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Forest and land fires in Pelalawan District, Riau, Indonesia: Drivers, pressures, impacts and responses

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Abstract. *Tata HL, Narendra BH, Mawazin. 2018. Forest and land fires in Pelalawan District, Riau, Indonesia: Drivers, pressures, impacts and responses. Biodiversitas 19: 494-501.* Pelalawan District of Riau Province, Indonesia was one of the districts most damaged by fire in 2015. Analysis of factors driving the fires, of pressures arising from the fires and of responses to the fires in Pelalawan District was conducted using two approaches: semi-structured interviews regarding social and policy aspects, and analysis of biophysical factors such as soil properties and spatial data. Results showed that forest functions (i.e. the functions served by different forest types) was positively related to hotspot density (R^2=0.9868), while distance to nearest road less affected hotspot distribution (R^2=0.1612). Multiple regression analysis of the relationship between hotspots density and four variables resulted in the following model: Y = 0.005384 + 0.000021 Soil Type + 0.000019 Distance to Road + 0.000038 Forest Functions + 0.000017 Land Use type. The pressures were expansion for agriculture, plantation and forest encroachment. Despite many negative impacts of fire, the burning practice on peatland could improve the pH and peat soil fertility (particularly ash and P contents). As a response to fire, a standard operational procedure for forest- and land-fire prevention was launched by the Governor of Riau Province in late 2015. A comprehensive and integrated policy package for forest and land fire prevention and control should include a social dimension in order to effectively reduce fire risk in the district.

Keywords: Forest fire, fire susceptibility, hotspots, peatlands, policy intervention

INTRODUCTION

Peatland is a unique ecosystem which stores large amount of carbon (Page et al. 2010; Warren et al. 2017) and has a large water holding capacity (Rezaneshad et al. 2016). However, the peatland ecosystem is fragile; when damaged its condition changes drastically. Channel development in peatland drains water and accelerates oxidation, which increases CO_2 emission into the atmosphere (Gaveau et al. 2014; Van Noordwijk et al. 2014; Marlier et al. 2015; Wilson et al. 2016). Once peatlands dry out, they are prone to fire (Taufik et al. 2015; Turetsky et al. 2015).

For many years, Indonesia has been suffering from recurrent forest and land fires. A recent report showed total burnt area in Sumatra and Borneo in 2015 was 1.34 million km^2 (Miettinen et al. 2017). The year 2015 was the most catastrophic fire season on record in Indonesia (Field et al. 2016). The World Bank reported that economic loss due to forest and land fire in 2015 amounted to IDR 221 trillion (World Bank 2016). The fires also had significant negative impacts on human health (Gaveau et al. 2014; Reddington et al. 2014; Marlier et al. 2015).

Geographical Information System (GIS) and remote sensing are a common tool used for forest and land fire susceptibility mapping (Dewi et al. 2015; Nurdiana and Risdianto 2015; Field et al. 2016; Harris et al. 2017). The map of fire susceptibility is important as part of the Early Warning System for fire prevention. In developing a map of fire susceptibility of an area, hotspot series data are recorded, collected and analyzed (Samsuri et al. 2012; Usman et al. 2015; Mukti and Rushayati 2016; Tata et al. 2017). One hotspot point represents a pixel size area on the land that has higher temperature compared to the surrounding based on certain temperature threshold detected by a satellite (Giglio et al. 2003; Amri and Sitanggang 2015; Harris et al. 2017).

Riau Province was one of the five provinces in Indonesia that was most affected by fire in 2015 (Harris et al. 2017; Prayoto et al. 2017). Riau has a large peatland area, amounting to 4,062,420 ha, of which 66.75% has been converted into smallholder and industrial plantation area. Peatland conditions in these two land use types have changed dramatically owing to human intervention (Miettinen et al. 2016). The total burnt area in Riau Province indicated by hotspot analysis is reported to be about 90,709 km^2, which is about 19.02% of the total burnt area in Sumatra Island (Mietttinen et al. 2017).

Therefore, the objective of this study was to develop an understanding of the factors driving forest and land fire in Pelalawan District of Riau Province; of the impacts of these fires on the peat soils; and of the responses of local government to forest and land fire.

