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Paper:

Recent Peat Fire Activity in the Mega Rice Project Area, Central Kalimantan, Indonesia

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The original objective of the Mega Rice Project (MRP) in Central Kalimantan, Indonesia – to convert one million hectares of tropical swamp forest to paddy fields – instead produced large areas of abandoned farmland with bare peat subject to frequent fires. To understand how peat fire occurrence is related to drought, we analyzed 1997 to 2007 United States Department Commerce National Oceanic and Atmospheric Administration (NOAA) hotspot data, sea surface temperature (SST) anomalies, and weather data. We found that peat fire activity was proportional to drought severity as determined by SST anomalies, and that peat fires – the number of hotspots – correlated strongly with SST anomalies, implying that MRP area peat fires are related to peat dryness. Surface fires start when ground water levels (GWL) are about 20 cm below the ground surface, and hundreds of such fires can occur with deeper GWL. A detailed and precise hotspot distribution map showed that large MRP areas (Blocks A and C) located on deep peat layers have high fire density due to ongoing human disturbance, classifying MRP area peat fires as a man-made disaster.

Keywords: Peat fire, hotspot, sea surface temperature anomalies, drought, ground water level

1. Introduction

Some 83% of the over 27 million hectares of peatland in Southeast Asia is in Indonesia, mainly on the islands of Papua, Sumatra, and Kalimantan [1]. Of the total of 225,234 km^2 of Indonesian lowland peat area, 26% is in Kalimantan and peatland in Central Kalimantan accounts for 53% (**Table 1**).

In 1996, the Indonesian Government initiated the Mega Rice Project (MRP) in Central Kalimantan to convert one million hectares of peatland to fields for cultivating rice and promoting transmigration (migration inside of Indonesia). To open up this area and make it suitable for cultivation, over 4,000 km of primary, main, secondary-, tertiary-, and fourth-level channels were dug between the Sebangau and Barito Rivers between January 1996 and July 1998, initiated by forest clearance. Due to inadequate consideration of topography and peatland hydrology, these channels overdrained peatland [2], significantly and adversely affecting the area. Hotspot density (hotspots/km^2) in MRP areas was 3.28, compared to 0.96 in non-MRP areas, during 1997 to 2007, making fire frequency there 3.42 times that in non-MRP areas. Digging channels irreversibly dries peat to the consistency of charcoal when ground water drains away after large-scale peatland clearance, preventing peat from absorbing nutrients and retaining moisture [3]. Peat soil in cleared MRP areas dried easily, becoming a ready fuel source during the dry season. This was worsened by abnormal droughts induced by El Niño events in 1997, 2002, 2004, and 2006, producing widespread peat fires. Human activity – land prepared by intentional slash-and-burn practices and unintentional fire occurrence – is thus the major factor behind these fires.

Our study objectives were to better understand how drought and peat fires were related in the MRP area as indicated through hotspot and weather data analysis and to identify areas affected by peat fires.

2. Methods

2.1. Study Area

Our Sentinel Asia Project target [4] was tropical peatland around the Central Kalimantan Province capital of Palangkaraya in Indonesia. It covers 2 to 3.5° South Latitude and 113.2 to 115° East Longitude, involving Blocks A to D and the southern part of MRP Block E and the Trans-Kalimantan Highway between Palangkaraya and Banjarmasin.

2.2. Materials and Methods

We analyzed 1997 to 2007 SiPongi and United States Department of Commerce National Oceanic and Atmospheric Administration (NOAA) hotspot data on MRP area peat fires, mapping hotspots using 9,240 grids of 1 km^2 to determine where the worst fires occurred. We

Table 1. Hotspots (fires) and peatland in Indonesia From Kalimantan and Sumatra NOAA satellite data.

