

## IMPACT OF THE 1997 FIRES ON THE PEATLANDS OF CENTRAL KALIMANTAN, INDONESIA

Page, S.E.<sup>1</sup>, Rieley, J.O.<sup>2</sup>, Bohm, H-D.V.<sup>3</sup>, Siegert, F.<sup>3</sup>, & Muhamad, N.Z.<sup>2</sup>.

1: Department of Biology, University of Leicester, Leicester, LE1 7RH, U.K.

tel: +44 116 2525923, fax: +44 116 2523330; e-mail: [sep5@le.ac.uk](mailto:sep5@le.ac.uk)

2: School of Geography, University of Nottingham, Nottingham, NG7 2RD, U.K.

tel: +44 115 9515449; fax: +44 115 9515248; e-mail: [jack.rieley@nottingham.ac.uk](mailto:jack.rieley@nottingham.ac.uk)

3: Kalteng Consultants, Kirchstockacher Weg 2, D-85635 Hohenkirchen, Germany.

tel: +49 8102 774848; fax: +44 8102 774850; e-mail: [viktorboehm@t-online.de](mailto:viktorboehm@t-online.de)

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### Introduction

The area of peatlands in Indonesia is approximately 20 million hectares (Mha), which is nearly 11% of the total land area (Rieley *et al.*, 1996). The vast majority are lowland, ombrogenous systems that support a natural vegetation of peat swamp forest on top of peat that ranges from 0.5 m to more than 10 m thick (Rieley & Ahmad-Shah, 1996). Approximately 50% of these peatlands exceed 2 m in thickness (Anderson, 1983).

Almost all of Indonesia's peatland is located in three large islands, Borneo (Kalimantan), New Guinea (Irian Jaya) and Sumatra. Central Kalimantan province contains about 3 Mha of peatland and studies have been carried out on the ecology and environmental importance of the peat of this area since 1993. This research was well established therefore when Indonesia was affected by the 1997 El Niño-Southern Oscillation (ENSO) event and provided the opportunity to observe and measure some of its environmental consequences.

The climatic changes brought about by ENSO events have global consequences, but effects are particularly pronounced in Indonesia and other parts of the Western Pacific where drought conditions may be produced as a result of the greatly extended dry season compared to 'normal' years. Over the last three decades ENSO events have occurred several times, resulting in droughts of varying severity. In 1982/83 the prolonged dry season resulted in severe forest fires in East Kalimantan where more than 3 Mha of land burned, including 0.55 Mha of peat swamp forest (Johnson, 1984). There were minor droughts and less severe fires in 1987, 1991 and 1994.

In Central Kalimantan, in non-ENSO years, there is a dry season of usually three or four months duration between May/June and September. Rain still falls in dry seasons but the frequency and intensity of events are reduced greatly. During the 1997 ENSO event, the dry season, spanned eight months from March to December, during which there was hardly any rainfall.

At the start of the dry season in 1997, as is normal at the commencement of every dry season in Indonesia, many fires were started in order to clear deforested land of vegetation prior to planting crops and trees. Many of these fires spread into forest areas where they burned with greater intensity. In Kalimantan, Sumatra and Irian Jaya fires started in this way were either located on, or spread to, peatland where both the surface vegetation and underlying peat were ignited. In Central Kalimantan, the situation was exacerbated by a programme of massive peatland conversion, the so-called Mega Rice Project (MRP). This scheme was initiated in 1995 with the aim of converting one million hectares of wetland (mostly peatland) to agricultural use (Notohadiprawiro, 1998). Between January 1996 and July 1998 over 4000 km of drainage and irrigation channels were constructed throughout the area designated for the MRP and forest clearance on this land was initiated. After removal of the commercial timber, the remaining tree debris was removed by means of fire as the cheapest, most readily available land clearance tool.

Various assessments have been made of the amount of land in Indonesia that was damaged by the 1997 fires. Initial estimates indicated that approximately 4.5 Mha were affected (Liew *et al.*, 1998 quoted in Schweithelm, 1998), but this was increased subsequently to 9 Mha (BAPPENAS, 1998). Of this latter area, as much as 1.45 Mha was peatland that was either in a natural condition supporting peat swamp forest, degraded peatland with secondary vegetation, or agricultural land of farms and plantations on drained peatland. Two of the most intensive sources of smoke and particulate matter reaching the atmosphere were the fires centred on the peatlands of Central Kalimantan and Riau in South Sumatra. In both of these areas vegetation and underlying peat caught fire, contributing greatly to the so-called haze (particulate-laden smog) that drifted north and west to affect Singapore and Malaysia. During this time solar radiation in Central Kalimantan was reduced to 40% of normal levels (H. Takahashi, pers. comm.) whilst visibility was reduced to 25 m. It is estimated that the fires resulted in over US\$ 3 billion in damage from losses in agriculture, timber, non-timber forest products, hydrological and soil conservation services, and biodiversity benefits, whilst the haze cost an additional US\$ 1.4 billion, most of which was borne by Indonesians for health treatment and lost tourism revenues (Schweithelm, 1998).

