CONNECTION BETWEEN FIRE ACTIVITY AND LAND COVER/USE CHANGE IN SUMATRAN PEATLANDS 2007-2015

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ABSTRACT: In this study we investigate the connection between fire activity, peatlands and anthropogenic land cover/use changes in the provinces of Riau, Jambi and South Sumatra, Indonesia, from 2007 to 2015. We combine Moderate Resolution Imaging Spectroradiometer (MODIS) active fire detections with peatland land cover/use maps (2007 and 2015). Our results show that during the nine years studied, fire density (i.e. number of fires per area) is more than three times higher in peatlands than in mineral soils. Within peatlands, areas that had experienced land cover/use change between 2007 and 2015 had clearly the highest fire density with 421 fires/100km^2. In comparison, areas that remained as managed land cover/use types controlled by either small-holder farmers or industrial companies experienced moderate fire activity (116 fires/100km^2 and 159 fires/100km^2 respectively), while primary forests had hardly any fires (2 fires/100km^2). But in absolute fire numbers, unchanged peatland areas experienced nearly as much fire activity as the changed areas over the nine years study period (62494 and 67030 fire detections respectively). 58% of the study area was not affected by fire activity at all during the study period, while 10% of the study area was affected by fires in three or more years. These repeated fires were most common in areas undergoing land conversion and in undeveloped deforested peatland areas.

1. INTRODUCTION

Vegetation fires occur in the humid equatorial Southeast Asia with varying annual severity, occasionally causing severe damage and transboundary haze pollution. Increase in the occurrence of fire activity over the past few decades in the naturally very fire resistant humid tropical environment has been largely attributed to land conversion and land management activities. Increase in fire activity particularly in the peatland areas has made them the main source of haze pollution in the region.

In this study we investigate the connection between fire activity, peatlands and anthropogenic land cover/use changes in the provinces of Riau, Jambi and South Sumatra, Indonesia, from 2007 to 2015. We combine Moderate Resolution Imaging Spectroradiometer (MODIS) active fire detections with peatland land cover/use maps (2007 and 2015) providing information on the extent of peatlands as well as land cover/use distribution and changes during the study period.

2. MATERIALS AND METHODS

2.1 Study area

The study area covers three provinces of Riau, Jambi and South Sumatra, in the island of Sumatra, Indonesia (Figure 1). These three provinces include 86% of all Sumatran peatlands, containing all of the major peat domes. The peatlands in these provinces have experienced dramatic land cover/use changes since 1990 (Miettinen et al. 2016) and experience yearly fire activity in varying intensity. The total study area is approximately 226 000 km² with a population of 20 Million (Table 1).

Table 1. Information of study area

Province	Area (km^2)	Population (millions, in 2015)	Population Density (Person/km^2)
Jambi	49,144	3.412	69
Riau	90,189	6.344	70
South Sumatra	86,621	10.680	123
Total	225,954	20.436	90