	Number of hotspots (fires)		**Peatland areas (km^2)** (Hoijeer, et. al., 2006)		
	Total 1997 - 2007 (a)	% Indonesia (a/b)	Peatland (c)	Total area (d)	% Peatland (c/d)
KALIMANTAN	318,579	49.6	58,379	531,506	11.0
Central Kalimantan	**131,705**	**20.5**	**30,951**	**154,289**	**20.1**
West Kalimantan	94,705	14.8	17,569	147,527	11.9
SUMATRA	281,626	43.9	69,317	464,301	14.9
Riau	93,363	14.5	38,365	92,141	41.6
South Sumatra	89,958	14.0	14,015	84,198	16.6
INDONESIA	641,968 **(b)**		225,234	1,919,317	11.7

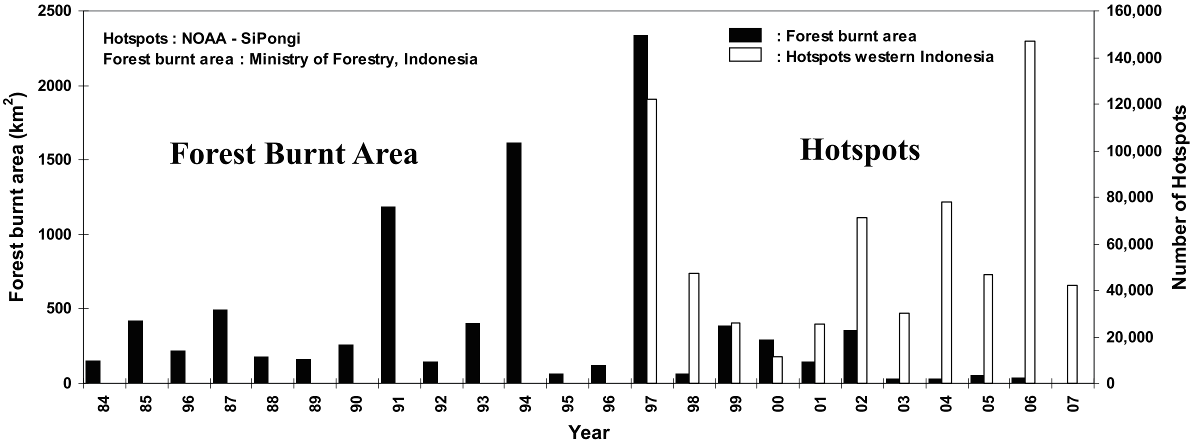

Fig. 1. Burned forest and number of hotspots in Indonesia from 1984 to 2007.

also analyzed monthly and daily precipitation data from the Tjilik Riwut Climatology Station at Palangkaraya Airport and monthly sea surface temperature (SST) anomaly data from the NOAA-National Weather Service to clarify the relationship between peat fire occurrence and abnormal drought enhanced by El Niño events. We measured ground water levels (GWL) in a peat swamp forest on the right bank of the Sebangau River near Palangkaraya at 2.32°S, 113.90°E [5].

3. Results and Discussion

3.1. Indonesian Fire History

Indonesian forest fires due to deforestation became marked from the early 20th century. Official reports on burned forest areas provided by the Ministry of Forestry of Indonesia became available only from 1984. Recent Indonesian forests burns and the number of hotspots were recorded in western Indonesia – Sumatra, Kalimantan, Java, Bali, and Sulawesi Islands – by NOAA satellite from the Japan International Cooperation Agency Forest Fire Prevention Management Project (JICA-FFPMP) (**Fig. 1**). Over 1,000 km^2 of forest area burned in 1991, 1994, and 1997, with the highest incidence in 1997. Over 60,000 hotspots or fires were recorded in western Indonesia in 1997, 2002, 2004, and 2006. The highest number was 147,143 in 2006, making it the worst fire year since 1997.

According to Seigert and Hoffman [6], a fire or hotspot identified by NOAA-AVHRR satellite with a defined area of 1.21 km^2 may indicate a fire or fires within this area. Although hotspots thus provide information on location and burned area, their accuracy is low due to poor infrared sensor resolution (1.1×1.1 km). Researchers are now developing ways to determined burned areas using hotspot data [7]. We estimated burned area roughly by introducing a hotspot duplication factor. Our hotspot data is "daily" and requires a duplication factor to take into consideration the overlapping ratio of each hotspot or fire. If a fire in the same location lasts ten days, for example, the duplication factor is 0.1.