The objectives of this investigation were to provide more accurate estimates of the area of fire affected peatland within Central Kalimantan, encompassing near-pristine, forested peatland and degraded and drained peatland, and to quantify some of the environmental consequences of the fires. A combination of remote sensing and field checking was employed. Some of the environmental impacts of the fires are discussed and predictions made concerning the future sustainability of tropical peatland in this province.

## **Materials and methods**

A study area of approximately 24,500 km<sup>2</sup> (2.45 Mha), most of which was peatland, was delimited based upon one full LANDSAT-TM scene. This area extended from Sungai (River) Katingan in the west to Sg. Barito in the east and from north of the provincial capital of Palangka Raya to the Java Sea in the south (Figure 1). This encompasses the entire catchment of Sg. Sebangau, most of which retains an almost natural vegetation cover of peat swamp forest, and also the whole of the mega-rice project area (between Sg. Sebangau and Sg. Barito).

Two LANDSAT-TM images, one from May 1997 (pre-fire image) and the other from March 1998 (post-fire image), were compared in addition to several radar ERS SAR (RADAR) images from early 1997 (pre-fire) and late 1997 (post-fire). Standard methodologies were employed for image processing, geometric correction, signature analysis and change detection. The images were integrated and compared, over different time periods, using a Geographical Information System in order to determine changes in land use and vegetation classes. Areas of land affected by the 1997 fires were delimited on the later images and the location, extent and former land use for these damaged areas were determined. This fire-scar assessment was checked by superimposing the fire hotspot data obtained from the ATSR NOAA satellite onto the 1998 LANDSAT image. Extensive ground-truthing had been carried out prior to the fires in order to check image classification of land-use and vegetation. Post-fire ground-truthing within the study area was carried out both on foot and by low level aerial reconnaissance to verify the existence and magnitude of burn scars.

Additional fieldwork was designed to address some of the environmental consequences of the fires. At fire scar sites, estimates were made of the depth to which the peat surface had been lowered by combustion losses. The area of the fire scars and values for peat bulk density and carbon content were combined with information on the thickness of combusted peat in order to calculate the amount of carbon lost to the atmosphere by combustion of the peat surface. Additional estimates were made of carbon emissions from combustion of above-ground plant biomass.

## **Results**

### Location and extent of fire scars

The fire hotspot data obtained from the NOAA satellite showed good correlation with the fire scars detected on the LANDSAT and SAR images. Within the 2.45 Mha study area, 586,235 ha (24%) were damaged by fire (Table 1). This compares with 750,000 ha of fire damaged peat and swamp forest in the whole of Kalimantan, i.e. 11% of the total resource of 6.8 Mha (BAPPENAS, 1998). Proportionally, therefore, more than twice the amount of peatland in the study area was damaged by fire than in the whole of Kalimantan. Classification of the burnt areas reveals that greatest fire damage was in peat swamp forest. The distribution of fire scars is strongly correlated with the canals constructed within the MRP area where wholesale forest clearance had been authorised by the Indonesian Government. Degraded peat swamp forest and land cleared for agriculture and urban settlement (around Palangka Raya) were also a focus for many of

the fires. Within the MRP area approximately 80% of the landscape was burned. In contrast, the pristine peat swamp forest wilderness to the west of Sg. Sebangau suffered less than 20% damage and most of this was in and around transmigration settlements.

### Loss of peat

Field survey of burn scars revealed a loss of surface peat from a minimum of 0.20 m to a maximum of 1.50 m. A conservative overall estimate suggests that the thickness of peat lost by combustion during the fires averaged 0.40 m over the extensive peatland areas of Central Kalimantan. In some locations the intensity and duration of the fires, as a result of both surface and sub-surface fires, was such that a much greater thickness of peat, from 1.0 to 1.5 m, was removed.

By applying two estimates for the thickness of peat burned away (0.40 m and 1.00 m) lower and upper limits to the total volume of peat lost from the fire damaged areas (Table 2) have been calculated. The range of total carbon lost from combusted peat within the study area is obtained by combining these data with an average value of 57% for peat carbon content and  $0.10 \text{ g cm}^{-3}$  for peat bulk density (Neuzil, 1997).