MATERIALS AND METHODS

Study site

The study was conducted in Pelalawan District, Riau Province, Indonesia located between 0 48’32” N and 0

24’14” S and between 101 30’40” E and 103 23’22” E. It covers an area of 1,382,210 ha, consisting of 1,276,433.44 ha land, 39,146 ha rivers and lakes, and 66,630 ha marine. Peatland covers 155,349.9 ha. Of the total district area, 863,725 ha is forest area, which represents about 15.70% of the total forest area of Riau Province) (BPS Pelalawan, 2014).

Procedures

The primary field data consisted of vegetation conditions after fire in 2015 and soil samples. The burnt peatland use-types in Pelalawan District were selected purposively; namely forest, rubber plantation, oil palm plantation and agriculture. We also collected soil samples from unburnt secondary forest. The soil samples were collected by using an Eijkelkamp peat-soil auger from two plot samples; these were taken from the four land-use types, purposively. The soil from the unburnt secondary peat forest was taken as a control. The soils samples were analyzed for chemical and physical properties following regular procedures at the Indonesian Soil Research Institute in Bogor. Only peat depth of two layers, i.e. 0-50 cm and 50-100 cm, were sent to the laboratory. The chemical properties consisted of pH, water content, Nitrogen content (Kjeldhal), available Phosphorus (P_2O_5, Bray1), and pyrite. The ash content, organic matter, and C-organic were analyzed using the lost-on-ignition method (Maswar et al. 2011).

Spatial data related to forest and peatland fires were collected, such as: hotspot NOAA18 data for the years 2013-2015 from the Mitigation Disaster Agency of Riau Province (BPBD, *Badan Penanggulangan Bencana Daerah Riau*); topography and village maps of Geospatial Information Agency (*Badan Informasi Geospasial*, BIG); land-use type for the year 2015; and forest functions for the year 2014 from the Directorate General of Planology (the Ministry of Environment and Forestry, MoEF): peatland hydrological data for the year 2015 from the Directorate General of Pollution Control and Environment Degradation (MoEF).

Some key respondents were interviewed by using semi-structured interview and questionnaires. The respondents were selected purposively at province, district, sub-district, and village levels. They consisted of representatives of the Forest Service of Riau Province; the Agency of Disaster Mitigation of Riau Province; the Forestry, and Estate Crops services of Pelalawan District; the Nature Conservation Unit of Riau; the Teso Nilo National Park; the head of sub-districts Kerumutan and Ukuy; the head of Kerumutan village and farmer groups of Teluk Meranti. Data collected concerned their perceptions of forest and land fires, and of fire prevention measures.

Data analysis

We analyzed factors (both biophysical and social factors) driving forest and land fire in Pelalawan District of Riau Province. The soil properties were analyzed using analysis of variance (ANOVA) of two factors, viz. peat depth and land-use types. A General Linear Model (GLM) for each parameter was estimated using software of IBM SPSS statistics ver. 21.

Spatial data were analyzed via the following four steps: (i) each variable of the model was classified; (ii) each factor of fire susceptibility was weighted; (iii) score and score estimation of each sub-factor was calculated, using formula of Samsuri et al. 2012 and Tata et al. 2017; (iv) a rescaling score was calculated using the formula of Arianti et al. (2007) and Tata et al. (2017).

Score of sub-factor

$$(X_i) = \left(\frac{o_i}{e_i}\right) x \frac{100}{\sum_{i=0}^{n} \frac{o_i}{e_i}} \tag{1}$$

Number of expected hotspots of each sub-factor

$$(e_i) = \frac{T x F}{100} \tag{2}$$

$$\text{Score } R_{out} = \left[\frac{(\text{Score } e_{input} - \text{Score } e_{min})}{(\text{Score } e_{max} - \text{Score } e_{min})} X (\text{Score } R_{max} - \text{Score } R_{min})\right] + \text{Score } R_{min} \tag{3}$$

Note:

X_i = Score of sub-factor
o_i = Hotspot number of each sub-factor
e_i = Expected hotspot number of each sub-factor
T = Total hotspot number
F = Area percentage of each sub-factor
Score R_{out} = Score from rescaling calculation
Score E_{input} = Score of estimated input
Score E_{min} = Minimal value of estimated score
Score E_{max} = Maximal value of estimated score
Score R_{max} = Maximal score of rescaling calculation
Score R_{min} = Minimal score of rescaling calculation