Base on the high number of hotspots recorded in 1997 – 122,319 – total burned area is estimated at 35,000 km^2 for a duplication ratio of 0.3 – a burned area exceeding the official estimated burned forest area of 2,338.5 km^2 in 1997. Hotspot data covers both forest and nonforest land. We assume a direct proportion between the number of hotspots and total burned area. Burned forest areas parallel trends in the number of hotspots for 1999 to 2002, but this was not duplicated in 2003 to 2007 despite the high number of hotspots for these years, which indicates that many recent fires in Indonesia occurred in non forest areas.

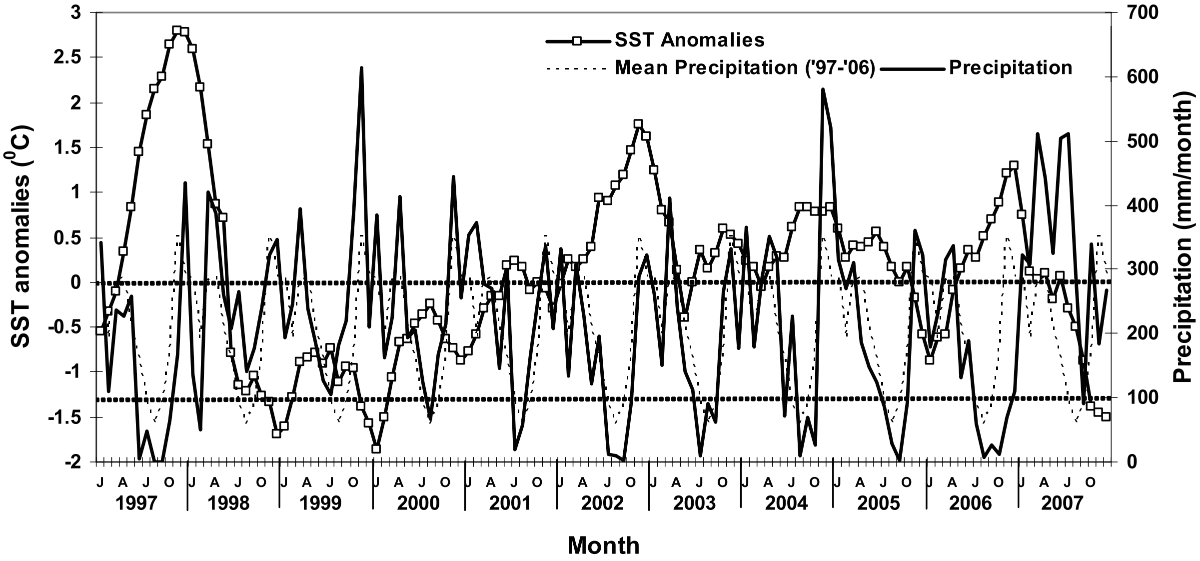

Fig. 2. SST anomalies and precipitation in the study area from 1997 to 2007.

According to Hoijeer et al. [1], peatland accounts for 25.9% of Kalimantan and 30.8% of Sumatra from the 225,234 km^2 of peatland in Indonesia. Over 83% of Kalimantan peatland lies in Central and West Kalimantan and over 75% of Sumatra peatland in Riau and South Sumatra Provinces. In western Indonesia, fires occurred mainly in Kalimantan (49.6%) and Sumatra (43.9%) (**Table 1**). Fires in Kalimantan and Sumatra mainly occurred in Central Kalimantan (20.5%), West Kalimantan (14.8%), Riau (14.5%), and South Sumatra (14.0%) that has large area of peatland. Central Kalimantan fires responsible for 2/5 of Kalimantan and 1/5 of western Indonesia.

3.2. Recent Sea Surface Temperature (SST) Anomalies, Drought, and Fire Occurrence

The Southern oscillation index (SOI) and sea surface temperature (SST) anomalies, related to atmospheric and oceanic dynamics, together cause drought in years coinciding with strong El Niño events [8]. Trenberth [9] suggests that El Niño events occur when SST anomalies exceed $+0.4°C$ for 6 months or longer.

