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Enhancing water levels of degraded, bare, tropical peatland in West Kalimantan, Indonesia: Impacts on CO_2 emission from soil respiration

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Abstract. *Astiani D, Burhanuddin, Gusmayanti E, Widiastuti T, Taherdjadeh M. 2018. Enhancing water levels of degraded, bare, tropical peatland in West Kalimantan, Indonesia: Impacts on CO_2 emission from soil respiration. Biodiversitas 19: 472-477.* The major drivers of deforestation in West Kalimantan have been the development for large or small-scale expansion of agricultural activities; the establishment of oil palm and other plantations; fire; and degradation of forests particularly from industrial logging. Our previous research findings have shown that such activities in affected peatland areas have lowered the water table levels (down to 0.5-1.0 m depths), and have significantly increased CO_2 emissions from the peat soils. It has been demonstrated that unmanaged, lowered water tables in peatlands act as one of the main factors inflating soil carbon emissions - an issue that has assumed global significance in recent decades. Regulating peatland water tables has the potential to mitigate degraded peatland carbon emissions as well as improve the hydrological functions for communities who farm the peatlands. However, we are still uncertain exactly how much impact controlled raising of the peatlands water tables will have on reducing soil CO_2 emissions. The research described here aimed to mitigate CO_2 emissions by raising and regulating water levels on drained peatland to restore and enhance its hydrological functions. The results confirmed that raising the water table significantly decreases CO_2 emissions and improves water availability and management for crop production in the coastal peatland of Kubu Raya district, West Kalimantan. Water levels previously at 60cm below the soil surface were regulated to raise the watertable up to just 30 cm below the surface and this reduced peatland carbon emissions by about 49%. However, longer-term monitoring is required to ensure that the hydrological benefits and CO_2 mitigation can be sustained.

Keywords: Carbon emission, climate change mitigation, peatland water restoration, water table

INTRODUCTION

It is predicted that rainfall patterns in the equatorial land of Indonesia will be shifted if the global climate change continue taking place (IPCC 2014; Li et al. 2007). Changes in precipitation patterns will have substantial influences on tropical forested peatland. because ecosystem processes such as net primary production is governed by rainfall patterns (Churkina and Running 1998; Knapp and Smith 2001) and efflux of carbon dioxide from the forest soil (Astiani et al. 2014; Davidson and Janssens 2006). Natural peatlands and peatland forests have soils characterized by persistent anaerobic conditions, in which decomposition proceeds much more slowly than in upland mineral soils where conditions promote decomposition resulting in relatively low carbon densities. These forests also has impact on water input to peatland lanscape (Astiani et al. 2017a; 2017b). However, when peatlands are subject to prolonged drought and to lowering of their water table, the pattern of their organic matter decomposition is altered. Previous research has indicated that water table levels influence carbon emission from bare peatland soil (Astiani et al. 2015; Astiani et al. 2016).

The tropical peatland of West Kalimantan (approximately 1.74 million hectares, in area) has an “Af” tropical climate, but irregular ENSO events have affected this region for many years. These ENSO years likely have impact on decreasing the lanscape water level of the ecosystem, and therefore affect surface water availability and soil carbon emissions in the peatlands. Studies by Bellisario et al. (1999), even though carried out on a small spatial scale, have shown that CO_2 exchange rates in peatland forests can be interpreted in terms of environmental and ecological variables; for example, changes in the frequency and intensity rainfall and drought events, leading to incresed or lowered water tables of a landscape, appear to have a significant impact on soil CO_2 fluxes, especially in tropical peatland.

The major drivers of deforestation in West Kalimantan Indonesian have been the small-scale expansion of agricultural activities; the conversion of forests into new agricultural land, and into oil palm and other plantations; fire; and the on-going degradation of forests particularly from industrial logging (Curran et al. 1999; Curran et al. 2004; Langer and Siegert 2009; Carlson et al. 2012, 2013). These activities in the region have decreased water table levels largely as a result of drainage ditches (0.5-1.0 m in depth) established within affected areas to promote growth of cultivated plants, but have also significantly increased CO_2 emissions from the peatlands (Astiani and Ripin 2016;

Astiani et al. 2014; 2015; 2016). It has been shown that unmanaged water tables in previously permanent peatland is one of the predominant factors inflating soil carbon emissions. Moreover, drained peatland is more susceptible to accidental fires, which have become one of the highest sources of carbon emissions to the atmosphere from this region.