Rescaling score for each factor was used to calculate multiple scores of several factors using Composite Mapping Analysis (CMA) method as explained by Samsuri et al. (2012) and Tata et al. (2017). Multiple regression analysis was used to determine the weight of each factor. The regression model shows the relation between estimation of hotspot density and composite score of each factor. The best regression model for each factor was chosen based on the coefficient determination (R^2). The weight of a factor was resulted from a comparison between regression coefficients of the factor to the total amount of regression coefficients. The fire susceptibility level of an area (polygon) was determined based on scores of rescaling and the weight of the factors. This was calculated using the field calculator in the ArcGIS software.

The estimated value of hotspot density of each area represents the fire susceptibility level. This was classified into four classes (Tata et al. 2017) i.e.: (i) Less susceptible, when the estimated value of hotspot density per km^2 is less than 0.061; (ii) Rather susceptible, when the estimated value of hotspot density per km^2 is less than 0.121; (iii) Susceptible, when the estimated value of hotspot density per km^2 is less than 0.181; (iv) Very susceptible, when the estimated value of hotspot density per km^2 is more than or equal to 0.181.

The map of fire susceptibility was then overlaid with the sub-district administrative map. The total area of each level of fire susceptibility was analyzed based on this map.

The in-depth interview data with key stakeholders on policy and regulations related to fire prevention was analyzed and synthesized.

RESULTS AND DISCUSSION

Hotspot number and distribution

According to NOAA18 satellite data, the number of hotspots in Pelalawan District decreased from 2911 to 2017 (30.71%) during the year 2013 to 2014. In 2015, the hotspot number again decreased to 1784 (11.55%). The majority of hotspots usually occurred in June to August. However, an anomaly was shown in 2014, when most hotspots occurred in February and March. Monthly hotspot data in the period 2013-2015 is shown in Figure 1.

Hotspot distribution for Pelalawan District, Riau Province was developed based on the hotspot data from the years 2013 to 2015, as shown in Figure 1. Recurrent fires occurred in some places in Pelalawan District, e.g. Teso Nilo National Park, Teluk Meranti, and Ukuy sub-districts.

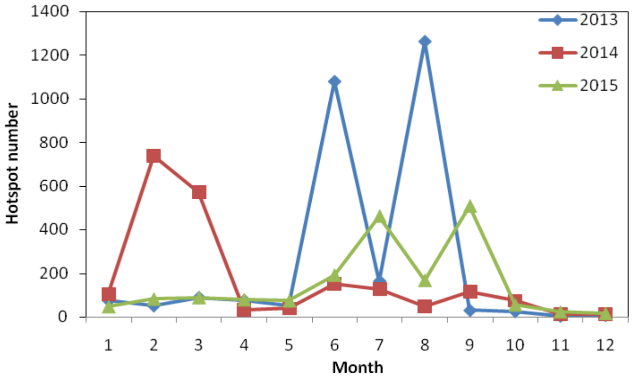

Figure 1. Hotspot data in 2013-2015 in Pelalawan District, Riau Province, Indonesia

