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FIRE IMPACTS AND CARBON RELEASE ON TROPICAL PEATLANDS IN CENTRAL KALIMANTAN, INDONESIA

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Abstract

During 1997 and 1998 intensive land irrigation and clearance activities in Indonesia, combined with a greatly extended ENSO-related dry season, created conditions for several months of forest fires. Fires were particularly intense in the lowland peatlands of Kalimantan and Sumatra where both forest and peat fires occurred. A 24,910 km^2 (2.491 MHa) study area in Central Kalimantan has been used to investigate the consequences of fire on peat swamp forest using LANDSAT TM/ETM and ERS-1/2 radar satellite images. By combining data from remote sensed images with GIS and field measurements, it has been possible to determine fire impact, carbon storage in the peatlands and carbon emission by fire. Results indicate that 32% of the study area has been fire affected (796,901 ha); the largest scars are in areas impacted by logging, forest clearance and peatland drainage. Systematic peat drillings showed that huge amounts of carbon are stored in this tropicl peatland (average peat thickness approx. 2.5m) suggesting that the contribution of tropical peat to the global resource is much greater than thought previously and could be as much as 20-30% of the total. Using GIS interpolation algorithms a 3 dimensional volume model was calculated showing that more then 9 Billion m^3 peat are stored in Block C of the 1 Mio ha rice project area (4400 km^2).

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 resulting in approx. 3 Gm^3 of burned peat calculated for Block C. Total carbon losses from the 1997 peatland fires in the study area are estimated to be in the range 0.218 to 0.491 Gt C, with the greatest contribution to emissions of atmospheric CO_2 derived from peat rather than forest combustion.

Introduction

Central Kalimantan has one of the largest areas of tropical peat swamp forest (PSF) world-wide (Rieley et al., 1996). Up to the beginning of the 90ies large areas of pristine PSF remained. In 1996 a giant land-use conversion project was initiated by the Indonesian government in order to develop 1 Million ha of wetlands, mostly PSF, (Boehm *et al*., 2000) into fields for rice cultivation and transmigration (Mega Rice-Project, MRP). Between January 1996 and July 1998 more than 4000 km of irrigation channels (Fig. 1a, 1b, 2d) were laid out in the peat swamp (Notohadiprawiro, 1998). Because topography and hydrology of the peatland were not sufficiently considered beforehand, and sluices were not properly planned, the peatland was severely drained by these channels.

The situation was aggravated in 1997 by the El Nino. Central Kalimantan was the major region in Indonesia where peatlands were on fire. The dry season spanned six months from mid May to end of October 1997 during which there was hardly any rainfall. Hundreds of fires were started in order to clear deforested land of vegetation. 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. Many of these fires spread into forest areas where they burned with greater intensity and both the surface vegetation and underlying peat were ignited.

Several assessments have been made of the amount of land in Indonesia that was damaged by the 1997 fires (Barber & Schweithelm, 2000). Initial estimates indicated that approx. 3.06 Mha were affected (Liew et al., 1998), but this was increased subsequently to 6.6 Mha (BAPPENAS, 1998) and 13.18 Mha (Fuller & Fulk, 2001). Of this latter area, at least 1.4 Mha was peatland that was either in a natural condition supporting PSF, 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 South Sumatra. In both of these areas vegetation and underlying peat caught fire, contributing greatly to the socalled haze (particulate-laden smog) that drifted across SE-Asia. It is estimated that the fires resulted in over US$ 9 billion in damage from losses in agriculture, timber, nontimber forest products, hydrological and soil conservation services, and biodiversity benefits, whilst the haze cost an additional US$ 300 million, most of which was borne by Indonesians for health treatment and lost tourism revenues (BAPPENAS, 1998).