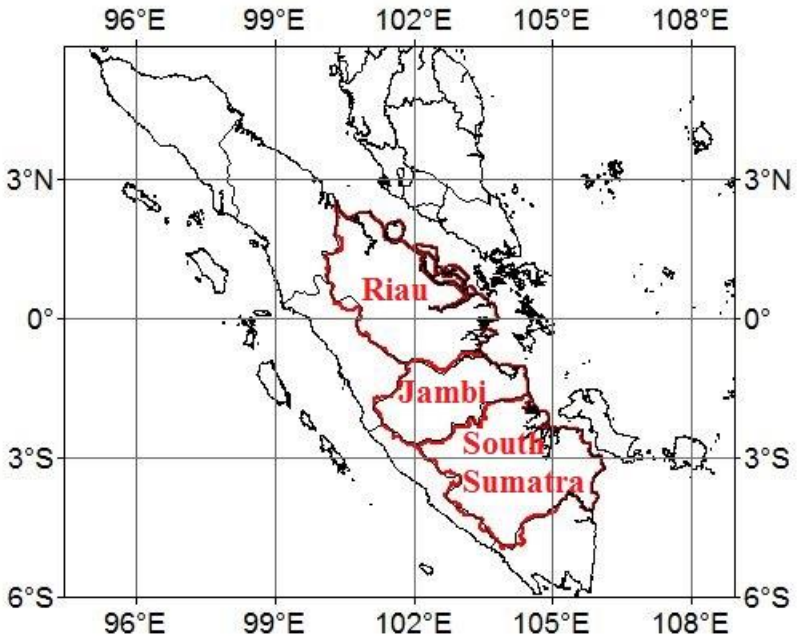

Figure 1. Study area

2.2 Active fire data

Moderate Resolution Imaging Spectroradiometer (MODIS) Collection 6 active fire data (Giglio 2016) were used in this study. The data were downloaded from the Fire Information for Resource Management System (FIRMS) MODIS Fire Archive (https://firms.modaps.eosdis.nasa.gov/download/). The MODIS sensor can be found on-board two satellites (Terra and Aqua) which pass over Sumatra four times a day. This allows good detection of the general fire distribution in the study area. All active fire detections (i.e. hotspots) acquired during the nine years study period from 1st Jan 2007 to 31st Dec 2015 were analysed to investigate fire activity in the study area.

2.2 Peatland map

The most unique ecosystem of the study area is peatland. The peatlands are mainly located on the eastern coast of Sumatra. The extent and locations of peat land were extracted from the atlas published by Wetlands International that have the scale of 1:700 000 (Wahyunto et al 2003). 65% of the peatland was found in Riau, covering 45% of its total area. Only 12% of peatland was in Jambi, covering 15% of its total area. The distribution of the peatlands in the three provinces in the study area is shown in Table 2.

Table 2. Peatland distribution in the study area

Province	Peatland Area (km2)	Peatland percentage (%)	Peatlands of the study area (%)
Jambi	7121.0	14.5	11.6
Riau	40114.4	44.5	65.2
South Sumatra	14336.2	16.6	23.3
Study area	61571.6	27.2	100.00

2.3 Peatland land cover/use maps

The 2007 and 2015 peatland land cover/use maps were created using visual image interpretation. The 2007 was created from SPOT5 data, while the 2015 map was based on Landsat 7 ETM+ (Enhanced Thematic Mapper) and Landsat 8 OLI (Operational Land Imager) data. The classes used in the 2007 and 2015 maps, as well as in the change map derived from the two maps are provided in Table 3. For details of the mapping procedure please refer to Miettinen et al. (2016).

Table 3. Classes of peatland land cover/use maps 2007, 2015 and the change map

Peatland land cover/use map 2007		Peatland land cover/use map 2015		Peatland land cover/use change map 2007-2015	
NO	**Class Name**	**NO**	**Class Name**	**NO**	**Class Name**
1	Water	**1**	Water	**1**	Unchanged water
3	Pristine peat swamp forest (PSF)	**3**	Peat swamp forest (PSF)	**2**	Unchanged PSF
14	Slightly degraded PSF				
15	Moderately degraded PSF	**4**	Degraded PSF	**3**	Unchanged degraded PSF
16	Heavily degraded PSF				
2	Seasonal water	**2**	Seasonal water	**4**	Unchanged undeveloped deforested area (UDA)
5	Tall shrub/secondary forest	**5**	Tall shrub/secondary forest		
6	Ferns/low shrub	**6**	Ferns/low shrub		
10	Clearance	**10**	Clearance		
7	Small holder area (SHA)	**7**	Small holder area (SHA)	**5**	Unchanged small holder area (SHA)
8	Industrial plantation	**8**	Industrial plantation	**6**	Unchanged industrial plantation
9	Built-up	**9**	Built-up	**7**	Unchanged urban
11	Mangrove	**11**	Mangrove	**8**	Unchanged mangrove
				9	Changed - PSF to degraded PSF
				10	Changed - forest (PSF or degraded PSF) to UDA
				11	Changed - forest (PSF or degraded PSF) to SHA
				12	Changed - forest (PSF or degraded PSF) to industrial plantation
				13	Changed - industrial plantation to SHA
				14	Changed - UDA to industrial plantation
				15	Changed - SHA to industrial plantation
				16	Other change

2.4 Hotspots Repeatability

For each year from 2007 to 2015, yearly active fire detection point shape files were converted into raster files of resolution 1 km with value 1 representing at least one active fire detection inside the pixel and 0 meaning no hotspots. These raster files were then summed up for the nine study years to derive information on the fire repeatability (i.e. in how many years fires had been detected in a given pixel).

