The Impact of Surface Fires on Peatland in the Land Preparation Area belong to the Community

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Abstract

It is well known that at least 20 million of Indonesia's people were directly or indirectly affected by the 1997/1998 Indonesian forest and field fires, where 10-11 million acres of forest and fields burnt. Haze contains many air pollutants such as CO, CO_2, SO_2, $NO_{(x)}$ and NH_4. These and bacteria caused thousands of people in Riau, Jambi, South Sumatra, and Central, West and East Kalimantan to be hospitalized, with 527 fatalities in a mere three months. It has also been found that 80% to 90 % of the Indonesian fires resulted from estate crops and industrial forest plantations as the result of actions by companies and communities. The communities claimed that using fire in land preparation is cheap, easy and quick, but unfortunately the facts are not clear from much scientific evidence.

In order to determine the impact of peatland fires started by communities during land preparation, an experimental land preparation using fire in peatland was conducted in a village area in Pelalawan, Riau Province, Sumatra. The main objective of the research was to evaluate the response of the ecosystem, including greenhouse gas emissions released by the fires used for land preparation for agricultural purposes by the community. The results of the research show that factors such as fuel load, fuel bed depth and water table performance are critical to the degree of peat destruction and ultimately affect green house gas (GHG) emissions released during burning.

Key words: fires, GHG, land preparation, peat, Riau, Sumatra

1. Introduction

Transboundary haze pollution due to the smoke from land preparation using fire has become a big problem in Indonesia every year, especially when the dry season comes, since ten years ago. It has been found that most of the smoke originates from illegal land preparation fires in oil palm and industrial forest plantations (60%-80%) as well as from shifting cultivation, which, unfortunately, is usually blamed for the smoke (Saharjo, 2007). It is well known that when fires broke out in many provinces in Indonesia, many people blamed shifting cultivation as the cause of them, because communities were using fire for land preparation for agricultural purposes. People engaging in shifting cultivation used fire for their land preparation, because it was cheap and easy to do, and it had been done for thousands years (Goldammer, 1993) with no environmental problems like those happening now. Shifting agriculture systems in their early practice and extended use were possible largely due to low human population pressure on the forest resources. They provided a sustainable base of subsistence for indigenous forest inhabitants, and their patch impacts had little

effect on the overall forest ecosystem stability (Nye & Greenland, 1960).

Humans probably had a role in starting forest fires in recent millennia, and may have deliberately burned forest to improve hunting for thousands of years (Qadri, 2001). As prehistoric human settlers of the Indonesian archipelago began to switch from hunting and gathering to growing crops, they used fire to clear agricultural plots in the forest. The cycle of forest clearing, cultivation and abandonment is known as swidden, kaingin or shifting cultivation, an agricultural system adopted throughout most of the region over a period of thousands of years. Swidden cultivation has continued into this century in locations where soils are too poor to support permanent cultivation of annual crops.

Smoke problems, especially those resulting from community activities, should be reduced but they cannot be directly postponed or prohibited, because previous experience has shown that banning the use of fire for preparation of land belonging to communities results in more fires and damage (Saharjo & Husaeni, 1998). Accordingly, they still may use fire for their land preparation but under controlled conditions, especially with

regard to smoke problems, which have been implicated in emissions of trace gases produced during burning. One of the promising solutions is a burning method producing less smoke. This low-smoke burning method is pre-scribed burning which produces less smoke.

Smoke management strategies for prescribed burning consist largely of conducting fire under specified fuel loading, fuel moisture regimes and meteorological con-ditions, and specifying ignition techniques that maintain the smoke's environmental impact within acceptable limits (Debano *et al*., 1998). Smoke management prac-tices include reducing fuel loads, improving combustion efficiency, igniting fires effectively and mopping-up efficiently. The specific practices used in a locality or region depend largely on the fire management objectives to be satisfied and the types of fuel to be burned (Debano *et al*., 1998). Prescribed burns conducted when small fuel moisture is low, large fuel moisture is high, and forest floor moisture is high also substantially reduce emissions by making less fuel available for combustion. Prescribed fires can have a wide range of particulate emissions fac-tors, with magnitudes of these factors depending on whether the fire is dominated by flaming combustion or smoldering. Smoldering fires have the greatest emissions factors for nearly all combustion products (Debano *et al*., 1998). Avoidance of potential smoke problems is achieved by scheduling burning during the season when fuel moisture and meteorological conditions are likely to result in reduced smoke emissions or involvement of urban areas. Dilutions involve controlling emission rates by fire management techniques or scheduling prescribed fires for when atmospheric processes favor unstable conditions and therefore maximum mixing of the lower atmosphere. A key to good smoke dilution and dispersal is accurate weather forecasts of wind speed and direction, atmospheric stability and mixing heights (Debano *et al*., 1998).

