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THE RING OF FIRE: TACKLING INDONESIA'S PEATLAND FIRE DYNAMIC

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SUMMARY

Peatlands are a significant component of the global carbon (C) cycle, yet despite their role as a long-term C sink, they are increasingly vulnerable to destabilisation. The shift from C sink to source is happening rapidly in SE Asia and particularly in Indonesia, where combined pressures of land use change and fire on peatland C dynamics and their environmental and socio-economic consequences are increasingly apparent. The present-day peat fire dynamic of Indonesia is the consequence of a ‗perfect storm' of events providing key ingredients for fire activity, namely an abundance of both fuel and ignition sources. We discuss the link between deforestation, drainage, fire and accelerating C emissions. Using data on fires over the period 2010-2015, the location, scale and controls on peat driven C emissions are addressed. The paper concludes by advocating land management options to reduce future fire risk as part of wider peatland management strategies, while acknowledging the substantial governance and political challenges associated with damping down the current fire dynamic.

Keywords: *peat fire, peat swamp forest, tropical peatland, Indonesia, GHG emissions*

INTRODUCTION

Peatlands are a globally important carbon (C) pool. While covering only ~3% of the Earth's land surface, they contain an estimated 500 to 700 Gt (=Pg) of C, likely exceeding that contained in the world's vegetation (500 Gt). In terms of both area (3.6 million km^2) and C storage (400-600 Gt), the most extensive peatlands are found in northern regions of the world, but there are also significant deposits in the humid tropics. Collectively, these cover some 0.4 million km^2 with a total C pool of 80 to 90 Gt (Page *et al.,* 2011). Their greatest extent is in Southeast (SE) Asia (0.25 million km^2; 69 Gt C), with 57 Gt C in Indonesian peatlands and a smaller 9 Gt C in Malaysia. Most peat C has accumulated over long time periods; yet despite their role as a C sink throughout the Holocene, peat C pools are increasingly vulnerable to destabilisation through a combination of land use change, fire and climatic warming. Nowhere is the shift from peatland C sink to C source happening more rapidly than in insular SE Asia where there are combined pressures of land use change and fire on peatland ecosystem C dynamics.

Hydrology plays a critical role in the peatland C cycle. The position of the water table controls the rate at which aerobic microbial decomposition (mineralization) of organic matter, and hence the rate of peat accumulation, can proceed. Under conditions of near permanent waterlogging, the absence of oxygen in the soil profile favours the accumulation of undecayed or partially decayed organic matter facilitating long-term ecosystem C storage, but water table drawdown accompanying anthropogenic land use change increases both the rate of peat mineralization and the risk of fire. It is estimated that drained tropical peatlands contribute almost 70% (~200 Mt C) of global drainage- and fire-derived greenhouse gas (GHG) emissions from organic soils, with a smaller 30% from drained northern peatlands (Biancalani & Avagyan 2014).

In SE Asia, the contemporary peat fire dynamic is the consequence of both an abundance of fuel and of ignition sources. Landscape-scale forest clearance and peat drainage combined with widespread use of fire as a cheap, fast and effective means to clear large areas of forest debris and regrowth have led to an increase in fire activity. It is not only deforested and drained peatlands that are at risk of fire since the fire-resilience of remaining fragments of peat swamp forest has been reduced, placing them at increased risk of ignition. Where peat swamp forest has burnt once, it will undergo secondary succession back to closed forest. But in reality, the standing and dead timber remaining from the first fire will increase the chance of a second fire, placing the ecosystem on a trajectory towards fire-prone scrub with very limited opportunity for forest recovery (Hoscilo *et al.,* 2011).

Although the most severe fires of recent years can be linked to droughts driven by the ENSO climate anomaly (e.g. Page *et al.,* 2002), abnormal weather conditions are not a prerequisite for peat fires. Indeed fires are now a regular feature of every dry season, even those of short duration (Gaveau *et al.,* 2014), and are as much a product of rapid land use change (e.g. Field et al. 2009) as they are of climatic variability. This new fire dynamic means that peat fires in this region can no longer be considered occasional events that result in short-term perturbations of the peatland ecosystem followed by medium-term recovery to a new stable state. With every fire season, they are an intensifying environmental concern with profound implications for GHG emissions, air quality, human health, local livelihoods and regional economies. This short paper reviews the link between fire, land use change and GHG emissions in Indonesian peatlands focusing on the period 2010 to 2015. It presents data on fire location and extent and apportions fire-derived GHG emissions to different land covers. The paper ends by comparing the scale of GHG emissions from peat fires and peat oxidation and considers opportunities for land management options to mitigate these emissions and the risk of future fires.