Hydrological restoration of such degraded peatlands, by increasing and regulating the peatland water table, could be of significant benefit in reducing carbon losses into the atmosphere, while at the same time improving the hydrological functions of the lands. However, we are still uncertain exactly how much impact restoring the water table to higher levels would have on reducing carbon dioxide emissions into the atmosphere. The objective of the research project described in this paper was to mitigate peatland CO_2 emissions by increasing and regulating water table level through water-flow dams established to reduce water flow rate out of drainage ditches. The impact of this intervention on soil carbon emissions from the peatland was measured.

MATERIALS AND METHODS

Study sites

This study was conducted in coastal peatland in Kubu Raya District, West Kalimantan, Indonesia ($0^0$13' S and $109^0$26' E; ~ 4 m asl.), about 3 km from the northern perimeter of Kuala Dua. The peatland type is classified as ‘ombrotrophic’, meaning that it receives all of its water from rainfall. At the nearby Supadio Airport weather station in Pontianak (~8 km from the study site), daily rainfall and temperature measurements have been compiled for regional and long-term climatic records over the last 10 years.

Water level enhancement

The area of study was on land mostly 5-10 years post-burning (August 2007-2011). The peatlands had bean cleared of their forest cover, burned, and drained for 6-12 months before being planted with corn, cassava, pineapple, or being left and then invaded by *Imperata* grasslands or peatland fern. A recently burned parcel of land was added after wildfires in August 2011. These burned sites were affected by 3-4 m depth of canal establishment.

Water-flow dams were built in the drainage canals to slow down water flow along the canals. Dam types were built that are stable, and cost-and time-effective. The selected design was a two-wall dam, made from externally-harvested Jonger (*Ploiarum alternifolium*), with sand-filled bags and peat soil in between. The dams were slow down the current, with excess water channeled over the center of the dam to avoid too much water pressure accumulating during the rainy days, and to prevent erosion of the peat soil on either side of the dams. The dams were designed to approximately determine the landscape’s water table levels. Eight water-flow dams were built to produce water levels of 30, 40, 50, and 60cm below the peatland surface. Within one year of dam establishment, 2 water-flow dams had broken and needed to be repaired. The cause of the disruption was high intensity monthly rainfall in 2017.

Peatland soil properties

The peatland soil was sampled down on the site of the water table gradation to a depth of 1-meter. The samples were replicated three times systematically at each site, and each 1-meter core was composited. Soil samples were taken to laboratory to check for bulk density, pH, C, N, and P contents.

CO_2 emission monitoring after dam establishment

Peatland soil CO_2 respiration after dam establishment was assessed in the period February 2016 through to February 2017. The Soil CO_2 assessment was carried out using a Licor-8100, Automatic Soil CO_2 Respiration Measurement device. The Licor was attached to a chamber which was placed on a 20 cm-diameter-soil collar. Weekly assessments were done at each water level site (water levels at 30, 40, 50, and 60cm below the soil surface), each at 6 points of measurement which were permanently set up using 20cm-diameter-soil-collars made from PVC. The assessment was carried out at the minimum (6:00-8:00 am) and maximum (12:00-14:00 am) rates for daily respiration, and then the values were averaged to represent diurnal soil CO_2 respiration rates. The annual measurement result for 2016-2017 was a bit skewed, since there was no dry season occurrence during the period February 2016 to February 2017.

Landscape hydrological survey

After the establishment of the water-flow dams, intensive water table level assessment was carried out from March through to December 2016 to check the impact of the dams on the water table in the peatland of each dam site. For this purpose, 12 piezometers had been set up in the surrounds of the peatland study area. The piezometers were made from 4-inch-diameter PVC pipes, perforated along their length to allow horizontal water movement into and out of them. Water level was recorded weekly at the same time as soil respiration measurements were taken.

Data analysis

Overall data were presented as Means ± Standard Error (SE). Daily (CO_2-emission) respiration rates for each week were derived from the average of the minimum and maximum daily measurements taken one day each week. Monthly CO_2 respiration means were determined by calculating from the means ± SE of the weekly assessments.