3. RESULTS

3.1 Temporal fire distribution

From 2007 to 2015, in total nearly 238 280 hotspots were detected in the study area. 48% of them were found in Riau, which had the highest fire density (126 fires/100 km^2) and only 14% in Jambi with density of 67 fires/100 km^2. Jambi and South Sumatra experienced very similar temporal fire patterns with one peak burning season per year, typically from July to October (Figure 2). Riau, on the other hand, experienced two peaks of fire activity pear year, a generally minor peak around February-March and the main fire season around June-August. Large inter-annual variability is also visible in Figure 2, with a few serious fire episodes over the past few years (e.g. 2013 and 2014 in Riau as well as 2015 in Jambi and South Sumatra).

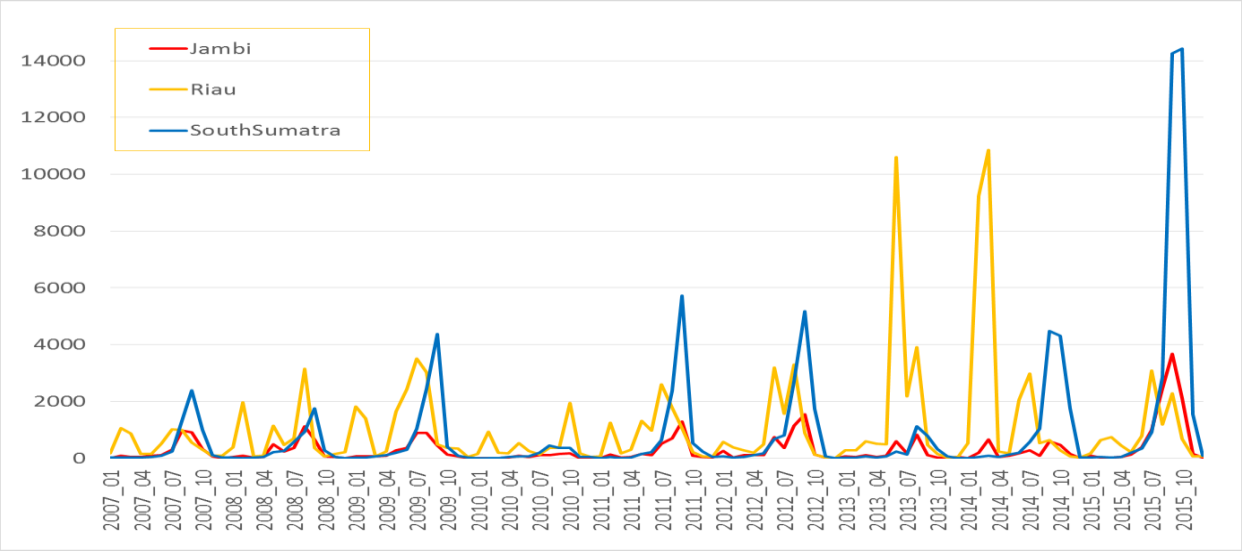

Figure 2. Hotspots distribution by month

3.2 Fire distribution on peat and mineral soils

Of all the hotspots detected in 2007-2015, 54% were detected on peatland, which cover only 27% of the total land area (Table 4). The hotspot density in peatlands was more than three times higher than in mineral soil areas (210 fires/100 km^2 vs. 66 fires/100 km^2). Among the provinces, Riau and Jambi have much higher fire density in peat than in mineral soil (Figure 3). Throughout the study period, fire activity has strongly concentrated on peatlands in those two provinces. Riau and Jambi have also clearly higher peatland fire density than South Sumatra (65 fires/100km^2). Note that in South Sumatra the fire density in peat and non-peat areas is on the same level, indicating that in South Sumatra soil type does not have strong correlation with fire occurrence (at least when averaged over the study period of seven years).

