Peat lost by fire in Kalampangan area, Central Kalimantan, Indonesia

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Abstract. Fire is a major threat to the existence of peatlands because once drained, dry peat is flammable. In addition, tropical peat ecosystems, including their flora and fauna, are affected more severely by fire than by illegal logging. Fires in peatlands are mostly caused by human activities, such as opening canals for plantations and agricultural development. The peat soil becomes dry due to the lowering of the groundwater level, therefore it is very easy to burn. We recorded that the peat loss within the area of regrowing forest was reaching 44.2 cm deep on average, 32.1 cm within the opened and 53.9 cm within the degraded forest area. Loss of peat will also cause loss of carbon, about 337.9 tC/ha in the regrowing forest area, 240.0 tC/ha in open area and 382.6 tC/ha in the degraded forest area.

1. Introduction
Fires are a major threat to the existence of tropical peatlands and their associated flora and fauna because the damage inflicted is greater than the impact of illegal logging activities. Fires in tropical peatlands occur during the lowering of groundwater table in the dry season when they become dry and highly flammable. Dry peatland conditions will occur more rapidly and over longer periods if canals have been made for agricultural activities and plantations without hydrology control.

According to many experts that many fire events within the area of Mega Rice Project, in Central Kalimantan, Indonesia, caused a great loss of peat layers. [1] who did this research, the peat loss by fire in 2002, reported that the peatland fires (open area), have brought about the peat loss reaching 42 cm deep on average. The extent of peat loss to fire depends on the depth of the groundwater. [2] reported that the peat fire event in the area of block C, of Mega Rice Project, resulted in 51 cm deep of peat loss. [3], [4] recorded that the peat loss in the same area was ranging from 27 cm up to 33 cm deep. Optimum conditions for deep peat fires include: (1) a low water table, (2) low soil moisture, and (3) available fuelwood in the peat matrix. Physically, the deeper peat layers (20-50 cm) contain more wood debris than the surface layers [5].

Fire suppression on peatland demands significant expenditure of money time. To completely extinguish a peat fire requires 200-450 liters of water/m2, in order for the water to fully extinguish the ground fire, as well as to flood the ground surface to prevent the supply of oxygen into the soil [1].
Depending on the scale of the fire, suppression efforts involving just rain at low intensity may not be able to extinguish the fire in the soil. As a result, the embers will continue to emit thick smoke, due to incomplete combustion [6], releasing harmful gases into the atmosphere that cause public health problems. Further research on peat fires, especially in Indonesia as reported by [2] that the peat fires in 1997, released from 810 Mt to 2.570 Mt of carbon into the atmosphere. [7] also reported that an average of 74 Mt of carbon per year between 2000–2006 was released by the Bornean peat fire. This amount of carbon released from peat fire only has made Indonesia became one of the world’s largest CO2 emitters [8]. The gases released into the atmosphere are CH4, CO2, and CO, the most dominant being CO2 [9]. Ammonia, hydrogen cyanide and fine particles are very dangerous, although their life in the atmosphere is shorter than that of greenhouse gases, these particles affect the earth system and the environment at least on a short time scale [10]. Particulate concentrations (PM10) in Palangka Raya in 2015 were > 2,500 μg/m3 [11] higher than in 2002 and 2006 which was <2,000 μg/m3 [12]. Fires also caused socio-economic losses to society, with those in 2015 estimated at IDR 221 trillion [13].

2. Objective
The objective of this study, as previously done by [1], was to determine the losses of peat and carbon due to fires that always occur at 3 different areas, which are a regrowing forest area, an open area, and degraded forest.

3. Method
Experiments were conducted in the Kalampangan area within the former Mega Rice Project Block C (S: 2° 17' 21.23, E: 114° 1' 58.31"), Central Kalimantan, Indonesia (Fig.1) in 2014. The area was heavily degraded as a result of peat drainage and deforestation. Large-scale fires occurred during El Niño in the years 1997, 2002, 2006, 2009 and 2015. To measure the loss of peat due to fires, iron pipes were installed into the peat by boring in three different locations:

(1) The regrowing forest area (RF) with pipe codes of 1, 2, 3, 4 and 5 (Fig. 2), which was burned in 1997 and 2002. The dominant tree species were tumih (Combretucarpus rotundatus), gerunggang (Cratoxylon arborescens), acacia (Acacia mangium) and mahambung (Shorea smithiana).
(2) An open area (DB) with pipe codes of 6, 7, 8, 9, 10 and 11 (Fig. 3), which was burned in 1997, 2002 and 2009. This area was dominated by ferns, including kalakai (Stenochlaena palustris), hawuk (Pteridium aquilinum) and lampesau (Blechnum serrulatum).
(3) A degraded forest area (DF) with pipe codes of 12, 13 and 14 (Fig. 4), which has not been burned before. The dominant tree species were tumih (Combretucarpus rotundatus), hangkang (Palaquium leiocarpum), punak (Tetramerista glabra), jelutung (Dyera polyphylla).