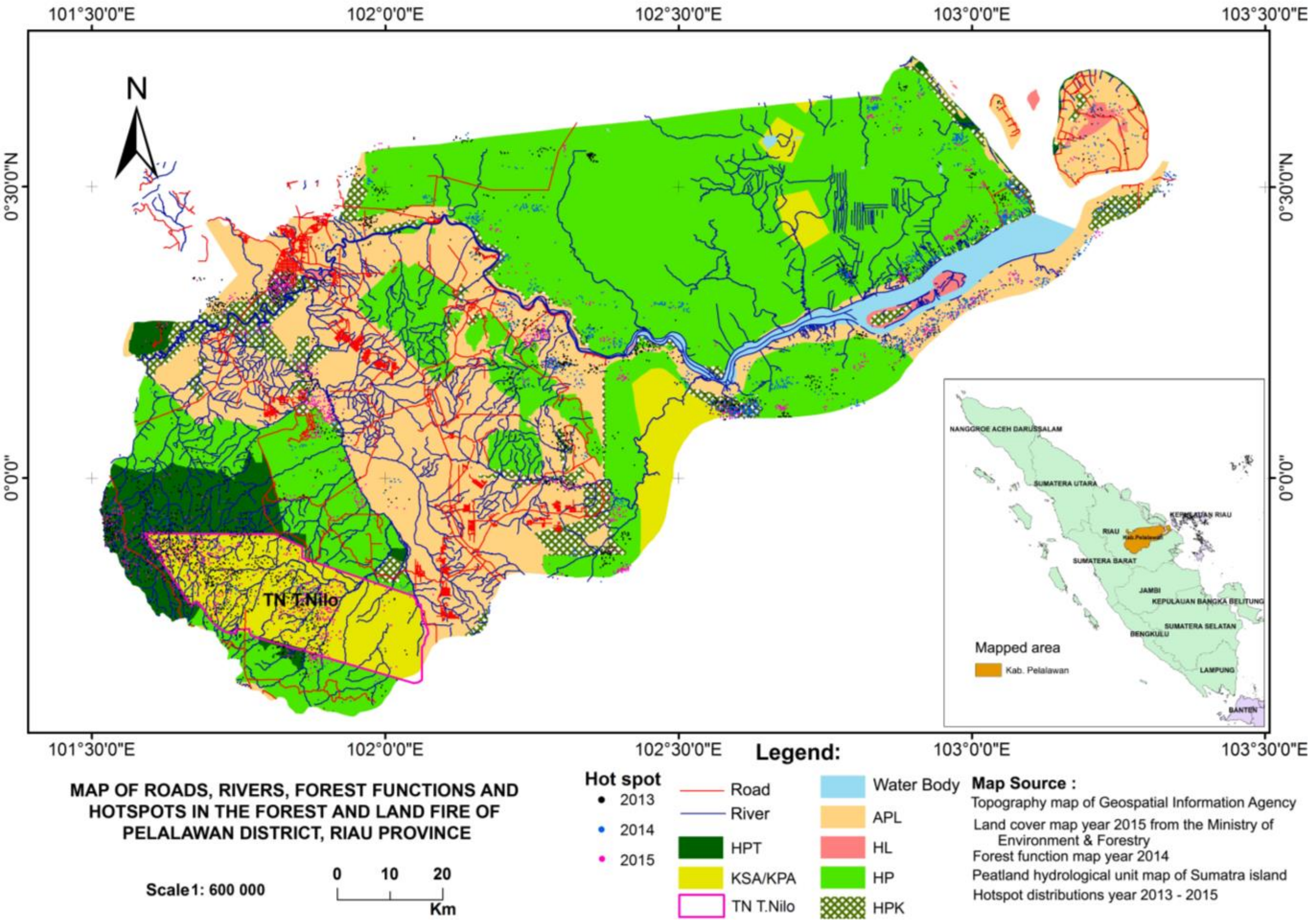

Figure 1. Hotspot distribution in Pelalawan District, Riau Province, Indonesia, for the years 2013-2015. (Note of legend: HPT=limited production forest, KSA/KPA: conservation forest/wildlife sanctuary, TN T.Nilo: Tesso Nilo National Park, APL: non-forest area, HL: protection forest, HP: production forest, HPK: converted production forest)

Table 1. Hotspot density and score resulting from re-scaling for values of the four variables: soil type, nearest distance to a road, forest function and land-use type