Table 4. Fire distribution between peat and mineral soil areas.

	area (km^2)	**%**	**Hotspot number**	**%**	**Hotspot density (N/100km^2)**
Peatland	61572	27	129524	54	210
Mineral soil	164383	73	108756	46	66
Entire area	225954	100	238280	100	105

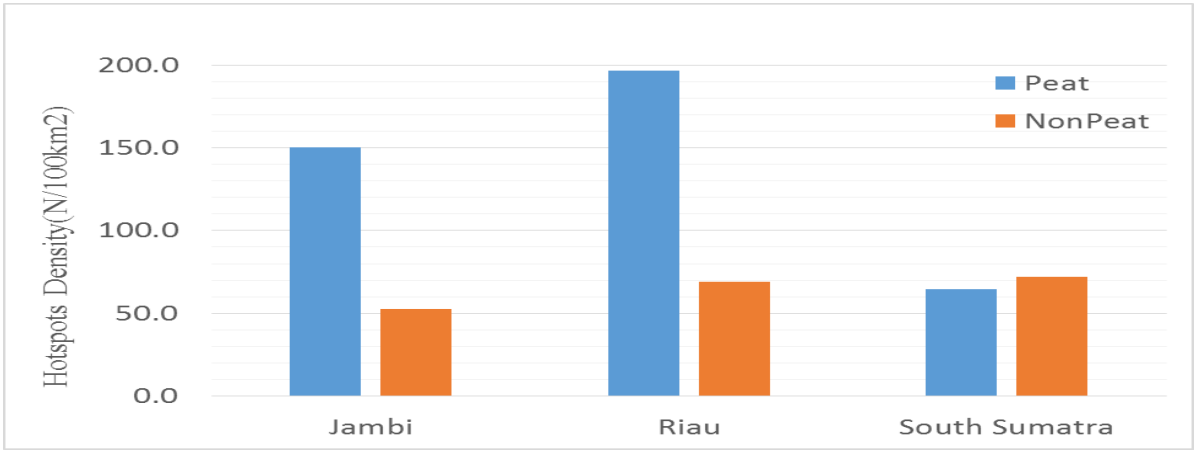

Figure 3. Hotspots Density

3.3 Connection between peatland fire and land cover/use changes

The analysis of fire distribution between land cover/use change types in peatland (Table 5) shows that areas that experienced land cover/use change during the study have clearly higher fire densities. In Jambi and Riau, fire density in changed peatland areas is more than three times higher than in unchanged areas. In South Sumatra the difference is somewhat less, but changed areas still have more than twice the fire density of unchanged areas.

Table 5. Fire density (fires/100 km^2) in changed and unchanged peatland areas

	Jambi	Riau	South Sumatra	Study area
Unchanged peatland area	109	122	199	137
Changed peatland area	386	406	464	421

Among the changed classes, areas that have changed from forest to undeveloped deforested areas have the highest fire densities: 872, 614 and 952 fires/100 km^2 in Jambi, Riau and South Sumatra respectively (Figure 4). Several other changed classes have also high fire densities, resulting in the overall clearly higher fire densities in changed areas reported in Table 5. Among the unchanged areas, the undeveloped deforested areas have the highest fire densities: 435, 457 and 243 fires/100 km^2 in Jambi, Riau and South Sumatra respectively.