According to monthly SST anomalies and precipitation from 1997 to 2007 and mean monthly precipitation from 1997 to 2006 in the study area (**Fig. 2**), high amounts of precipitation occurred monthly in 2007 even in the dry season, resulting in a precipitation abnormality, so we have excluded 2007 precipitation in defining mean monthly precipitation here. Positive SST anomalies tend to occur more frequently now (**Fig. 2**), with the highest in November 1997 at $+2.8°C$. High positive SST anomalies were also observed in November 2002 at $+1.75°C$, December 2004 at $+0.84°C$, and December 2006 at $+1.29°C$. From these positive SST anomalies, we classify 1997 as the strongest El Niño year in the last two decades, 2002 and 2006 as moderate El Niño years, and 2004 as a weak El Niño year. We found these positive SST anomalies strongly related to the precipitation period and amount.

During periods of positive SST anomalies (El Niño events), precipitation over Indonesia drops below average [10], causing long dry seasons and severe droughts. According to Mackinnon et al. [11], a dry month is defined as when mean monthly rainfall is less than 100 mm, and a wet month is one in which mean monthly rainfall exceeds 200 mm.

We found that the normal dry season in Kalimantan, which has a mean monthly rainfall of about 100 mm, is in July and August [12]. Mean monthly precipitation records from 1997 to 2006 (**Fig. 2**) indicated that the dry season in Central Kalimantan occurred from July to September – months having under 100 mm of mean monthly rainfall – 90.2 mm for July, 59.3 mm for August, and 89.4 mm for September. Monthly October precipitation from 2002 to 2006, except for 2003, tends to be below the mean, however, so we use July to October as the dry season in Central Kalimantan here.

Severe droughts with monthly precipitation under 100 mm occurred in June to October 1997, in July to October 2002, in August to October 2004, and in July to November 2006, when SST anomalies exceeded $+0.8°C$. Low positive SST anomalies of $+0.24°C$ in July 2001, $+0.6°C$ in October 2003, and $+0.39°C$ in July 2005 further induced long dry seasons in non-El Niño years in July to August 2001, July to September 2003, and July to October 2005 (**Fig. 2**).

The strong correlation of $R^2 = 85.19\%$ between monthly dry season precipitation and SST anomalies indicates that Central Kalimantan drought severity is proportional to positive SST anomalies, as expressed by

$$y = 16.857x^2 - 81.505x + 120.33$$

in which y = precipitation and x = SST anomalies (**Fig. 3**). This formula shows that higher SST anomalies bring lower precipitation. SST anomalies exceeding $+0.3°C$ may induce dry months with under 100 mm precipitation, and $+0.8°C$ SST anomalies may induce severe droughts

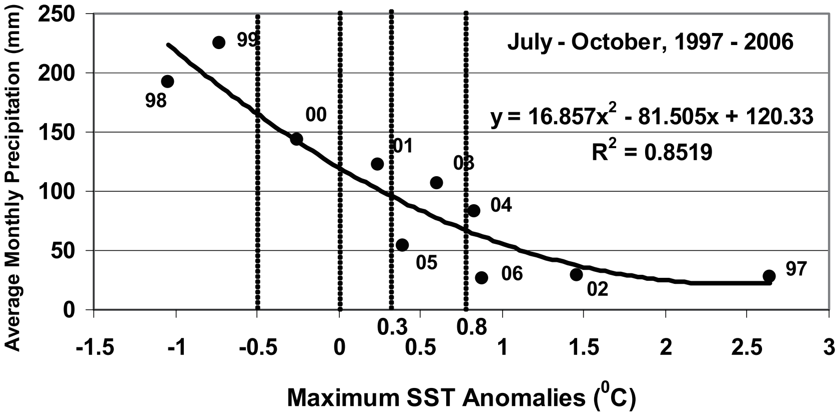

Fig. 3. Relationship between precipitation and maximum SST anomalies from July to October 1997 to 2006.