METHODS

Our approach involved linking burnt area to peat extent, land cover status and fire-derived GHG emissions for the period 2010-2015 (until end of October 2015). Burnt area was obtained from MODIS gridded fire data products. MODIS tiles covering Sumatra, Kalimantan and Papua (results for Papua are not presented here) were processed. One MODIS grid cell covers an area of 1 km^2 (100 ha) but not every fire results in the burning of the whole grid cell. To obtain an estimate of the burnt area within a grid cell, the number of surrounding (neighbouring) cells was considered, on the assumption that the fraction of a cell that had burnt was proportional to the number of surrounding cells that were also ‗hotspots' in the same period. For each day, for each fire observation and for each grid cell, the number of neighbouring fire cells was counted and attributed to the centre grid cell; the minimum number being zero and the maximum 8. On an annual basis the maximum number of neighbouring fire cells was determined and the burnt area related to the number of neighbouring cells, starting at 10% burnt area for a fire cell without neighbouring cells (i.e. 10 ha), and increasing by 10% burnt area for each subsequent neighbouring cell. A fire cell with the maximum of 8 neighbouring fire cells was considered to have a conservative 90% burnt area (90 ha); a percentage of 100% burnt area was not applied, as remnant pockets of unburned vegetation are often observed after fires while a small percentage of intensively drained peatland is open water that cannot burn. The burnt area estimate was validated for an area of approximately 6.8 Mha covering part of Central and South Kalimantan (D. Gaveau, unpub. data). The two burnt area products were compared and revealed an acceptable degree of agreement, while acknowledging both errors of omission (under reporting of burnt area) and commission (overestimation). This gave confidence in the accuracy of our MODIS hotspot burnt area method, although additional sensitivity analyses will be performed for additional validation. The burnt area calculated in this way was then overlaid onto maps of peatland extent, using the peat map of BBSDLP (Ritung *et al.,* 2011) and land cover status, using Margono *et al.* (2014) to provide forest/non-forest data over the period 2000-2012, while data on 2010 and 2015 plantation extent (oil palm and pulpwood plantation areas developed or under development) were provided by CRISP (*Miettinen et al.,* 2012, 2016).

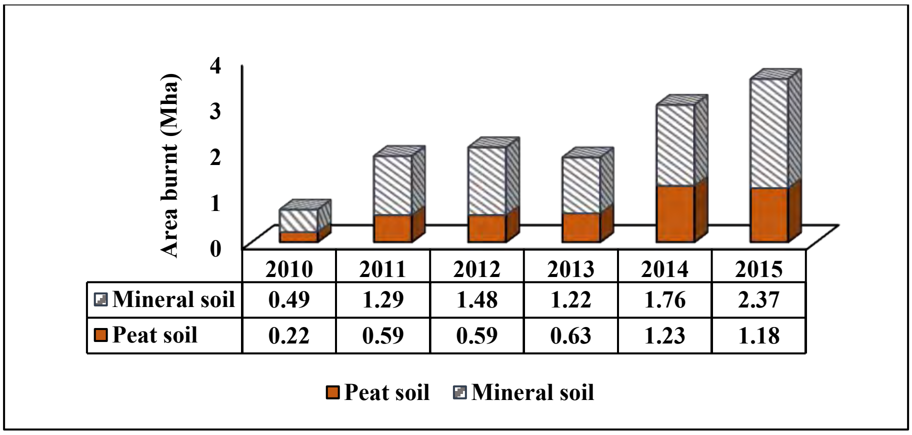
Emissions from belowground (peat) fires were calculated using fuel load data from Konecny *et al.* (2016) and GHG emissions factors (CO_2, CH_4, N_2O) from Smith *et al.* (2016). Aboveground (biomass) fuel load values were obtained from IPCC (2006) and corresponding GHG emission factors from Stockwell *et al.* (2014). Using the knowledge of fuel load from recurrent peat fires (Konecny *et al.,* 2016), we accounted for the decrease in peat lost in each subsequent fire, which results in intact peat swamp forest having emissions that are 4.6 times higher (699 t CO_2-e ha^{-1}) than the third fire in a deforested peatland (153 t CO_2-e ha^{-1}), including both peat and aboveground biomass emissions. Given that emissions even from third fires in peatlands are still many times higher than those from fires on mineral soils, it follows that all fires in peatland areas have far higher emissions than fires in other land covers. Further details of the methodologies employed in this study are available in Hooijer *et al.* (2016).