The objectives of this investigation were to provide more accurate estimates of the area and fire impact on the vegetation of fire affected peatland within Central Kalimantan, encompassing near-pristine, forested peatland and degraded and drained peatland, to quantify carbon emissions by this fire disasterand to elucidate some of the environmental consequences of the fires. A combination of remote sensing, GIS and field checking and field measurements was employed. The pre-fire land cover and bumed area was derived from Landsat TM images. The burned area was also assessed from images acquired by the European ERS SAR radar satellite. Information from radar was necessary to reliably assess the burned area, because active microwave systems are able to penetrate haze and clouds with hamper optical satellite systems. Field measurements included peat drillings to determine peat depth and the thickness of the burned peat layer and Carbon emission measurements. Some of the environmental impacts of the fires are discussed and predictions are made concerning the future sustainability of tropical peatland in Kalimantan.

Material and Methods

When fire affects vegetation there is a significant decrease in ERS radar backscattering. We used this property to map burned scars in multitemporal change detection analysis by generating an artificial image product in which ERS-1/2 SAR images acquired before (July 1997) and after the fire (October 1997) were combined into a single colour image suitable for visual interpretation (Fig. 2A). The pre-fire vegetation cover was derived from a Landsat TM image acquired in May 1997. An interpretation key was established from Geographical Positioning System (GPS) recorded ground observations of the pre-fire vegetation and fire damage for both, ERS and TM. The results of the ERS-SAR based fire impact analysis was compared to burnt scars detected in a Landsat TM image acquired 6 months after the fires in March 1998 Fig. 2B). To estimate the amount of peat stored in this tropical ecosystem, peat drillings have been performed for Block C of the MRP area on more than 100 locations (Fig. 3C, left). All drillings were made along the new of tree trunks and their remaining root system (Fig 3A).

Measurements of CO_2 emissions in exposed, deforested peatland were done over two years.

An infrared gas analyser based method was used for in situ determination of CO_2 emissions on 20 cm diameter study plots, cleared from green vegetation in Block C (Vasander & Jauhiainen, 2001). A cylindrical aluminium chamber with a flexible synthetic-rubber sealing was placed over a selected study plot and air from the chamber-covered area circulated between the CO_2 analyser (PP Systems, model EGM-2) and the chamber. A battery-powered fan mixed sample air and prevented formation of concentration gradient inside the chamber. Carbon dioxide flux rate is detected as a linear increase in chamber CO_2 concentration during measuring period of 4 minutes, and in calculus it is proportioned to area and time.

Results

a. Fires 1997

ERS change detection images of the MRP area were used showing burnt scars in yellow to orange colours (Fig 2A). The first relatively cloud free post-fire Landsat TM image (118-62, 29.3.1998, RBG: 543) from the study site was available only 6 months after the fires (Fig. 2B). A comparison with this Landsat TM image shows a good agreement between burnt scars detected by ERS and by TM in red colour (Fig. 2B). Major discrepancies occur in agricultural areas, which are detected as burnt in ERS but unburned in the TM image. This effect results from fast regrowth of vegetation on burnt agricultural areas. The Landsat TM image has some haze in the upper left corner and technical defects. Dark red colours indicate burnt peat swamp forests. The extent of the burnt area was assessed by visually delineating red coloured

Land cover	Damage [ha]	Total Area [ha]	% of land cover	% of burned area
Closed, periodically inundated forest (type A)	1.196	16.821	7,1%	0,2%
Fragmented, periodically inundated forest	20.460	130.446	15,7%	2,6%
Closed peat swamp forest (type A)	9.809	217.069	4,5%	1,2%
Closed peat swamp forest (type B)	288.832	1.030.010	28,0%	36,2%
Open peat swamp forest	23.876	40.719	58,6%	3,0%
Fragmented peat swamp forest	55.297	78.955	70,0%	6,9%
Forest Mosaics, Other Vegetation & Forest	139.313	257.713	54,1%	17,5%
Swamp grassland	31.073	75.822	41,0%	3,9%
Agriculture, fallow land	109.869	302.555	36,3%	13,8%
Bush land	93.969	207.884	45,2%	11,8%
Other land cover	23.212	133.624	17,4%	2,9%
Total	**796.906**	**2.491.619**	-	**100,0%**