Factors	Area (km^2)	Hot-spot number	Density (hs km^{-2})	Score R-out	Regression models for each factor & R^2
Soil type :					
Peat	7671.2	3987	0.520	100	$Y_{ST} = 7E\text{-}09e^{0.2705X}$
Mineral	5530.0	2511	0.454	87	$R^2 = 0.5275$
Distance to road (km) :					
1	2628.6	832	0.317	10	$Y_{DR} = -0.0004X^2 + 0.0143X + 0.4575$
3	2871.7	1423	0.496	50	$R^2 = 0.1612$
5	1626.9	1060	0.652	85	
10	2013.5	1448	0.719	100	
20	1519.7	663	0.436	37	
40	2321.5	1072	0.462	42	
Forest function :					
Production forest (PF)	6075.9	2068	0.340	6	$Y_{FF} = 0.2239e^{0.0636X}$
Protection forest (RF)	89.4	34	0.380	10	$R^2 = 0.9868$
Non-forest area	3737.0	1505	0.403	12	
Limited production forest	646.4	605	0.936	63	
Nature forest reserve	1190.1	1348	1.133	82	
Converted production forest	703.4	930	1.322	100	
Land use type :					
Waterbody	159.7	8	0.050	11	$Y_{LU} = 0.0998e^{0.1406X}$
Shrubs	44.1	122	2.768	100	$R^2 = 0.6233$
Swampy shrub	1061.0	1182	1.114	46	
Dry-land secondary forest	168.0	81	0.482	25	
Secondary swamp forest	2890.4	186	0.064	12	
Forest plantation	2306.7	792	0.343	21	
Estate	3480.0	807	0.232	17	
Settlement	115.9	1	0.009	10	
Mining	13.7	1	0.073	12	
Dry-land agriculture	223.6	34	0.152	15	
Mixed dry-land agriculture & shrubs	739.0	626	0.847	37	
Swamp	24.0	14	0.584	29	
Paddy-field	59.9	25	0.418	23	
Bare-land	1601.2	2619	1.636	63	

Hotspot density

Hotspot density was calculated based on four factors, i.e. forest functions, land-use types, soil types, and distance to the nearest road. In the Indonesia Law no. 41/1999, the state forest area can be distinguished based on its functions, which are classified into three main categories, namely conservation, preservation, and production forests. Regression analysis for the four factors is shown in Table 1. Table 1 showed that forest function (FF) has the strongest positive relationship with hotspot density compare to other factors (R^2=0.9868). In contrast, distance to nearest road has the lowest relationship with hotspot density.

Map of fire susceptibility

Multiple regression analysis for the effect of the four variable determining hotspots density produced the following model: Y = 0.005384 + 0.000021 ST + 0.000019 DR + 0.000038 FF + 0.000017 LU, where ST is soil type, DR is distance to road, FF is forest functions, and LU is land use type.

Each factor (independent variable) was weighted based on the regression model. The contribution of each of the four variables was estimated to be: soil types (22%), distance to road (20%), forest function (40%) and land use type (18%). The map of fire susceptibility was created, as shown in Figure 2.

The level of fire susceptibility was calculated for each sub-district. Overall, 49.9% of the area of Pelalawan District is classified as least susceptible to fire, while 11.9% of the district is classified as highly prone to fire. Teluk Meranti sub-district, which is dominated by peatland, has the largest area classed as highly prone to fire (Table 2).