RESULTS AND DISCUSSION

Peatland soil properties

One of the important properties measured was peat bulk density. Vertical distribution of soil bulk density within 20cm intervals down to a depth of 5.20 m is described in Figure 1.

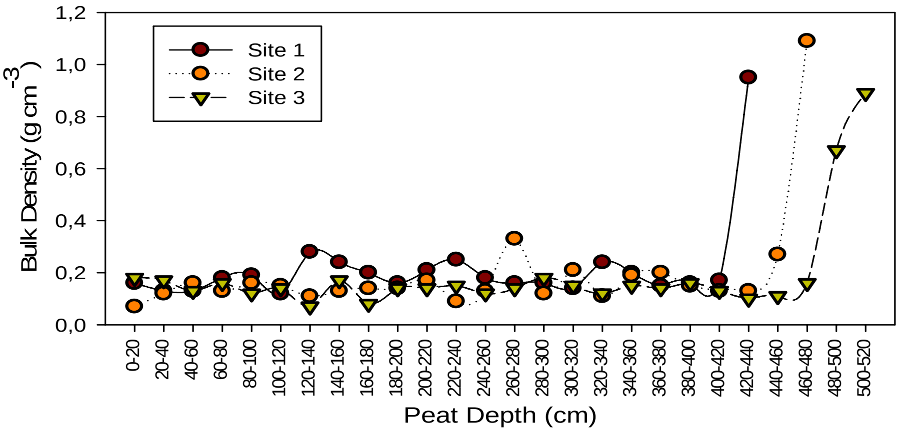

Figure 1. Distribution of peat bulk density in relation to vertical depth at three sampling locations in the peatland soil


A B C

Figure 2. A. A drainage ditch in peatland before, B. During, and C. after the establishment of the water flow-dam

The vertical distribution of peat bulk density values, down to a depth of 4 m, showed little variation (Fig 1). Most 20 cm layers had bulk density between 0.1 and 0.2 g cm^{-3} with just some samples at depths between 4m and 5.2 having values >0.2g cm^{-3}. This indicates that the soils of this this peat landscape can be classified between Fibrist and Hemist stages in the USA soil taxonomic system. The stage of peat decomposition has impacts on the rate of its carbon emissions.

Chemical properties of the peat soil determined within the landscape were available N and P (mean N= 1.88%, P=14.4 ppm). Carbon content was very high 51.5-54-5 % and pH very low (3.98-4.25). Macro nutrient availability was very low to low as a consequence of the soil high acidity.

Water flow Dams' Establishment and water level monitoring in peatland landscape

In January-February 2016, flow dams had been built to set various water levels on the peatland landscape. Four water level sites were set up; i.e 30, 40, 50, and 60 cm below soil surface, based on drainage ditches 5-6 m wide. To achieve this goal, a total of 750 sand and soil-filled bags were used to create the dams to establish the different water-level sites in the peatland The activities involved in constructing the flow dams are depicted in Figures 2.A, B, and C.

The water level in the waterflow dams had impacts on the water levels within the peatland landscape nearby. However, the water level that was set up in the dams represented the maximum level of water that could be reached during rain or for 3-4 days after rainfall events, except on unusual heavy rain days When rainfall input fills in the peatland landscape, the additional rain water fills up the ditches and consequently the flow increased in drainage ditches and then the water moved rapidly to a lower part of peatland landscape and then flowed out into nearby river until the water level as high as the dam set up.

Higher water levels in the drainage ditches subsequently caused water levels in the landscape to rise, approaching closer to the peat surface. When there was no rain for 1-2 weeks, the data assessments indicated that the water level fell significantly, by 5-15 cm below the levels that were set up. The water level assessment activities, piezzometer, and the distribution of peatland water levels in the landscape are depicted in Figure 3.A, B, and 4.