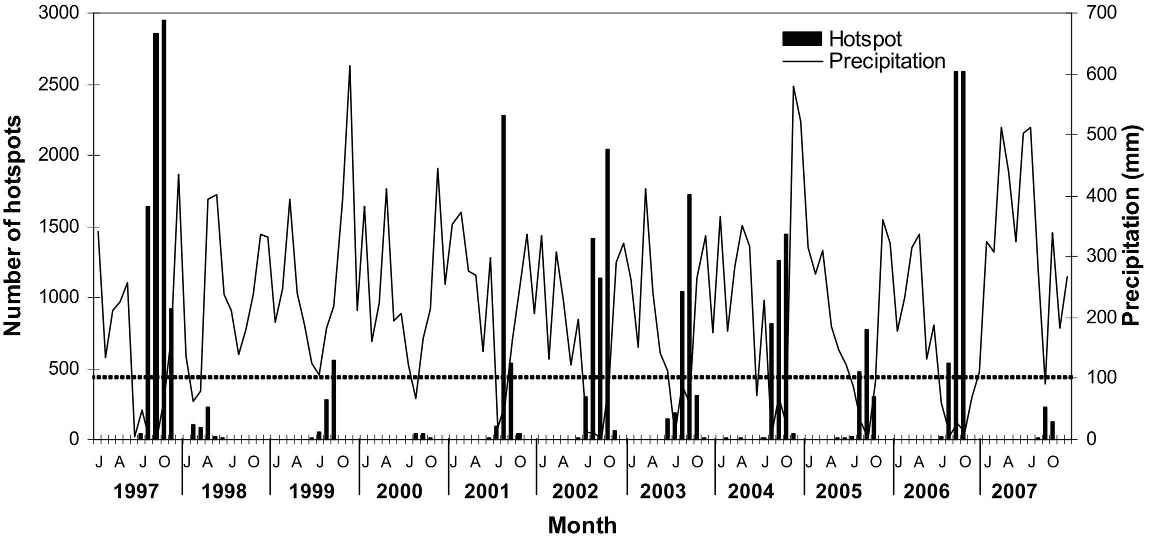

Fig. 4. Precipitation and hotspot occurrence in the MRP area from 1997 to 2007.

with monthly precipitation under 50 mm. Wet months with over 200 mm monthly rainfall usually occur when SST anomalies are under -0.5°C.

Over 90% of hotspots in the MRP area from 1997 to 2007 (**Fig. 4**) occurred between July and October during the dry season. High numbers of hotspots were detected primarily in El Niño year dry seasons, with 8,401 in 1997, 4,961 in 2002, 3,591 in 2004, and 5,734 in 2006, when El Niño enhanced longer dry periods. Fire events peaked in these years in August, September, and October, when the area had precipitation below 100 mm.

High numbers of fires occurred in the dry seasons of non-El Niño years 2001, 2003, and 2005, when positive SST anomalies were low. Even low positive SST anomalies in July to August 2001, July to September 2003, and July to October 2005 exacerbated fire occurrence. Hotspots numbered 2,959 in 2001, 3,410 in 2003, and 1,583 in 2005, suggesting that fire occurrence is associated with severe droughts as indicated by positive SST anomalies, and we concluded that peat fires in the MRP area are no longer limited to El Niño years.

We found a strong relationship of R^2 = 86.42% between the number of hotspots and positive SST anomalies in July to October in 1997 to 2007 (**Fig. 5**), expressed as

$$y = 1.852x^2 + 2153.5x + 1954.6$$

in which y = the number of hotspots and x = SST anomalies. Positive SST anomalies thus clearly induced high numbers of fires. Hotspots or fires numbered over 4,500 with high positive SST anomalies – over $+0.8$°C – in 1997, 2002, 2004, and 2006. The highest number of hotspots occurred during the 1997 dry season following the highest SST anomalies in this year. A relatively high number of fires was observed also, however, in non-El Niño years with positive SST anomalies, i.e., in 2001, 2003, and 2005. Over 1,500 fires occurred in these years when SST anomalies exceeded $+0.3$°C, indicating that even low positive SST anomalies yield high numbers of fires.