The purpose of the present research was to determine the impact of using fire in land preparation areas belong-ing to a community on the peatland surface area, includ-ing greenhouse gas emissions released during burning.

2. Study Area and Method

2.1 Study area

Research was conducted in the period of August 2001 through July 2002 in a peatland area dominated by Sapric belonging to the community of Pelalawan Village, Pelalawan Sub-district, Pelalawan District, Riau Prov-ince. Based on survey results and information in their book about the land site, with maps and soil information, Solok and Pekanbaru (1997) stated that the research site in Pelalawan District was dominated by peat and in-cluded in the 'peat dome' physiographical group. 97.1 % of the site was located on 0%-8% slopes, while the rest was located on slopes of 8%-15%.

The climate in Pelalawan District cannot be distin-guished from that of Riau Province, generally being tropical with an annual rainfall ranging from 2,500 to 3,000 mm with daily temperatures between 22°C and 31°C. According to data from the Meteorological and Geophysical Agency, Ministry of Transportation, the annual rainfall in the period between January and December 2001 at the site was 3,794.5 mm, accounted for by 86 rainy days.

A vegetation analysis showed that the research site was dominated by shrubs and ferns, the trees found inclu-ded *Shorea macrophylla, Macaranga pruinosa, Ficus sundaica, Stenochlaena palustris, Parastemon uruphyl-lus, Baccaurea pendula, Nephorlepis flaccigera* and *Gleinchenia linearis*.

2.2 Methods: plot establishment and field experiments

Before burning, three plots of 400 m^2 (20 m x 20 m) each surrounded by a one-meter canal with a depth of 1.5 m were set up at a Sapric peat site located on community land in Pelalawan, Riau, Indonesia (Fig. 1). In each plot, three sub-plots of 2 m^2 were established and chosen randomly for the estimation of fuel load, fuel bed depth and fuel moisture. Another sub-plot of the same size was selected for estimating the rate of spread of the fire, flame height, flame temperature and peat destruction through heat penetration.

Before slashing and burning were conducted, envi-ronmental conditions (temperature, relative humidity and wind speed) were measured, and fuel and peat characters were identified. Following those activity, slashing was conducted where big logs (diameter of more than 10 cm) were removed from the plot. The slashed logs and branches were separated throughout the plot and dried under the sun for about three weeks.

After three weeks, when the slash and small logs had dried, the entire plot was burned using the ring method, which is the technique usually used by the community to burn dried logs and branches. Burning was started under one command and proceeded in a clockwise direction, with a bamboo torch used as the source of fire. The fire was allowed to spread naturally in the subplot, finally ending in the middle of the ring with no fire jumping to non-target areas. Through this technique the community needed no help from other groups because they could handle the fire by themselves, *i.e*., to burn one hectare, only three persons were needed. During burning, the fire behavior (rate of the spread of fire, flame length, flame temperature) was monitored and recorded using a handy camera, and greenhouse gas emissions were taken at different stages of combustion (flaming, smoldering and glowing) using a handy pump. Burning was done in the afternoon in the period of 13.00 to 17.00 p.m. using a torch made from bamboo filled with gasoline. Imme-diately following the burning, the fuel left in all plots was measured.

2.3 Estimations of fuel load, fuel bed depth and fuel moisture
2.3.1 Estimation of fuel load

All vegetation found in the sub-plot in each plot,

including shrubs, seedlings, saplings, poles and trees were cut down and the understorey was slashed. After slashing was accomplished, the debris was dried under the sun for three weeks as was usually done by the community. To estimate the fuel load, three sub-plots of 2 m^2 (2 m x 1 m) were set aside in the plots (Fig. 1). The amount of plant materials both living and dead in the sub-plots were collected and weighed following the three weeks of drying.