Figure 3. Piezometer measurement and set up in a peatland site impacted by an overflow dam

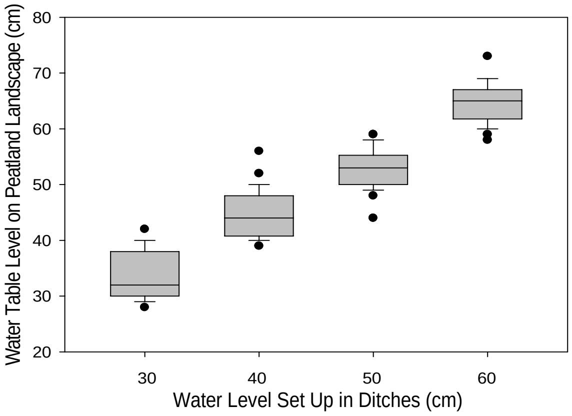

Figure 4. Weekly distribution of watar table level on peatland landscape of each canal water-table set up

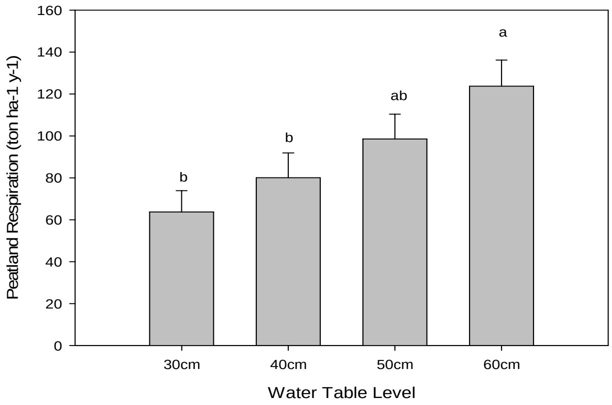

Figure 5. Mean annual peat respiration rate (tons CO_2 ha^{-1} yr^{-1}) on the peatland landscape in response to rise in the water table achieved by regulating the water level in flow dams on drainage ditches. Columns topped by the same letter ('a' and/or 'b'), do not differ significantly at the 5% level of probability.

Peat CO_2 respiration rates measured in the peatland landscape

After dam establishment, the measurement of peat CO_2 respiration was started as earliest as possible to capture data for the driest part of the year 2016, in order that the calculated annual CO_2 emission value would be representative of a full year's weather impacts. However, as it turned out, there were almost no dry months in this 2016 La Nina year. Thus our annual CO_2 respiration rate calculated for the year 2016 can be considered to be atypical of the value that might be obtained in a more 'normal' year.

The water table set up had a great influence on the peatland landscape CO_2 respiration rates. Results show that peat respiration significantly decreased when flow dams caused the water table to rise higher in the soil profile. The peatland respiration rates were 63.7 ± 10.2, 80.1 ± 11.8, 98.5 ± 11.9, and 123.7 ± 12.5 tonnes CO_2 ha^{-1} y^{-1} respectively for water table depths of 30, 40, 50, and 60cm below the soil surface (Figure 5). This demonstrated that when the water table is lowered to 60 cm below the soil surface due to canal construction on peatlands, the level of soil CO_2 respiration reaches levels twice that recorded in peatland in which the water table is restored to a depth of around 30 cm. The results indicate that when canals have alraedy been established on peatlands, it is possible to reduce the peat respiration rates by regulating the water table to rise closer to the soil surface. In this study, raising the water level in the flow dams from 60cm to 50, 40, and 30cm below the soil surface, decreased the soil CO_2 respiration by 20.4%, 35.2%, and 48.5% respectively.

Even though there was not a distinct dry season in the La Nina year of 2016, the lowest water level of 60cm or more below the surface could be considered as the approximate level for the water table in a typical dry season. This result suggests that a large-scale lowering of the water table levels during the dry season deepens the oxic layer of the peat, increasing exposure of the substrate available for decomposition, thus elevating the rates of respiration and CO_2 emission into the atmosphere. Water table level controls many biogeochemical processes in the peat (Limpens et al. 2008).