3.3. Ground Water Level and Fire Occurrence

The GWL from 2001 to 2006 tended to progressively decrease following droughts both in El Niño years 2002, 2004, and 2006 and non-El Niño years 2001, 2003, and

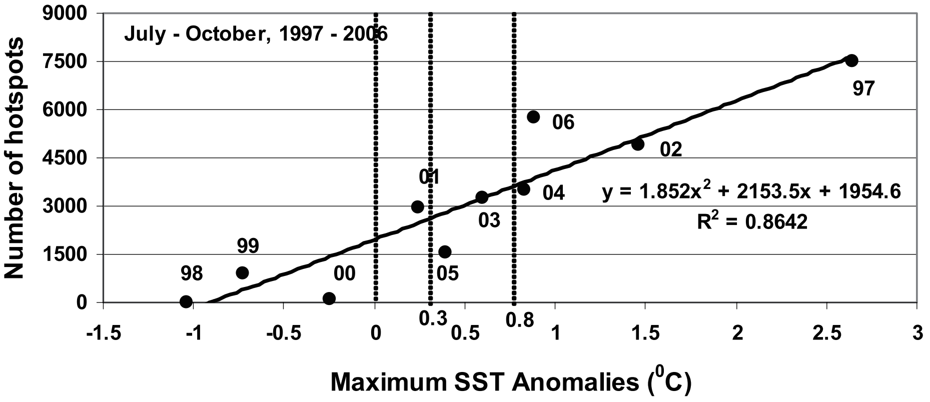

Fig. 5. Relationship between number of hotspots and maximum SST anomalies from July to October 1997 to 2006.

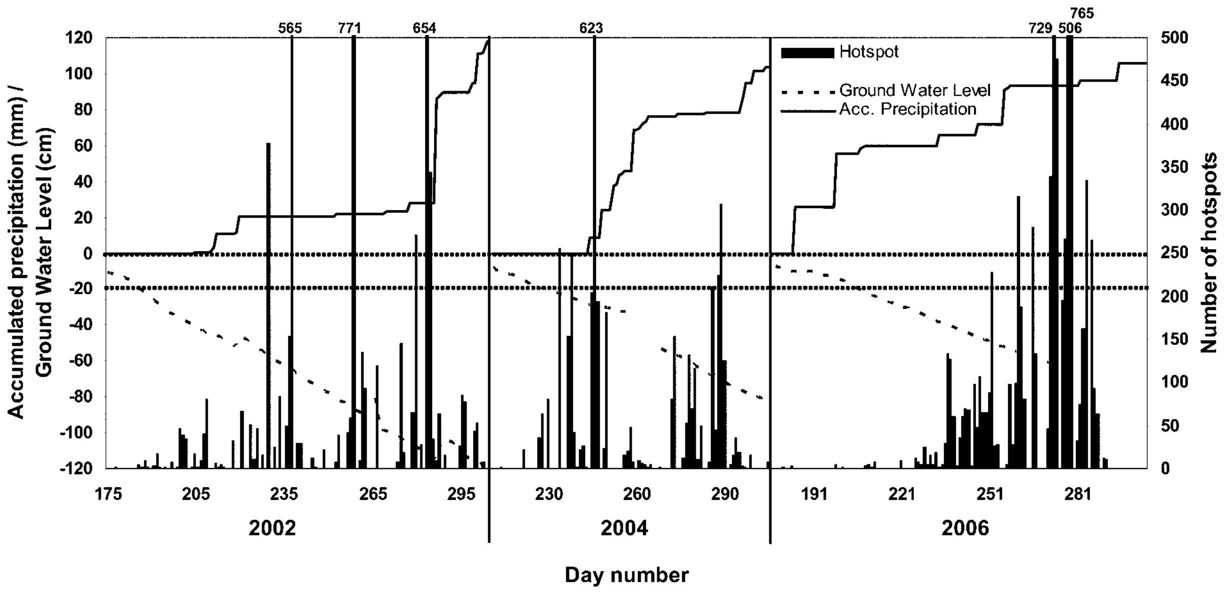

Fig. 6. GWLs, daily hotspot occurrence, and accumulated precipitation in the MRP area in 2002, 2004, and 2006.