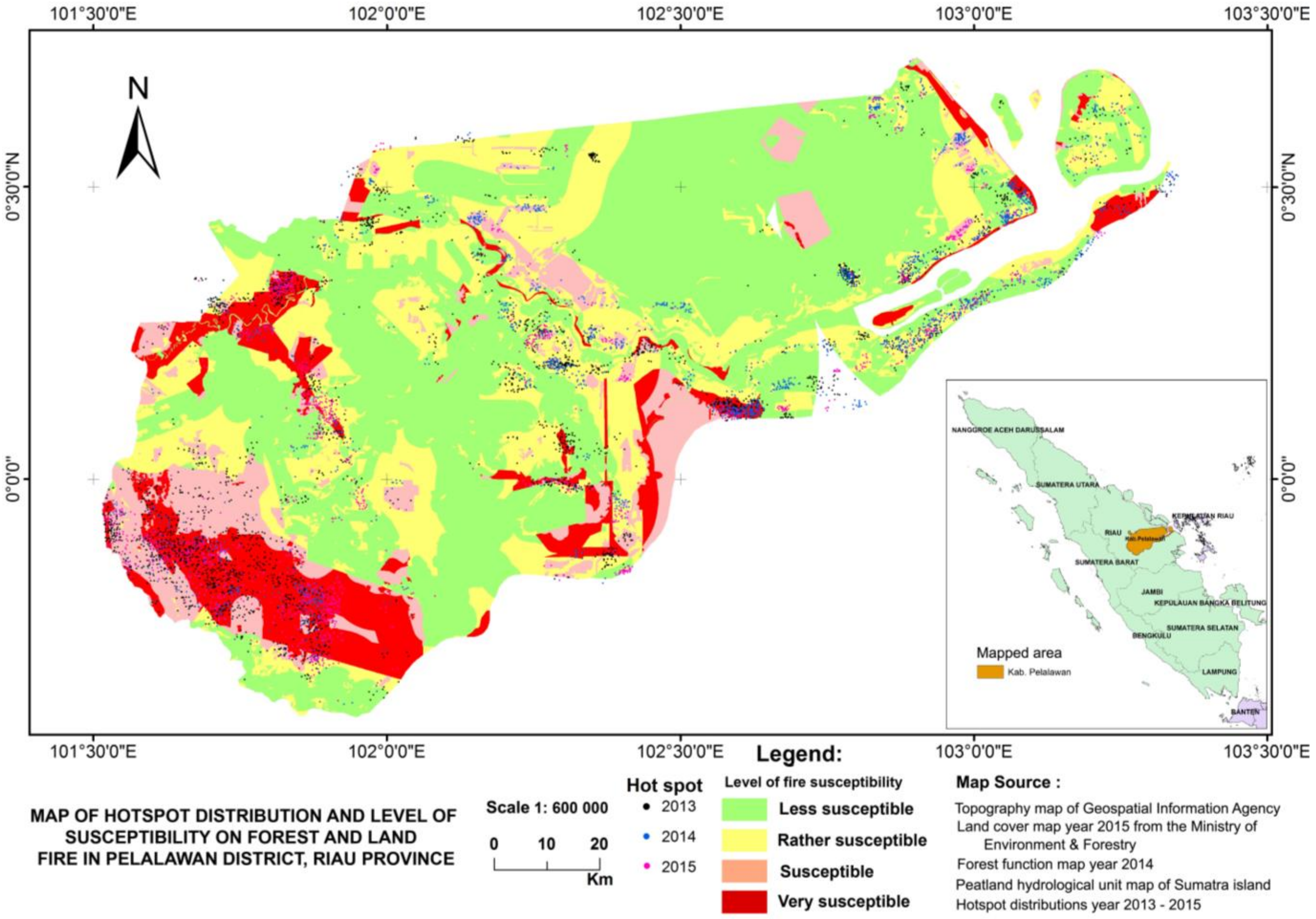

Figure 2. Map of fire susceptibility on forest and land in Pelalawan District, Riau Province, Indonesia

Table 2. Area of land (ha) within each fire susceptibility level for each sub-district of Pelalawan District, Riau Province, Indonesia

Sub-district	Area (ha) of each susceptibility level					Proportion of sub-district area (%)
	Less susceptible	Rather susceptible	Susceptible	Very susceptible	Total	
Bandar Petalang	24,530.1	10,956.2	728.0	28.8	36,243.1	2.9
Bandar Sei Kijang	4,520.2	5,440.6	26.2	23.0	10,010.0	0.8
Bunut	24,410.2	17,915.2	1,697.0	519.2	44,541.6	3.6
Kerumutan	23,822.9	30,334.8	21,386.3	18,315.0	93,858.9	7.6
Kuala Kampar	26,935.5	21,142.4	3,917.3	9,603.3	61,598.5	5.0
Langgam	35,812.4	34,732.4	41,588.1	33,072.0	145,204.9	11.7
Pangkalan Kerinci	10,899.2	3,782.1	343.1	5,494.6	20,519.0	1.7
Pangkalan Kuras	57,728.5	27,251.0	15,869.4	21,867.5	122,716.4	9.9
Pangkalan Lesung	25,905.8	13,131.5	3,013.1	1,834.5	43,884.8	3.5
Pelalawan	51,724.3	65,133.5	14,530.5	4,882.6	136,270.9	11.0
Teluk Meranti	274,673.9	86,181.4	25,490.0	8,287.6	394,632.9	31.7
Ukui	59,848.7	16,949.5	13,291.9	43,462.7	133,552.9	10.7
Total	620,811.6	332,950.5	141,880.9	147,390.9	1,243,034.0	100
Percentage area of each susceptibility level to total area (%)	49.9	26.8	11.4	11.9	100	

Impact of fire on peat soils

The soil properties on burnt peatland vary between four land use types (namely secondary forest, oil palm plantation, rubber plantation, and agricultural crops) as shown in Table 3. The land use types significantly affected several soils properties, namely: pH, water content, bulk density and content of P_2O_5. The water content was the only variable affected by the peat depth. The upper layer (0-50 cm) had lower water content than the lower peat layer (50-100 cm). Other properties, such as ash content, organic matter, C organic, N_{total}, CEC, and pyrite, were not affected by land use type or by peat depth.