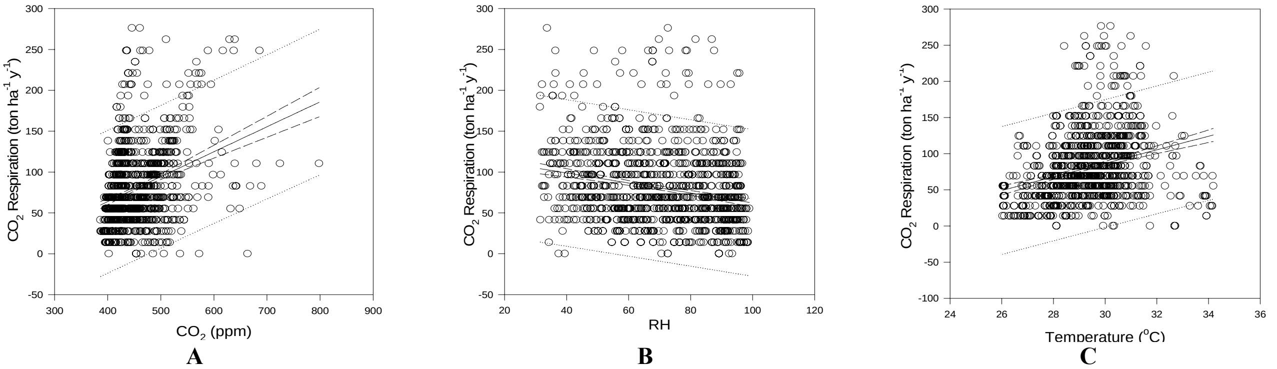

Figure 5. Regression analysis of peatland CO_2 respiration rates on site factors other than soil water level; namely: A. Surface carbon dioxide concentration; B. Relative Humidity; and C. Temperature. The Multiple Linear Regression of the four site factors is CO_2 Respiration =-108,469 + (0.353 * CO_2) - (0.691 * Soil RH) + (4.112 * Soil Temp) + (0.0787 * Water Level), N = 1236, Rsqr = 0,727, $p<0.001$

Other site factors that impact on peatland respiration (i.e. peat surface water, CO_2 concentration, temperature, relative humidity and water content within 0-15cm of peat depth) were investigated. Correlation data analysis shows that all site factors mentioned were correlated with soil respiration. However, further investigation with Multiple Linear Regression showed that CO_2 concentration, temperature and relative humidity could predict CO_2 respiration rates ($P < 0.05$). Regressions of respiration rate on each significant site factor (surface CO_2 concentration, relative humidity, and temperature) considered independently, are presented in Figure 5a, b, and c. The results are supported by other assessments (Bouwman 1990) that peat water level controls soil aeration which elevate the availability of oxygen to soil microorganisms that impacted on the dynamics of CO_2 fluxes on peatland. Inubushi et al. (2003) mentioned that in tropical peatland, soil respiration rates is impacted more by soil moisture than soil temperature, since soil temperature in the tropics is relatively not too much variation seasonally.

There was no dry season in 2016; thus we did not have an opportunity to compare the impact on water table levels and CO_2 respiration rates of differences between wet and dry seasons. However our results suggested that in practical terms variation in water table arising from seasonal effects will influence the magnitude of soil CO_2 respiration. It is important to treat peatland landscapes based on their water table levels. Increasing water table levels close to peatland surface reduced the CO_2 fluxes. Lengthening the period of assessment of CO_2 emissions beyond one year could confirm the results and strengthen future recommendations about how to manage peatlands hidrology to reduce soil CO_2 emissions.

However, regulated alteration of water levels in the peatland is likely also to have effects on the agricultural activities of local communities living in the landscape. Water table depth is important for plant growth; different plant species have root systems that can utilize water at varying depth. Following alterations in the the water level, it will be necessary to survey how these changes affect cultivated plants and their yield. Early findings of a survey of the community with agricultural land close to the experiment area suggest that a water table of 30-40cm below the surface is optimal for crop growth compared to a lower water level (>60cm). Another finding from the community is that crops grown on peatland in which the water level is close to the surface soil (10-20cm depth) retain a healthy condition due to sufficient availability of water.

In summary, it is critical to mitigate CO_2 emission from drained peatlands. However, rewetting and/or revegetating degraded peatland will not immediately reverse the effects of land-clearing and canal development that result in increased emissions (Ramchunder et al. 2009). It appears from our other preliminary results that in the second year of water table regulation, respiration levels have fluctuated less compared to the early stage following the establishment of the overflow dams. Longer-term monitoring of hydrological impacts and CO_2 emissions from water table regulation are required.

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