2.3.2 Estimation of fuel moisture

The fuel load moisture content was calculated by obtaining three samples of 100 grams each of materials found in the subplots (litter, leaves, branches and logs) that were taken and used as samples for moisture content measurements. The samples were put in an oven and dried for 48 hours at 75°C (Clar & Chatten, 1954). The fuel moisture content was estimated on a dry weight basis. The peat moisture was calculated by obtaining three samples of 100 grams of peat found in the subplots and using them as samples for moisture content measurements. The samples were put in an oven and dried for 48 hours at 75°C (Clar & Chatten, 1954). The peat moisture content was estimated on a dry weight basis.

2.3.3 Estimation of fuel bed depth

The fuel bed depth was measured by the average height of dried fuel that was spread out in each subplot.

2.4 Estimation of flame temperature, rate of spread of fire and flame height

2.4.1 Estimation of flame temperature

The flame temperature at 0 m above soil and 1 cm below the ground were measured using temperature sensors (thermocouples) and recorded using a data logger. The temperature sensors were placed in each subplot at two locations.

2.4.2 Estimation of the rate of spread of fire

The rate of spread of the fires when the surface was burning was measured by the average distance traveled
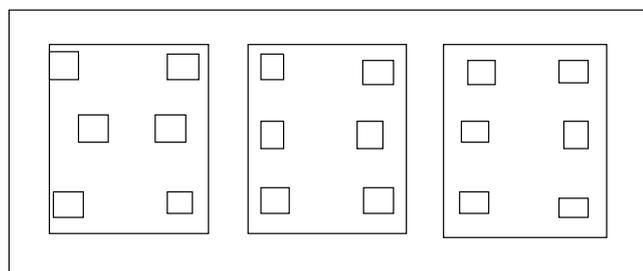
perpendicular to the moving flame front per minute, using a stop watch and tape and supported by the results of video camera recording.

2.4.3 Estimation of flame length

It was very difficult to measure the average flame length directly in the burning condition, so the flame length was calculated using scaled bamboo and supported by video camera recording.

2.5 Smoke sampling during burning

Smoke samples were collected by using a portable pump connected to a vacuum plastic. Smoke was taken at different phases of the combustion processes during burning, namely flaming, smoldering and glowing. Gases in the vacuum plastic were transferred to a vacuum bottle which was then sent to the Greenhouse Gas Laboratory of the National Institute for Agro-Environmental Science, Tsukuba, Japan for further analysis. The gases analyzed were CO, CO_2, N_2O and CH_4.

2.6 Follow-up after burning

Following burning, the burnt fuel percentage was estimated by identifying, collecting and segregating burnt materials based on their own fuel characteristics (litter, branches and logs) in the subplots.

Peat destruction due to the surface fire was estimated through heat penetration, which usually burnt the peat and blackened it.

2.7 Fire intensity

The fire intensity was calculated using Byram's equation (Chandler et al., 1983), FI=273 (h)$^{2.17}$, where: FI is fire intensity (kW/m), and h is flame length (m).

2.8 Data analysis

For statistical analysis, a completely random design of variance was used to test for differences among subplots, based on the following model (Steel & Torrie, 1981): Ymn = U + Tm + Emn, where Ymn = fuel and fire behavior parameter at subplot m in replication n, U = the mean of the treatment population sampled, Tm = treatment (slashing, drying, burning) and Emn = the random component. To detect significant differences in fuel and fire behavior parameters among the subplots (p≤0.05), the Duncan test was used (Steel & Torrie, 1981).

3. Results

After being slashed and dried, the highest fuel load found was 132.3 ton/ha in the third subplot. The total fuel load in the other subplots varied from 110.83 ton/ha to

Fig. 1 Sampling plots in the field experiment.

Table 1 Fuel load before burning (tons/ha).

Plot	Litter	Branches	Logs	Total
1	(20.83±1.44)a	(40.83±23.22)b	(57.50±2.50)a	(119.17±24.66)a
2	(23.30±7.63)a	(32.33±8.74)a	(55.17±10.78)a	(110.83±23.50)a
3	(22.50±2.50)a	(36.37±13.77)ab	(73.17±18.37)b	(132.33±25.64)b

• Different letters following standard errors indicate significantly different means (p≤0.05).