RESULTS

Using our approach, the total burnt area in Sumatra and Kalimantan over 2010-2015 was estimated to be 13 Mha, of which over half occurred as a result of fires during 2014 and 2015 (3 Mha and 3.6 Mha, respectively). There was an increasing trend in annual total burnt area from 2010 to 2015, both in peatland areas and on mineral soils, which may be attributable to the key drivers of land cover change and climate. The proportion of annual burnt area located in peatland in each year averaged ~33% (range 28 - 41%), with peak values of 1.2 Mha of burnt peatland in both 2014 and 2015 (Figure 1).

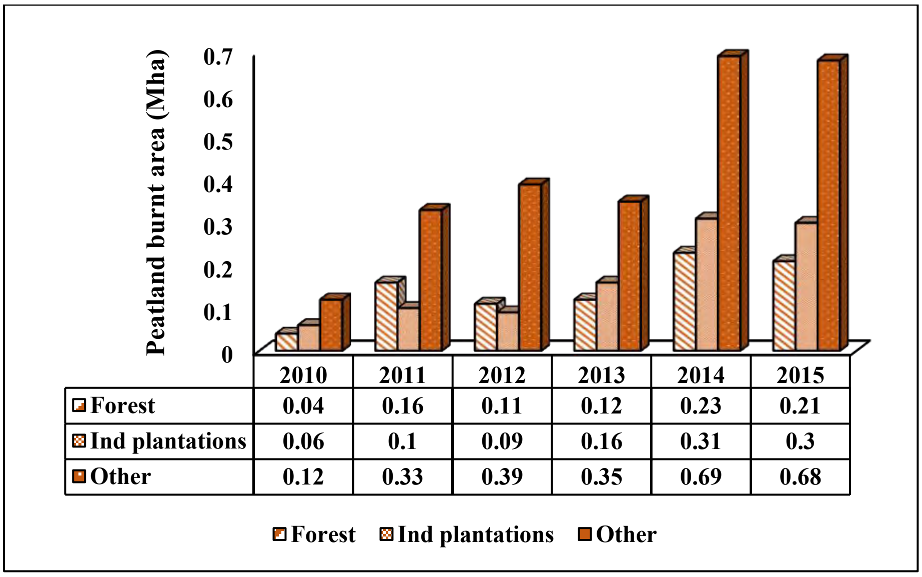
Within peatland, the area of forest that burnt steadily increased over the 6 year period, reaching a peak of around 227,000 ha in 2014 and 208,000 ha in 2015 (Figure 2). This amounts to the loss of some 0.9 Mha of peat swamp forest as a result of fires over the six year period. Burnt area inside land developed or being developed for industrial-scale plantations shows a similar trend, with around 300,000 ha burning in both 2014 and 2015. The largest burnt area category in all years, however, with pronounced increases in 2014 and 2015, is ‗other‘; this includes scrub, which may well have burnt during previous fire years, and also smallholder land (main land uses are for growing oil palm and vegetable crops).

In terms of peatland fire GHG emissions (Figure 3), these have risen steadily over the period 2010-2015 with the increase in burnt area. Using our approach, we calculate that the total peat fire emission over the 6 year period is 1700 Mt CO_2-e, which is 78% of the total fire emission of 2200 Mt CO_2-e (for fires on both mineral and peat soils; data not shown). Thus some 78% of the total 6 year emission is from fires on peatland despite these fires