Response to forest and land fire

According to the records for the Strategic Forest Planning Office at Provincial level in the years 2014-2019, the government of Riau Province targeted a 20% reduction in total hotspots annually for the years 2014 to 2019 (Dinas Kehutanan Provinsi Riau 2014). The number of hotspot reduced from 2911 in year 2013 to 1784 in year 2015, which accorded with the target of the Strategic Forest Planning Office of Riau Province.

The Governor of Riau Province released Regulation no. 11 in the year 2014 regarding the Centre of Forest and Land Fire Control of Riau Province (Gubernur Riau 2014). This regulation aims to strengthen the unity of steps and actions in forest and land fire control. The organization and roles of the Centre are described in the regulation. The Riau Province aims for a policy of "non-burning"; all concessions operating in Riau Province have an obligation in fire prevention and control. In addition, a Community's Fire Care Unit (*Kelompok Masyarakat Peduli Api*) has been established at the village level.

As a response to forest and land fire in 2015, the Governor of Riau Province also released Regulation No. 61/2015, on an Established Procedure for Forest and Land Fire Disaster Control. This regulation aims to provide guidance on forest and land fire disaster control in Riau Province (Gubernur Riau 2016). This is in accordance with the Government Regulation No. 21 of the year 2008, requiring disaster conditions to be officially announced and declared by the Governor at provincial level, or by Head of District at district level.

Discussion

The largest area of Pelalawan District that is very susceptible to fire is in the peatland, e.g. Teluk Meranti, where recurrent fires occurred in 2013-2015. Teluk Meranti is dominated by peatland. The community who live in the area use the peatland for agriculture such as oil palm, rubber and cash crops. Although a 'no-burning policy' was launched by the local government, nevertheless, up to mid-2015, fire was still being used in land preparation for agriculture. Some farmers selected as respondents for our interviews, stated that slash-and-burn has been used since long ago as part of their agricultural practices. The reason for their practice of prescribed burning was that it was a simple and fast technique for preparing land for agricultural use. The ash from the biomass burning is believed to improve soil pH and fertility. Saharjo (2007) reported pH of sapric peat soil was not affected by fire, while our study showed pH and ash content are affected by fire. Sulwinski et al. (2017) also reported soil pH and ash content of upper layer of fen-soil increased after it has burnt. It is shown in Table 3, that the upper layer of crop-land has the highest pH (4.70), ash content (11.38%) and P_2O_5 (423.15%), but low CEC (58.76%), compared to other land use classes. The high recorded phosphorus content suggests that the farmers are also giving high inputs to those peatlands where they plant crops regularly.

Table 3. The properties of peat soils from different land use types, namely unburnt secondary forest (SF), burnt secondary forest, burnt oil palm plantation, burnt rubber plantation, and burnt crop-lands, in Pelalawan District, Riau, Indonesia