119.17 ton/ha (Table 1). The fuel bed depth in the second subplot was the shallowest at 82.8 cm, and differed significantly from those of the other subplots, while the greatest depth was found in the first subplot at 100 cm (Table 2). The fuel load with the highest fuel moisture content following slashing was logs in the third subplot at 34.14 %, while the lowest was dry leaves in the second subplot at 9.54 % (Table 3). The peat moisture varied from 201.29% to 330.05% and differed significantly (Table 4). During burning it was found that rate of spread of the fires was highest in the third subplot at 1.11 m/minute, and the lowest in the first subplot at 0.47 m/minute (Table 5). The flame length was highest in the third subplot at an average of 3.09 m, and the lowest in the first subplot at 1.56 m (Table 5). The flame tempera-

ture at the ground (peat surface) in the third subplot was 1,000°C. This temperature was the highest, while the lowest was in the first subplot at 800° (Table 5). The highest fire intensity, 1830.55 kW/m, was recorded in the third subplot. It was differed significantly from those of the other subplots (Table 5).

Burnt litter (leaves) in the subplots varied from 5.9 tons in the first subplot to 8.9 tons in the third subplot, burnt branches varied from 8.5 tons in the first subplot to 14.8 in the third subplot, and burnt logs varied from 1.6 tons in the first subplot to 3.4 in the second subplot (Table 6). The depth and size of burnt peat varied in each subplot. The deepest burnt peat surface among the subplots was that of the second subplot at 31.87 cm with an area of 7 m^2 which was equal to 1.75% of the area burnt. The shallowest was 12.72 cm in the fourth subplot with an area of 22 m^2 which was equal to 5.5 % of the area burnt (Table 7).

CO_2 emissions during the flaming stage were found to range from 1,046 to 2,039 ppm; during the smoldering stage, from 3,985 to 5,681 ppm; and during the glowing stage, from 736 to 9,958 ppm (Fig. 2). CO emissions during the flaming stage were found to range from 149 to 172 ppm; during the smoldering stage, from 255 to 801 ppm; and during the glowing stage, from 297 to 470 ppm (Fig. 3). CH_4 emissions during the flaming stage ranged from 11.3 to 40.5 ppm; during the smoldering stage, from 15.5 to 113.2 ppm; and during the glowing stage, from 24.9 to 61.6 ppm (Fig. 4). N_2O emissions during the flaming stage ranged from 367 to 435 ppb; during the smoldering stage, from 526 to 853 ppb; and during the glowing stage, from 405 to 594 ppb (Fig. 5).

Table 2 Fuel bed depth in the subplot.

Plot	Depth (cm)
1	(100.0±39.96)b
2	(82.8±21.3)a
3	(98.4±47.3)b

- Different letters following standard errors indicate significantly different means (p≤0.05).

Table 3 Fuel moisture content before burning (%).

Plot	Leaves	Branches	Logs
1	(11.73±1.41)a	(18.85±2.29)a	(31.62±0.53)a
2	(9.54±1.88)a	(19.19±4.43)a	(30.31±5.10)a
3	(9.85±1.97)a	(19.74±3.03)a	(34.14±1.39)a

- Different letters following standard errors indicate significantly different means (p≤0.05).

Table 4 Peat moisture content at the site.

Parameter	Plot 1	Plot 2	Plot 3
Moisture content (%)	(201.29±74.63)a	(234.23±30.26)b	(330.05±78.41)c

- Different letters following standard errors indicate significantly different means (p≤0.05).

Table 5 Weather conditions and fire behavior parameters during burning.

Parameter	Plot 1	Plot 2	Plot 3
Weather condition			
Temperature (°C)	38	38	39
Relative humidity (%)	55	50	49
Wind speed (m/sec.)	0.41	1.09	1.07
Fire behavior			
Fuel load (tons/ha)	(119.17±24.66)a	(110.83±23.5)a	(132.33±25.64)a
Fuel moisture (%)			
Leaves	(11.73±1.41)a	(9.54±1.88)a	(9.85±1.97)a
Branches	(18.85±2.29)a	(19.19±4.43)a	(19.74±3.03)a
Logs	(31.62±0.53)a	(30.31±5.10)a	(34.14±1.39)a
Flame length (m)	(1.56±0.52)a	(2.11±0.26)ab	(3.09±1.07)b
Fire int. (kW/m)	(792.96±572.40)a	(1401.61±355.17)ab	(1830.55±634.74)b
Rate of spread(m/mnt)	(0.47±0.15)a	(0.99±0.26)ab	(1.11±0.32)b
Flame temp. (°C)			
1 cm below ground	70	90	95
Ground	800	985	1000
Slope (%)	0	0	0
Plot size (ha)	0.04	0.04	0.04
Duration (min.)	22.13	21.30	28.10
Burning time	11.22 a.m.	13.43 p.m.	14.54 p.m.