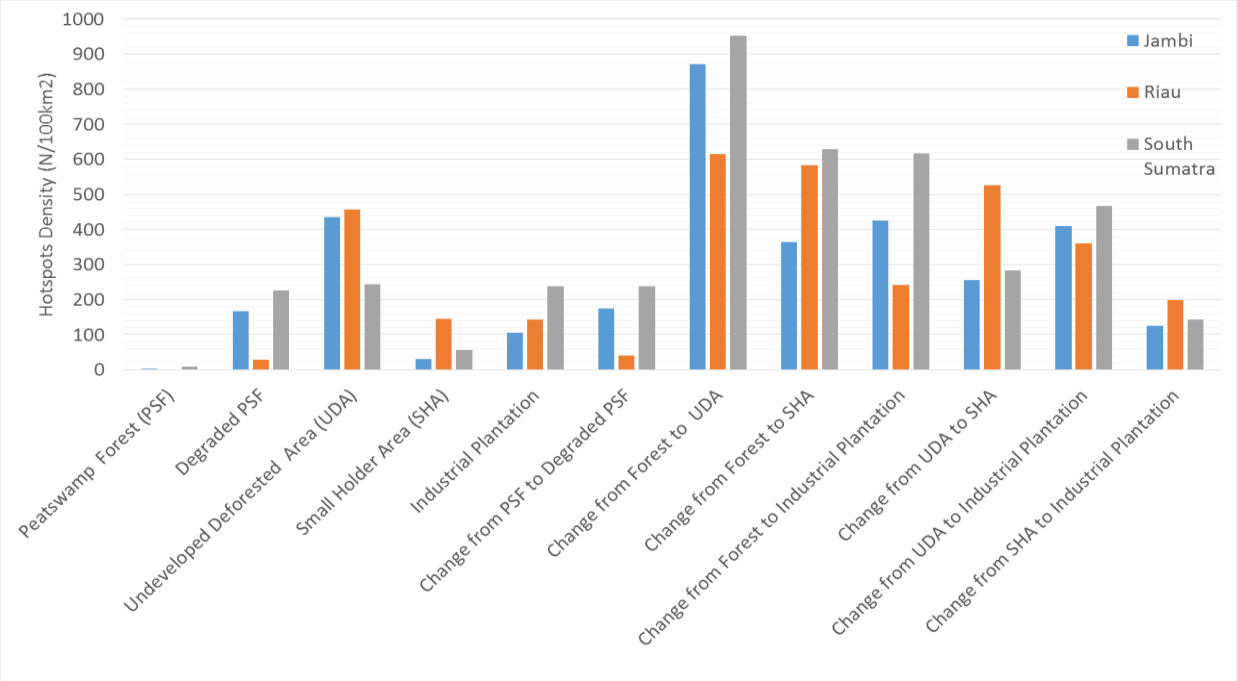

Figure 4. Fire density by land cover/use classes, including unchanged and changed areas

The only area that experienced hardly any fires is peatswamp forest. Note that even unchanged managed peatland areas (i.e. small holder area and industrial plantations) have moderate fire densities. Therefore, due to the large area of managed peatlands, the absolute number of fire occurrence in the unchanged areas is in fact rather close to the number of fires detected in the changed areas during the study period (62494 and 67030 fire detections respectively).

3.4 Fire repeatability

58% of the study area did not experience any fire activity during the study period. On the other hand, 10% of the study area were burnt in three or more years. These areas contained 38% of the all fires detected during the study period. Of the areas that did not experience land cover change during the study period, generally over 90% did not experience repeated fire activity (i.e. fire in three or more years; Figure 5). This indicates that fires in the unchanged areas are spread out in different locations in different years. Only the undeveloped deforested areas show signs of repeated fire activity, with up to 25% of the area experiencing three or more fire years during the study.

The changed areas, on the other hand, show much higher fire repeatability. Of the South Sumatran peatlands that changed from forest to undeveloped deforested area, nearly 50% burnt three or more times during the study period. Overall, the fire repeatability is clearly higher in areas that have experienced changes compared to those that have retained the same land cover/use (Figure 5), suggesting connection between fire and land cover/use changes.