When the pipes were installed in August 2014, a mark was set on the standing pipe at the litter surface (Fig 2), and the thickness of litter accumulation was measured (Table 1). The height of the mark from the peat surface was then remeasured in November 2014 after the occurrence of fire in the previous month, which occurred in October 2014. The balance of the height and litter thickness corresponds to the burned peat depth (Fig 3).

Five replicate core samples (volume: 100 cm³) were collected around the three sites using sharpened steel cylinders to avoid peat compression. Peat samples were collected and oven-dried at 105 °C for up to 96 hours. The carbon content of the peat soil was determined with a CN analyzer (Sumigraph NCH-22; Sumika Chemical Analysis Service Ltd., Osaka, Japan) [14]. Carbon loss was calculated using the following formula:

$$CL = 100 \times CC \times BD \times PD$$

Where CL is carbon loss (tC/ha), CC is carbon content (%), BD is bulk density (g/cm³) and PD is peat depth (cm).
Figure 1. Location of research sites in the Kalampangan area, ex Mega Rice Project Block C, Central Kalimantan, Indonesia

Figure 2. Installation of iron pipes at the 3 different locations

(A) Re-growing forest (RF)  (B) Degraded burn (DB)  (C) Degraded forest (DF)
Figure 3. Measurements of peat loss after fire at the 3 different locations.

The water table was measured hourly. At DF site was measured from January to December 2014 and DB site was measured from January 2013 to June 2014. Water logger is inserted into a perforated PVC pipe as the distance of the groundwater from the surface of the ground using a water pressure sensor (HTV-050KP; Sensez, Tokyo, Japan). No data at the RF site, the sensor was burnt.

4. Results
4.1 Litter thickness
Litter thickness also measures at every site to compare the accumulation of litter after the last fire (Table 1).

Table 1. Litter thickness at the location of installed pipes

| No. | Coordinate | Litter Depth (cm) | Mean±SD |
|-----|------------|------------------|---------|
|     | South      | East             |         |
| Plot 1 : Regrowing forest (RF) | | | |
| 1   | 02°17’37.2” | 114°01’49.3” | 10.1 | |
| 2   | 02°17’37.4” | 114°01’49.2” | 5.2  | |
| 3   | 02°17’37.2” | 114°01’49.6” | 3.3  | |
| 4   | 02°17’37.1” | 114°01’49.7” | 8.5  | |
| 5   | 02°17’37.3” | 114°01’49.8” | 2.6  | |
| Plot 2 : Degraded burn (DB) | | | |
| 6   | 02°18’38.6” | 114°01’21.4” | 7.1  | |
| 7   | 02°19’21.9” | 114°01’03.2” | 7.4  | |
| 8   | 02°19’28.0” | 114°01’04.8” | 5.6  | |
| 9   | 02°19’26.6” | 114°01’07.2” | 7.3  | |
| 10  | 02°19’30.3” | 114°01’07.2” | 6.2  | |
| 11  | 02°19’30.8” | 114°01’07.5” | 6.4  | |
| Plot 3. Degraded forest (DF) | | | |
| 12  | 08°20’51.2” | 114°02’21.2” | 18.2 | |
| 13  | 08°20’51.5” | 114°02’20.6” | 14.5 | |
| 14  | 08°20’51.3” | 114°02’20.5” | 19.2 | |
4.2 Peat loss
Peat loss illustration (Fig 4) at every site (RF: five iron pipes installed, DB: six iron pipes and DF: three iron pipes). The 2014 fire caused considerable loss of peat. Comparison between the three different peatland conditions shows that the DF experienced the highest peat loss at 53.9±21.9 cm followed by the RF at 44.2±17.1 cm and the DB at 32.1±12.6 cm.

Figure 4. Peat loss illustrations due to fire in three peatland conditions at Kalampangan

In addition, peat loss by fire in 2019 was about 50 cm as shown in Figure 5.