Assuming that all of the peatland areas that burned also supported peat swamp forest the amount of carbon lost to the atmosphere in the combustion of above-ground biomass could have amounted to between 50 to  $100 \text{ t C ha}^{-1}$ . These values are derived from the assumptions that (1) pristine peat swamp forest and heath forest vegetation has an above ground biomass carbon content of  $200 \text{ t C ha}^{-1}$  (Diemont *et al.*, 1997) and no more than 50% of the above-ground biomass was consumed by fire, (2) in degraded swamp forest logging has already removed half of the biomass and fire consumed 50% of the remaining biomass. These broad-brush estimates of the amount of timber remaining undamaged by fire are based on field observations but require more detailed investigation before accurate data can be produced. It was notable that in burnt areas many of the fallen trees showed little trunk damage but had been destabilised by the peat fires, which destroyed the root systems. The loss of carbon from combustion of above-ground forest biomass is estimated to be 0.033 Gt C.

Total carbon losses from the 1997 peatland fires in the study area are estimated to be in the range 0.167 to 0.367 Gt C, with the greatest contribution to emissions of atmospheric  $\text{CO}_2$  derived from peat rather than forest combustion.

### **Discussion and conclusions**

Mapping of burn scars indicates that fire damage is proportional to the level of prior human activity and forest disturbance, with developed areas having the greatest amount of burned land. This concurs with the results of research carried out in East Kalimantan following the 1982/83 fires when heavily disturbed forest burned away almost completely, leaving very few live trees. Pristine forest, in comparison, was much less affected and, even if it did go on fire, usually only the ground vegetation was consumed leaving the middle and upper tree layers intact (Schindele *et al.*, 1989). The problem with

peatland, however, is that once fire becomes established within the peat it destroys tree root systems. As a result, most of the trees become unstable and topple over even though they may experience minimal damage to their trunks and canopies. Many of the fire scar areas detected in the remote sensed images were found to have a large amount of fallen timber scattered over the burned peat surface.

The greatly reduced rainfall during the 1997 ENSO event led to a very marked drop in the level of the peat water table. At a peat water table monitoring station in peat swamp forest in the upper catchment of Sg. Sebangau, the water table fell to 98 cm below the surface in mid-November, 1997. Even so, this area was unaffected by forest fires. In comparison, the water table at this location in 1995 and 1996 remained close to the peat surface throughout the dry season with a maximum drawdown of only 20 cm. After the drought ended in December 1997 the peat water table responded very rapidly to rainfall events and returned to its normal wet season level within one month. (H. Takahashi, pers. comm.). Data on the peat water table in the drained and degraded peatlands of the megarice project are not available, but reports from local people suggest that the peat water table was at an extremely low level, up to 1.5 m or more below the peat surface, at the height of the ENSO-related drought (S. Limin, pers. comm.). This allowed some sub-surface peat fires to destroy a considerable thickness of peat.

Two linked factors have, therefore, played key roles in determining the distribution of fire scars: degree of forest disturbance and lack of peatland hydrological integrity. Areas of degraded peatland experienced excessive water-table drawdown during the ENSO drought whilst, in contrast, large areas of pristine peat swamp forest, despite experiencing a significant drop in water table, were relatively unaffected by fire. In the study area, the MRP was a major location for fire hot spots because:

- (1) the area was criss-crossed by an extensive system of wide and deep channels that facilitated excessive drainage of the peatland landscape.
- (2) the land had to be cleared of residual trees and wood debris with fire as the only economic method by which to achieve this, and
- (3) many people were able to access the previously inaccessible interior of this peatland landscape to exploit the residual timber resources, mostly using fire in the process.

The combustion of vegetation and surface peat resulted in a significant loss of carbon to the atmosphere of between 0.167 and 0.367 Gt C. If this figure is applied proportionately to the total area of peatland in Indonesia that was damaged during the 1997/98 fires (i.e. 1.45 Mha) the total emissions could have been in the region of 0.40 and 0.90 Gt C. This compares with an estimated net annual fixation in temperate peatlands of 0.10 Gt C yr<sup>-1</sup> and for tropical peatlands of only 0.06 Gt C yr<sup>-1</sup> (Franzen, 1994). These values also compare with a global annual emission from the burning of fossil fuels of 5.4 Gt C yr<sup>-1</sup> (Sundquist, 1993). By any level of comparison, therefore, the 1997/98 peatland fires in Indonesia were significant on both a regional and a global scale.

Peat combustion also resulted in a significant loss of nutrients (lost in smoke and ash) from what is already a nutrient-deficient ecosystem. Studies of the geochemistry of tropical peat have shown that the surface 1.0 to 1.5 m have an enhanced level of several

important plant nutrient elements as a result of bioaccumulation (D. Weiss, pers. comm.). Most of this nutrient pool has been removed as a result of the fires and this will have serious consequences for vegetation re-establishment, especially attempts at agricultural conversion programmes.