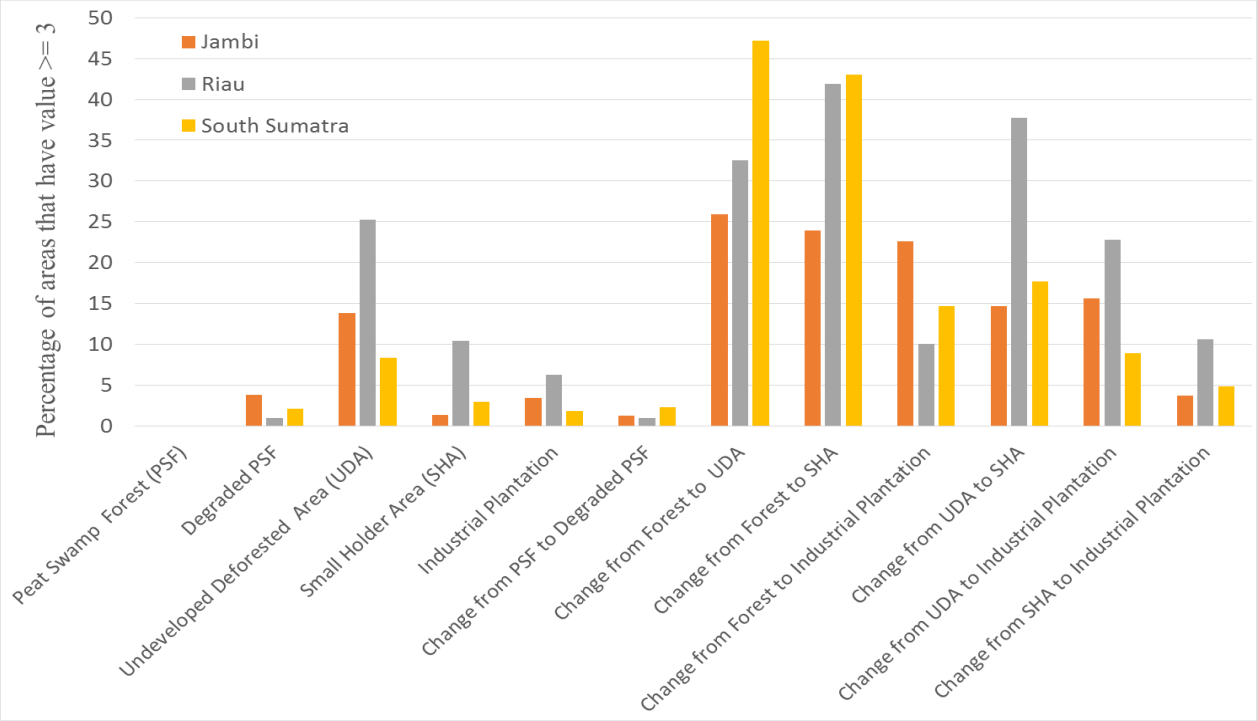

Figure 5. Fire repeatability by land cover change classes

4. DISCUSSION AND CONCLUSION

In this study we investigated the connection between fire activity, peatlands and anthropogenic land cover/use changes in the provinces of Riau, Jambi and South Sumatra, Indonesia, from 2007 to 2015 by combining MODIS active fire detections with peatland land cover/use maps. Overall, our results highlight once again the fire vulnerability of deforested peatland areas. Furthermore, the analysis revealed increased fire occurrence in peatland areas undergoing land cover/use changes. Areas that experienced land cover/use changes had clearly higher fire density (i.e. number of fires per area) than areas that retained the same land cover/use type throughout the study. However, it is important to notice that the results also show moderate fire activity in managed and rather high fire activity in undeveloped deforested peatland areas that retained their land cover/use type throughout the study. Due to the large and ever increasing extent of deforested peatlands, in absolute terms they are becoming an increasingly important source of the negative fire effects (e.g. haze), although in relative terms the fire density in these areas is lower than in areas undergoing changes. The only land cover type which had hardly any fires was pristine peat swamp forest. From fire prevention point of view, our results therefore advocate reforestation and rehabilitation of degraded peatland areas (rather than conversion to managed land cover types) and further improvement in fire handling and management practices in and near all peatland areas.

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