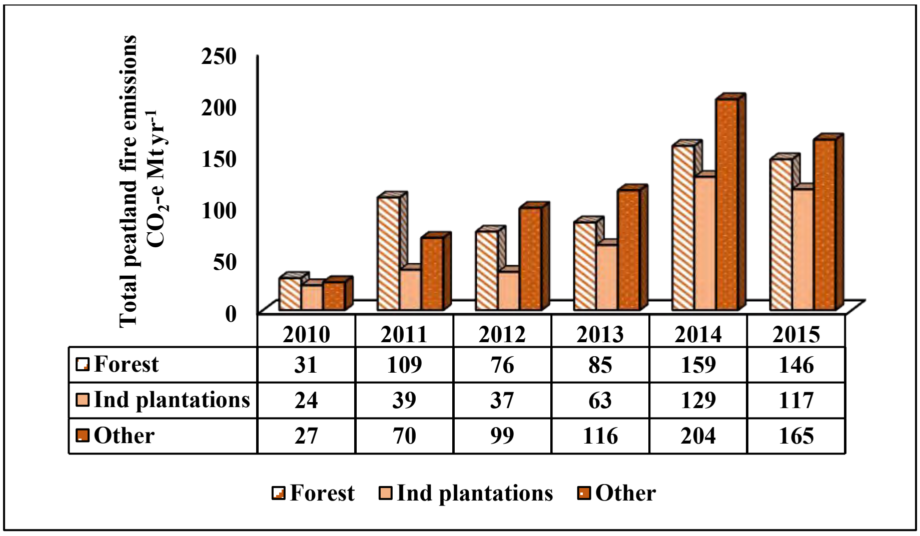
	2010	2011	2012	2013	2014	2015
▨ Mineral soil	0.49	1.29	1.48	1.22	1.76	2.37
■ Peat soil	0.22	0.59	0.59	0.63	1.23	1.18

Figure 1: Total burnt area (Mha) across mineral and peat soils in Sumatra and Kalimantan between 2010 and 2015; total burnt area over 6 years is 13.05 Mha, with 4.44 Mha on peat soils (34%) and 8.61 Mha on mineral soils (66%).



	2010	2011	2012	2013	2014	2015
▨ Forest	0.04	0.16	0.11	0.12	0.23	0.21
▨ Ind plantations	0.06	0.1	0.09	0.16	0.31	0.3
■ Other	0.12	0.33	0.39	0.35	0.69	0.68

Figure 2: Total burnt area (Mha) and land cover on peat soils in Sumatra and Kalimantan between 2010 and 2015; total burnt area over 6 years is 4.44 Mha, with 0.87 Mha (20%) in forest, 1.02 Mha (23%) in industrial plantations (both developed and under development) and 2.55 Mha (57%) in other land covers



	2010	2011	2012	2013	2014	2015
☐ Forest	31	109	76	85	159	146
☐ Ind plantations	24	39	37	63	129	117
■ Other	27	70	99	116	204	165

Figure 3: Total annual emissions of greenhouse gases (CO_2, CH_4, N_2O; expressed as CO_2-e Mt) from peatland fires across Sumatra and Kalimantan during 2010-2015. Emissions increase from a total of 82 Mt in 2010 to 492 and 428 Mt in 2014 and 2015, respectively. Total emissions over the 6 year period are ~1700 Mt CO_2-e, of which fires on forested peatland contribute 36%, fires in plantations (both developed and under development) contribute 24% and fires in other land cover categories (scrub and smallholder land) contribute 40%.

occurring on only 34% of the burnt area. Total CO_2-e emission from peatland fires alone is around 500 Mt yr^{-1} in both 2014 and 2015; these are lower estimates than some other assessments, mostly because lower emission factors for recurrent peat fires are applied in our study. It is important to note that these two most recent fire years (2014 and 2015) were in fact likely quite similar in magnitude. This is true when considering the total burnt area (peat and mineral soils) in Sumatra and Kalimantan (3 and 3.6 Mha respectively for 2014 and 2015), the total burnt peat area (~1.2 Mha in both years), and the burnt peat forest area (~0.2 Mha in both years).

DISCUSSION

In pre-disturbance landscapes in SE Asia there was limited risk of accidental ignitions or fire spread since the landscape was resistant to fire. But the new landscapes of fragmented forests and drained peatlands are highly fire-prone. The occurrence of extended droughts associated with ENSO-events undoubtedly exacerbates the intensity of peat fires, but this climatic phenomenon is not, in itself, the root cause. Our results show that there was a large burnt area on peatland in 2014 (a non-ENSO year) just as there was in the subsequent ENSO year of 2015, both resulting in similar GHG and, presumably, smoke emissions. This result concurs with the study by Gaveau *et al.* (2014) on the severity of fires and associated emissions in 2013, which again was a non-ENSO year. Between 2014 and 2015, the location of fires, and hence the impact of air pollution on large centres of population, was different. But while national and international attention focused on the 2015 fire year, the 2014 and indeed the 2013 fire years were also notable. This is an important finding underlining the need for fundamental changes in peatland management practices, regardless of year to year variability in climate.