LUT	Depth (cm)	pH	WC (%)	BD (g cm^{-3})	AC (%)	OM (%)	Corg (%)	N (%)	P (ppm)	CEC (cmol kg^{-1})	Pyrite (%)
SF	0-50	4.10	85.10	0.12	2.41	97.59	50.78	1.0	58.10	60.85	0.01
		(0.27) b	(0) bc	(0.03) ab	(4.19) a	(4.19) a	(2.18) a	(0.41) a	(75.17) d	(19.77) a	(0.09) a
	50-100	3.60	87.60	0.12	2.80	97.20	50.57	1.42	65.60	62.52	0.16
		(0.27) c	(0) b	(0.03) ab	(4.19) a	(4.19) a	(2.18) a	(0.41) a	(75.17) cd	(19.77) a	(0.09) a
SFB	0-50	3.10	84.20	0.08	6.61	93.39	48.59	1.44	24.0	75.31	0.13
		(0.19) d	(0.42) c	(0.02) d	(2.96) a	(2.96) a	(1.54) a	(0.29) a	(53.15) de	(13.98) a	(0.06) a
	50-100	3.35	86.90	0.13	6.07	93.93	48.87	0.99	7.0	65.28	0.02
		(0.19) cd	(1.41) b	(0.02) a	(2.96) a	(2.96) a	(1.54) a	(0.29) a	(53.15) e	(13.98) a	(0.06) a
OPB	0-50	3.60	84.20	0.11	7.68	92.32	48.03	1.25	111.83	60.47	0.20
		(0.15) c	(7.64) c	(0.02) bc	(2.42) a	(2.42) a	(1.26) a	(0.24) a	(43.4) c	(11.41) a	(0.05) a
	50-100	3.67	88.50	0.12	8.69	91.31	47.51	1.28	70.97	58.42	0.06
		(0.15) c	(1.21) b	(0.02) ab	(2.42) a	(2.42) a	(1.26) a	(0.24) a	(43.4) d	(11.41) a	(0.05) a
RB	0-50	3.15	87.65	0.11	3.26	96.74	50.33	1.29	206.65	99.32	0.08
		(0.19) d	(0.92) b	(0.02) bc	(2.96) a	(2.96) a	(1.54) a	(0.29) a	(53.15) b	(13.98) a	(0.06) a
	50-100	3.45	90.10	0.09	3.50	96.48	50.20	1.24	166.45	68.96	0.05
		(0.19) cd	(0.14) a	(0.02) cd	(2.96) a	(2.96) a	(1.54) a	(0.29) a	(53.15) bc	(13.98) a	(0.06) a
CRB	0-50	4.70	87.05	0.10	11.38	88.63	46.11	1.39	423.15	58.76	0.20
		(0.19) a	(1.91) b	(0.02) bc	(2.96) a	(2.96) a	(1.54) a	(0.29) a	(53.15) a	(13.98) a	(0.06) a
	50-100	3.80	90.45	0.10	3.73	96.27	50.09	0.98	193.0	95.51	0.15
		(0.19) bc	(1.48) a	(0.02) cd	(2.96) a	(2.96) a	(1.54) a	(0.29) a	(53.15) b	(13.98) a	(0.06) a

Note: LUT: land use type, SF: secondary forest, SFB: burned secondary forest, burned oil palm plantation, burned rubber farm, CRB-burned crops, WC: water content, BD: bulk density, AC: Ash content, OM: organic matters, Corg: C organic, N: Nitrogen, P: Phosphor, CEC: cation exchange capacity. Numbers in parentheses are standard error of means. Means followed by the same letters showed in the same column are not significantly different at 95 % confidence level of Tukey's post hoc test.

It is surprising that soil type has only a moderate relationship with hotspot density in Pelalawan District. This is connected to fact that frequent recurrent fires occurred in a national park which is located on mineral soils. It is evidence that fire incidence is not only affected by biophysical factors such as peat soil type. This contrasts with hotspot density in Kapuas district, Central Kalimantan Province (Thoha et al. 2014) and Musi Banyusin district, South Sumatra province (Tata et al. 2017), where hotspots mostly occur in peat soils.

The hotspot and recurrent fires that occurred in Teso Nilo National Park in Pelalawan District were driven by human activities. People used fire as a weapon for land grabbing. The WWF-Riau programme has reported that land encroachment has occurred in the National Park. Many social problems, such as land claims, have been encountered as a result of recurrent fires, as has also been shown in other parts of Indonesia (Purnomo et al. 2017; Cattau et al. 2016; Gaveau et al. 2017).

At the national and provincial level, the fire-prevention policy package has been comprehensive enough (Rosul 2015). However such regulations related to fire prevention appear not to be sufficient to stop fire hazard in the districts of Riau Province. Dewi et al. (2015) reported the existing law enforcement is inadequate to prevent fires in Kalimantan and Sumatra. We recommend the implementation of fire prevention on the ground needs also to include social participation approaches at the community level, such as: improving the capacity of the communities' fire care units; providing alternative and applicable non-burning technologies for preparation of agricultural lands; and creating incentive mechanism to reward the zero-burning practices, not only for the corporate sector, but also for the local communities.

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