- Different letters following standard errors indicate significantly different means (p≤0.05).

Table 6 Burnt fuel volume (tons).

Plot	Litter (leaves)	Branches	Logs
1	(5.9)	(8.5)	(1.6)
2	(7.6)	(11.5)	(2.1)
3	(8.9)	(14.8)	(3.4)

Table 7 Burnt peat depth and area.

Plot	Depth (cm)	Burnt area (m^2)	Percentage (%)
1	18	12	3
2	31.87	7	1.75
3	15.44	17	4.25
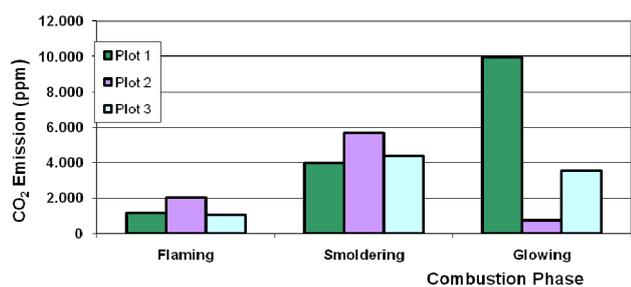
Fig. 2 CO_2 emissions (ppm) during combustion stages.
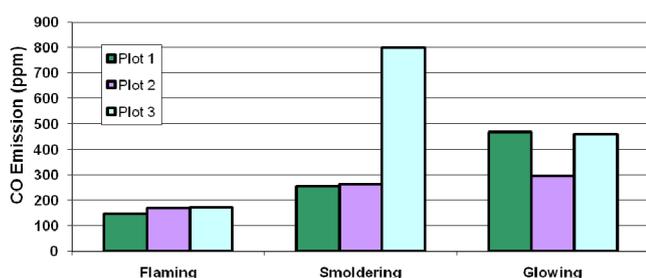
Fig. 3 CO emissions (ppm) during combustion stages.
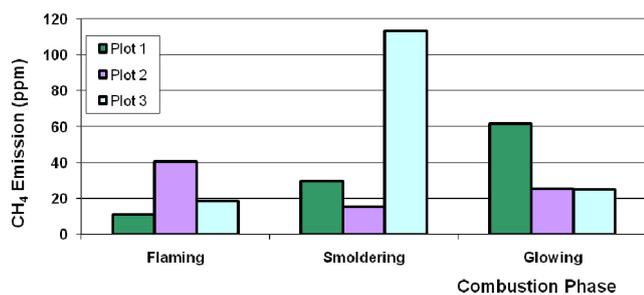

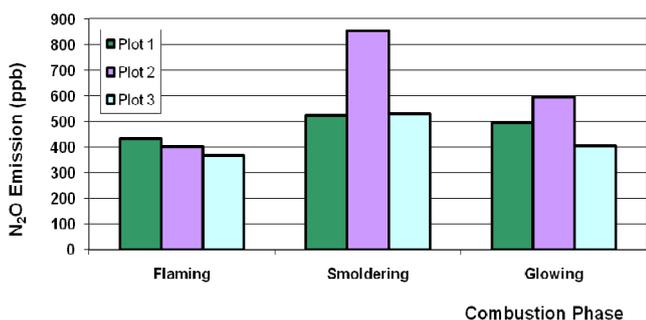**Fig. 4** CH_4 emissions (ppm) during combustion stages.

Fig. 5 N_2O emissions (ppb) during combustion stages.

4. Discussion

The three weeks of drying the fuel load in the subplots drastically changed the fire potency. The driest fuel moisture in all of the subplots varied from 9% to 11%. This driest fine fuel moisture is important because the fine fuel will be burnt as the first fuel. Drying of vegetation following slashing is practiced in Pelalawan before they burn it from the land. In practical application this drying makes the spread of fire relatively uniform. It also allows them to control the area easily and prevent the fire from spreading to non-target sites. Unburned portions of the field create significant problems for them when the site is planted, because those areas are usually the best breeding places for pests and diseases. The fuel bed depth, which varies from 98.4% to 100%, is one of the most important factors in causing different flame lengths, which results in different fire intensities and also has different penetration impacts that are linked with peat destruction. The degree of heat penetration also depends on the magnitude of the flame temperature resulting from the surface fire. Flame temperatures varying from 800°C to 1,000°C in the ground that have heat penetration below ground varying from 70-95 cm due possibly to the high peat moisture, that varies from 201.29% to 330.05%.