2005 (**Fig. 6**). Decreases mainly occurred in the absence of three days or more of precipitation. The GWL was at 0 cm at the ground surface at the end of rainy seasons in May 2002, 2003, and 2005 and June 2001 and 2006. During the dry season, the GWL decreased steadily later in the year to a low of −118 cm in October 2002, −81 cm in October 2004, and −63 cm in September 2006.

The GWL below the ground surface also decreased progressively in the dry season of non-El Niño years 2001, 2003, and 2005, becoming lowest GWL in September – −57 cm in 2001, −77 cm in 2003, and −67 cm in 2005. The rate of GWL decrease in non-El Niño years was 0.48 to 0.69 cm/day, slightly higher than the rate of decrease in El Niño years of 0.37 to 0.68 cm/day. In El Niño years, however, the GWL decrease below the ground surface lasted longer than in non-El Niño years at 130 to 220 days in El Niño years and 95 to 138 days in non-El Niño years.

These decreases show that the recent GWL in the Mega Rice Project (MRP) area became very deep, mainly in the dry season. According to Ludang et al. [13], channels and irrigation construction in Mega Rice Project areas lowered the peat water table and accelerated water movement away from peatland ecosystems, leaving them extremely dry in the dry season and creating a situation promoting fire ignition and combustion – a condition substantiated by the high number of fires in the dry season.

Surface fires in MRP areas started mainly when the GWL reached 20 cm below the ground surface (**Fig. 6**). Here, we distinguish between surface and peat fires as follows: surface fires consume above-ground fuel, while peat fires occur both on surface and in deep peat. A surface peat fire induces a peat fire that burn at a depth of 0-20 cm, mainly fueled by grass roots, humus, and small wood fragments. Deep peat fires burn at a depth of 20-50 cm, mainly fueled by large woody fragments and peat matrix [12]. We found that surface fires started when the GWL reached 20 cm below the ground surface.

Adinugroho et al. [3] stated that the risk of fires breaking out in peatland is highest when rainfall is extremely low. Fires usually started between 11 and 14 days after the start of droughts (days without precipitation), and number

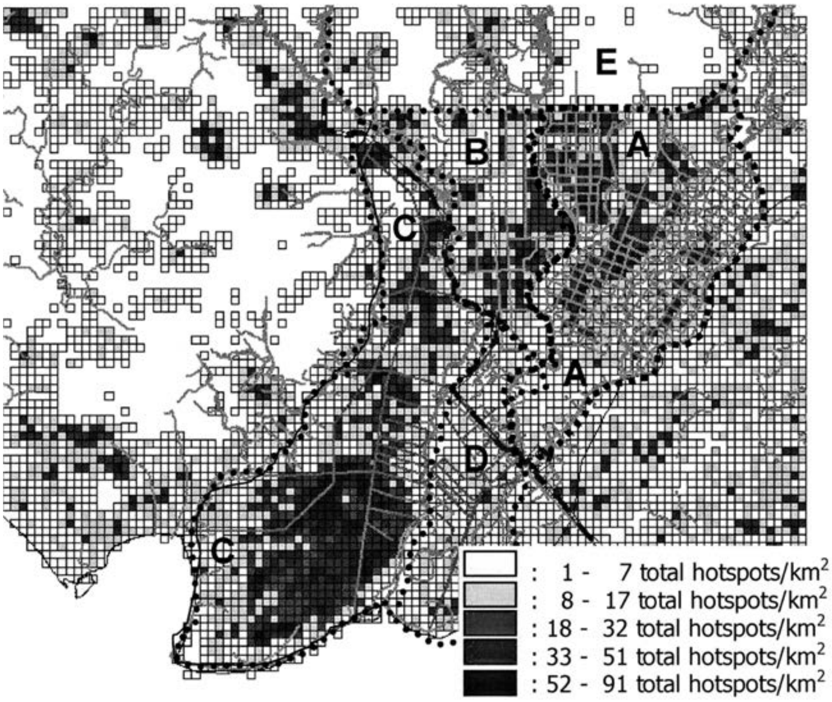

Fig. 7. Peat fire incidence from 1997 to 2007.

of fires increased until the dry season ended. The number of peat fires was higher during severe droughts. More than 50 fires occurred when GWL reached -40 cm and number of peat fires exceeded 100 when GWL dropped to -50 cm and deeper. Most recent fires in the MRP area occurred while the GWL was still decreasing below the ground surface – 83% of all fires in 2005, 93% in 2003, and over 98% in 2001, 2002, 2004, and 2006. This evidence strongly suggests that a deeper GWL below the ground surface induces higher numbers of peat fires.