Figure 5. Peat loss at University of Palangka Raya Forest
4.3 Carbon loss
Peat is a good place to store carbon stock if the peat burns it will release Carbon (Carbon loss) into the atmosphere. Based on this research, the release of carbon into the atmosphere was different at every study site (Table 2).

| Plot | BD (g/cm³) | CC (%) | Peat loss (cm) | Carbon loss (tC/ha) | CO₂ loss (tCO₂/ha) |
|------|------------|-------|---------------|---------------------|-------------------|
| RF   | 0.14       | 54.6  | 44.2          | 337.9               | 1240.0            |
| DB   | 0.14       | 53.5  | 32.1          | 240.0               | 880.7             |
| DF   | 0.13       | 54.6  | 53.9          | 382.6               | 1404.1            |

4.4 Water table
The water table was measure at DF site (January to December 2014) and DB site (January 2013 to June 2014). Data at the DB site was not complete until December 2014 because the sensor was burnt and also at RF site.

5. Discussions
From the measurements, DF areas had the highest peat losses followed by RF and DB areas. It was because DF had very low water table about -140 cm (Figure 6A), fairly thick layer of litter 17.3±2.47 cm (Table 1 and Figure 4), low level of peat maturity, bulk density 0.13 g/m³ (Table 2), very dry peat and deep root system, and that may become potential fuels for the next possible fire. While, RF with litter layer 5.94±3.26 cm (Table 1 and Figure 4), a middle level of peat maturity and bulk density 0.14 g/m³ (Table 2) remained lots of dead trees and may become fuel to the next possible fire. High wood content with low bulk density in the deeper peat layers enable oxygen percolates into the deeper peat layers when smoldering combustion occurs [5]. Burn depth will increase when the peat is drier but also depending on the water content of the peat [15,16]. Burn depth varies based on the frequency of the fire and will reduce with time in the same location [17].

In contrast, the DB area has been burned several times. With thin litter layer 6.66±0.71 cm (Table 1 and Figure 4), low water table -80 cm (Figure 6B), high level of peat maturity (compact peat) and bulk density 0.14 g/m³ (Table 2), the fuel (wood and roots) have begun to decrease. After combustion, organic carbon and total nitrogen in the remaining peat decreased whereas its mineral nutrients, pH and bulk density increased [18,19]. Due to imperfect burning, some combustible materials remained as dead trees and charcoal, may become fuel for the next possible fire [1].

In line with the trend of peat loss, carbon loss due to the fires (Table 2) was highest at the DF site followed by the RF and then DB sites. Peat loss caused carbon loss (Table 2). Here, carbon loss from the burned peats of forested areas (DF) was the greatest 382.6 tC/ha followed by RF 240.0 tC/ha and...
DB 337.9 tC/ha. DF area has never been burned since 1997. With a thick layer of litter, bulk density 0.13 g/m$^3$, water table -140 cm, very dry peat, the burned peat spread vertically to a certain point rather than horizontally. The amount of biomass consumed by the fire depends on how deep it penetrates the peat layers [20]. Burn depth varied with some occasions the fires recorded burned into a depth of 0.85 m resulted in carbon emissions 31.5 kgC/m$^2$ [21,2]. While RF area and DB area where the peat litter was thinner have been burned several times with bulk density 0.13 g/m$^3$ and water table about -80 cm.

At the studied location, the fires occurred four times in 1997, 2002, 2006, 2009 and 2014 and might result in a considerable peat loss. If the average peat loss from RF (burned three times in 1997, 2002 and 2014) is 44.2 cm then total peat loss is 132.6 cm. In DB (burned four times in 1997, 2002, 2009 and 2014), with the mean peat loss 32.1 cm then total peat loss is 128.2 cm. And, in DF (burned in 2014), with the total peat loss is 53.9 cm.

Peat loss will also reduce the ability of peat to hold water during the wet season. At these locations, heavy floods occurred in 2010, 2013 and 2015 (Fig. 7) which also been reported by [22]. Base on the climate data (Fig 8), the highest precipitation was in 2010 but floods were not so high. Moderate rainfall in 2013 caused floods that were slightly higher. And, in 2015, the rainfall was lower, but floods increased. These situations may indicate the ability of peat to absorb water has somewhat decreased.

![Figure 7. Flooding at CIMTROP base camp at Kalampangan area](image)

![Figure 8. Precipitation in the vicinity of the studied location](image)
6. Conclusion
Fires are a major threat to the existence of peat and make a huge contribution to greenhouse gas emissions. It is very difficult to extinguish once the fires occur because 1) the fires may penetrate a certain point under the ground, 2) a lot of water which is not available in place is required, 3) if the fires were not totally extinguished then a new fire will emerge, and 4) of smokes that may contain extremely dangerous gases and particulates. The loss of peat will reduce its ability to absorb rainwater and in consequence will contribute to more intensive flooding. Urgent measures are therefore required for better detection, prevention and reduction of peatland fires.

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