During the experiment conducted in each subplot, the weather conditions did not differ significantly. Air temperatures varied from 38°C to 39°C; the relative humidity, from 49% to 55%; and the wind speed, from 0.41 m/minute in the first subplot to 1.09 m/minute in the second subplot. The role of wind speed was very important during burning because all the subplots had 0% slope. It was found that the rate of spread of the fire was highest in the third subplot at 1.11 m/minute; the flame height was 3.09 m; and the flame temperature, 1,000°C. In addition, more time was needed in the third subplot to complete the burning, at 28.1 minutes. The measurements and calculations also indicated that the third subplot had the highest fire intensity recorded at 1,830.55 kW/m. The high fire intensity reached in the third subplot may have been due to the fuel bed depth and high flame length. The maximum peat area destroyed was in the second subplot, with 7 m^2 burnt due to heat penetration during burning, which reached 31.87 cm. The shallowest depth, 12.72 cm, was in the fourth subplot with a burnt area of 22 m^2. This means that controlled burning can be conducted safely and the fire prevented from jumping over to non-target areas. How the worst peat destruction occured during the fires actually depended on how much fuel load was burnt on the surface, which produced heat that could have penetrated into the peat, and that was affected by the peat type and its characteristics, $i.e.$, moisture content of the peat surface. This means that peat destruction can be prevented through higher moisture content in peat, which in this case came from the water canal that surrounded the area. Another important factor is the drying processes at the surface of the peat, which determine how much greenhouse gases are emitted during burning. If the fuel load at the surface is relatively dry then the greenhouse

gases emitted are not so big due to the fire being dominated by the flaming stage. Unfortunately, if the conditions for drying the fuel are not so good then more greenhouse gases will be emitted.

CO_2 emissions are quite high and mostly depend on the characteristics of the fuel left and the peat itself. The proportion of the total combustion processes which make up each stage is mainly controlled by the physical attributes of the fuel and to a lesser degree by the weather during the fire (Scholes *et al*., 1996). In the first plot, glowing stage produced more CO_2 than the smoldering and flaming stages, while in the second and third plot the maximum was found at the smoldering stage. More CO emissions were produced during the glowing stage in the first and second plots compared to the flaming and smoldering stages. Carbon monoxide (CO) is commonly produced with incomplete combustion of moist fuels, and high emissions of CO have been measured in the fire line of relatively low-intensity fires (Sanberg *et al*., 1975), with the amount of CO emitted by the fire being a function of combustion efficiency, increasing as efficiencies drop (Debano *et al*., 1998). Methane (CH_4) emissions were higher during the glowing stage than smoldering and flaming in the first plot, while in the second plot they were higher in the flaming stage and in the third plot, at smoldering stage. N_2O emissions in the first plot were higher in the smoldering stage, while in the second and third plots they were higher in the smoldering stage. Both NO and NO_2 are reactive gases that are emitted during combustion (Lobart & Warnatz, 1993). NO is a thermally stable product of combustion. Although NO_2 is less stable than NO, its abundance increases in smoldering fires (Clements & McMahon, 1980). Drying also determines the time needed for burning the materials, and this has implications for peat destruction and suppression activities. In order to let the fire spread naturally with minimal impact and less peat destruction, it is recommended to leave only small diameter (< 5 cm) logs (branches) for burning and make sure that the materials are dried with not more than 10% moisture content. If this is accompanied by an effective burning technique it will also reduce the smoke produced during burning.

Controlled burning especially by the local people can be used as one method of land preparation using fire as it is guaranteed by the law. Low impact from burning can be achieved through proper activities conducted before and during burning. Activities that can be conducted before burning include fuel selection, slashing and drying. Drying the fuel load at the surface for at least two to three weeks will reduce the fuel moisture content and make the rate of the spread of the surface fire relatively uniform, limiting the danger of wildfire occurrence. Another important factor is the role of water from canals that could protect the peat from heat penetration, thus preventing peat destruction by increasing the water table in the canal.

Acknowledgment

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