Extensive fire damage to the peat soils of Central Kalimantan will accelerate the changes brought about by drainage works. One of the most important natural resource functions of tropical peatlands at the regional scale is their role in regulating water in the landscape (Page & Rieley, 1998). The 1997 ENSO-related drought was followed by a period of above average rainfall, called La Niña. In Central Kalimantan, 1998 was an exceptionally wet year in which there was widespread flooding, particularly in and around the MRP area. These floods were worse than in previous prolonged wet seasons because removal of the forest and peatland drainage, combined with the consequences of the fires, impaired the hydrological functions of degraded peatland areas.

The prognosis for the future sustainability of the peatlands of Central Kalimantan is bleak. When the next prolonged dry season occurs, there will be a high likelihood of further fires. Since it is clear from the results presented above that fire damage increases in proportion to the level of human disturbance, and the rate of disturbance is increasing throughout the entire peatland area of Indonesia (20 Mha), the effects of future droughts and fires will be cumulative. Long-term prospects for this area are not promising even though the MRP has now been abandoned (July 1998). This area will experience a greatly heightened risk of fire damage during future dry seasons and flooding during rainy seasons. The question that remains to be answered is how long will it take for repeated fires on a large scale to upset the stability of the peat swamp forest ecosystem beyond the point of recovery? In its natural state, tropical peat swamp forest is in a dynamic relationship with its environment and any persistent change, particularly in climatic wetness, will have implications for its long-term stability (Page *et al.*, 1999). In a degraded state, tropical peatlands become an increasingly fragile natural resource. In recognition of this, one report on fire prevention planning (BAPPENAS, 1998) suggests that all peat soils in Indonesia should be subject to special regulations on land clearance, especially that burning of any kind, including managed burning, should be strictly prohibited. The results of this study indicate that in order to prevent a recurrence of the 1997 peatland fires much more attention needs to be paid to the natural resource functions performed by large peatland landscapes.

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## FIGURES and TABLES

Figure 1 : Location of the study area in Central Kalimantan province, Indonesian Borneo.

Table 1: Fire impact assessment based on peatland land-use and vegetation classes in a 2.4 Mha study area, Central Kalimantan, Indonesia. Figures are derived by comparison of pre- and post-fire LANDSAT-TM and ERS SAR (RADAR) images

Vegetation type/Land-use class	Total area (ha)	%
Total land area	2425323	100
Total land area damaged by fire	586235	24.2
<i>of which:</i>		
Peat swamp forest	253676	43.3
Degraded peat swamp forest	164036	28.0
Heath forest	448	0.1
Other land use classes	168075	28.7

Table 2: Estimated emissions of carbon to the atmosphere from peat and vegetation combustion in a large peat-covered study area in Central Kalimantan during the 1997 fires

Vegetation/ land-use class	Fire damage d area (ha)	Volume of combusted peat (m <sup>3</sup> ) assuming depth lost		Loss of C (Gt) from combusted peat* at depths of		Loss of C (Gt) from biomass	Total loss of C (Gt) - biomass + peat at depths	
		0.40 m	1.00 m	0.40 m	1.00 m		0.40 m	1.00 m
Peat swamp forest	253676	1.02 x 10 <sup>9</sup>	2.54 x 10 <sup>9</sup>	0.058	0.145	0.025**	0.083	0.170
Peat swamp forest (degraded)	164036	0.66 x 10 <sup>9</sup>	1.64 x 10 <sup>9</sup>	0.038	0.093	0.008***	0.046	0.101
Heath forest	448	n/a	n/a	n/a	n/a	<0.001****	<0.001	<0.001
Other land use classes	168075	0.67 x 10 <sup>9</sup>	1.68 x 10 <sup>9</sup>	0.038	0.096	n/a	0.038	0.096
TOTAL	586235	2.35 x 10 <sup>9</sup>	5.86 x 10 <sup>9</sup>	0.134	0.334	0.033	0.167	0.367

\* calculated by applying values of 57% for peat carbon content and 0.10 g cm<sup>-3</sup> for peat bulk density (Neuzil, 1997)

\*\* calculated on the basis of 50% timber left standing and assuming a biomass carbon content of 200 t C ha<sup>-1</sup> for peat swamp forest (Diemont *et al.*, 1997)

\*\*\* calculated on the basis of 25% timber left standing (same basis as above)

\*\*\*\* calculated on the basis of 50% timber left standing and assuming a biomass carbon content similar to that of peat swamp forest