Only 5 mm of accumulated daily precipitation affects fire activity in MRP areas only negligibly. Fires stopped for several days after large amounts of rain – 40.1 mm – fell at the end of August 2005. About 30 mm of precipitation in mid-September 2004 and 2006 and at the end of October 2002 suppressed fires, but severe drought continued until the end of October 2002 and 2004 and until mid-November 2006, inducing numerous fires in September and October. Fires stopped after an area had a large amount of precipitation in November 2002 to 2006, indicating that peat fires are suppressed naturally through heavy rainfall and after the wet season goes into full force as peatland becomes saturated, making it difficult for peat to burn [3].

3.4. Peat Fire Distribution

We calculated local MRP area fire density (**Fig. 7**, 1×1 km grids) based on daily hotspot data from 1997 to 2007. Almost all areas were affected by fires, with fire density the highest in the southern part of Block C. High fire density was also observed in central Block A, central Block B, and near main drainage channels in Block A.

A large area of Block C suffered severe peat fires with the number exceeding 5,100 in the southern part (113.89 to 114.07°E, 3.01 to 3.27°S). Fires numbered 528 in central block C (113.77 to 113.87°E, 3.36 to 3.39°S), 243 near Kalampangan Village (113.99 to 114.07°E, 2.30 to 2.35°S), and 376 around Tumbang Nusa Village (114.14 to 114.21°E, 2.46 to 2.55°S)

In Block A, fires exceeded 1,600 in the central part (114.42 to 114.56°E, 2.37 to 2.58°S) and 484 near primary (parent) channels (114.42 to 114.56°E, 2.23 to 2.28°S). In Block B, fires numbered 581 in the central part (114.35 to 114.42°E, 2.44 to 2.56°S).

The fact that these high-fire-density areas mainly involve paddy fields and abandoned farmland, mostly located near channels, suggests that dry-season practices using fire in land preparation and slash-and-burn activities in the dry season still continuing. Fires started to effect land preparation usually occur in the dry season to make the land ready for cultivation in the rainy season [14]. Local MRP community residents use channels for transportation and fishing, frequently building small camps near channels and using small fires for cooking. Carelessness with cooking fires and deliberately set land preparation blazes may thus start a fire spot that could spread quickly across large areas.

MRP area peat fires, as human-initiated, classify as a man-made disaster. Firefighting measures such as fire sensors and fire extinguishers – even if available – cannot detect or suppress underground peat fires, and human-initiated conflagrations must be prevented by reducing both intentional and careless fire use. This requires that people in MRP area communities must be trained and their awareness of fire prevention and fire extinguishing must be raised. Peat-fire prevention is vital to eliminating ecological disasters due to human activity and man-made climate change.

4. Conclusions

Our analysis of peat fire occurrence based on hotspots and weather data clearly showed that:

1 In the MRP area, peat fires were closely related to drought severity corresponding to SST anomalies. Peat fire activity – the number of hotspots – correlated highly ($R^2 = 86.42\%$) with SST anomalies, implying that peat fire occurrence in the MRP area is related to local peat dryness.

2 High peat fire density in Blocks A and C suggests that intensive ongoing human activity gives rise to fires, classifying peat fires in MRP areas as man-made disasters.

3 SST anomalies exceeding $+0.3°$C can potentially reduce precipitation and extend dry periods in Central Kalimantan, where such conditions in 2005 led to over 1,500 peat fires.

4 Surface fires tend to start from 11 to 14 days after a drought begins if ground water levels (GWL) decrease steadily and drop to about 20 cm below the ground surface.

5 Peat fires exceeding 100 hotspots tend to occur when the GWL is deeper than -50 cm, indicating that a deeper GWL during severe droughts induces a higher number of peat fires.

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