The scientific evidence on both the drivers of and the amount of GHG emissions from peat fires in insular SE Asia and their local to global consequences is now reasonably well established, yet this knowledge has been inadequately translated into land use policy and land management practices. A study of the 2006 peat fires established that 59% of the fire emissions from Sumatra and 73% of the emissions from Kalimantan originated outside timber and oil-palm concession boundaries (Marlier *et al.,* 2015); our data for 2010-2015 show a similar pattern, at least for land developed or under development for industrial-scale plantations. These results further emphasise that many actors play a part in the ‗ring of fire dynamic‘ with a steady year-on-year decrease in the remaining peat swamp forest through encroaching fires from all sides (both literally and figuratively) and that they all need to be engaged not just in fire fighting but in fire prevention. While some of the largest plantation companies have made commitments to ‗zero burning‘, ‗no deforestation‘, ‗no planting on peatland‘ and working with local communities to reduce fire occurrence (Padfield *et al.* in press), much more needs to be done to remove fire from the most vulnerable landscapes. While all peat landscapes in Sumatra and Kalimantan are now largely deforested, drained and fire prone, there are large differences in the extent and condition of the fragments of remaining peat swamp forest, and also in the condition and management of the non-forest areas, and therefore in the emissions generated by fires in such areas. Some peatland areas produce far more fire emissions than others: first and second fires in peat swamp forest are the greatest emission sources by unit area. Better understanding of these emission hotspots, and their nature, along with a determined effort to engage with all involved in managing fire prone landscapes could improve the planning and implementation of fire mitigation activities.

A comparison of the scale of GHG emissions arising from peat fires and oxidation (the latter estimated using land cover data from Miettinen *et al.* (2016) and IPCC (2014) for CO_2 emission factors) reveals that for 2015, the scale of emissions from both sources were likely comparable in magnitude (428 Mt CO_2-e from fires; 437 Mt CO_2-e from oxidation). Over the full 6 year period, peat fire emissions are estimated at 1696 Mt CO_2-e while peat oxidation emissions are 2621 Mt CO_2-e. Since the latter value can be considered conservative (only CO_2 emissions are accounted for), this comparison stresses the point that mitigating fire emissions is only part of the bigger issue of mitigating the total sum of GHG emissions produced as a result of peatland drainage. Overall, the most effective measure that Indonesia could apply to mitigate the continuation or even further increase of GHG emissions from peatlands would be to prevent fires in the remaining peat swamp forest fragments, and to restore the hydrology of peatland areas that are degraded. This is because forest fires generate the highest emissions per unit area: up ten times or more than fires in other land covers (e.g. Van Leeuwen *et al.* 2014) while the extent of drained peatland makes a major contribution to the high annual value for emissions from oxidation. In remnant forests, successful solutions must focus on the peat itself – i.e. on efforts to keep the peat wet. This will require hydrological interventions on drained peatlands adjoining remnant peat swamp forest in order to restore forest water levels. This will reduce both oxidative and fire emissions but have inevitable economic consequences for stakeholders involved in agricultural production, since high water levels will reduce or even completely halt the productivity of plantation crops. Opportunities do exist, however, to identify and develop alternative plantation crop species that tolerate higher water levels while still providing an economic return.

There are now some 140,000 km^2 of drained peatland across Peninsular Malaysia, Sumatra and Borneo (Miettinen *et al.* 2016); thus the geographical magnitude of managing such ‗high emissions' landscapes is daunting. There are technical and economic challenges to be overcome in persuading policy makers and land managers that peat water tables should be maintained at a sufficiently high level to reduce fire risk and oxidative emissions, as well as substantial governance and political challenges, including uncertainties over land rights and weak policy implementation. Addressing the contemporary Indonesian fire dynamic will require a radical shift in human behaviours and practices, but also a fundamental recognition that interventions will require strong and effective political leadership, financial investment, and an honest and transparent commitment from everyone involved in peatland management.

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