively, at UF, DF and DB sites (Hirano *et al.,* 2012). Although no significant difference among the sites, net CO_2 emission (positive NEE) increased according to disturbance degrees (drainage and fire). Both annual GPP and RE were significantly larger at PSF sites (UF and DF sites) than DB site. The largest NEE at DB site was largely because of much lower GPP due to less vegetation after fire outbreak. On the other hand, mean annual evapotranspiration (ET) for the same four years was 1529, 1365 and 1197 mm y^{-1}, respectively, at UF, DF and DB sites (Hirano *et al.,* 2015). Annual ET was significantly lower at DB site similarly because of less vegetation (less transpiration). During ENSO drought, RE increased because GWL was lowered. Also, GPP decreased because of water stress and shading by dense smoke emitted from peat fire, whereas increase in diffused solar radiation and higher CO_2 concentration can compensate the shading effect to some extent (Hirano *et al.,* 2012). As a result, net CO_2 emissions increased in ENSO years, even if direct CO_2 emissions through peat combustion were not considered.

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