Table 1: Percentage of burned land covers as derived from the combined evaluation of pre- and post-fire Landsat TM and ERS SAR images. Closed forest (type A): >70% forest cover, > 70% canopy cover; Closed forest (type B): >70% forest cover, 70% - > 40% canopy cover; Open forest: >70% forest cover, 40% - > 10% canopy cover; Fragmented forest: >40-70% forest cover, > 10% canopy cover; Forest mosaics: >10 – 40% forest cover, >10% canopy cover.

surfaces at a scale of 1:100,000. The processed image shows the burnt area, GPS tracks (green) from ground and aerial surveys are superimposed (Fig. 2C). Some areas identified as being burned in the ERS SAR mosaic appear unburned in th Landsat TM image (Fig. 2A, 2B) or are covered by clouds and haze. Comparison with NOAA AVHRR hotspots (Fig. 4) indicated that in these areas fire actually occured. The pre-fire land cover classification indicated that these areas were mainly agricultural areas, fallow land and not forests. We conclude that sparse vegetation (grass and bush lands) escaped detection by Landsat TM due to fast regrowth of vegetation within six month period. On the other hand, some fire scars escaped detection by ERS SAR, because they were afire after he ERS imagery has been acquired.

Burnt Scars and Fire Damage derived from Landsat TM images 1997/1998 and ERS images are shown in Table 1 for a 2.491 Mha area. 32% of the study area has been fire affected (796,901 ha); the largest scars are in areas impacted by logging, forest clearance and peatland drainage. The spatial pattern of fire occurrence shows that largest fire scars are located in areas drained by the recently established MRP-irrigation channels. The large block of undisturbed forest of the Sungai Sebangau catchment shows only some scattered fire scars in areas where intense logging occured previously.

b. Peat storage

The fire as can be seen from the uncovered root system has consumed more than 70cm of peat. In order to be able to calculate fire induced CO_2 emission and total carbon storage of the peat layer we performed peat drillings in regular intervals of 500m (Fig. 3C left). The left panel of Fig. 3C shows the GPS recorded location of peat drillings, the middle the surface profile and the right the peat depth. A three-dimensional representation of peat volume and surrounding vegetation cover of Block C in the MRP area was established (Fig. 3B and 3C). Up to 12m of peat have been measured. Using Geographical Information System (GIS) techniques we calculated peat volume of Block C with an average of 2.5 m peat thickness and used this figure to extrapolate the amount of peat for the whole MRP and Sebangau area. Block C contains **9 Billion m³** of peat. The MRP and pristine PSF area from Sebangau to Katingan rivers and from the Java Sea to Kasongan and Tangkiling hills contains approx. **64 Billion m³** with an average 2 m to 3 m peat layer. Our investigations show that in contrast to boreal peat ecosystems tropical peatlands store considerable more carbon (Jaya *et al.*, 2000).

c. Loss of peat

Field surveys of burned areas in Block C revealed a loss of surface peat from a minimum of 0.20 m to a maximum of 1.50 m (Fig. 3A). 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 the study site in 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 m to 1.5 m, was removed, (Page *et al.*, 2000).

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 g cm^{-3} for peat bulk density (Neuzil, 1997).

Table 2 contains 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.

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 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 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. 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 aboveground forest biomass is estimated to be 0.038 Gt C.

Total carbon losses from the 1997 peatland fires in the study area are estimated to be in the range **0.218 to 0.491 Gt C** (Table 2), with the greatest contribution to emissions of atmospheric CO_2 derived from peat rather than forest combustion.

Vegetation/ land-use class	**Fire damaged area (ha)**	**Volume of combusted peat (m^3) 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	298641	1.2×10^9	2.99×10^9	0.068	0.170	0.029**	0.097	0.199
Peat swamp forest (disturbed)	218486	0.87×10^9	2.18×10^9	0.049	0.124	0.009***	0.058	0.133
Other land use classes	279779	1.1×10^9	2.8×10^9	0.063	0.159	n/a	0.063	0.159
TOTAL	**796906**	$\mathbf{3.17 \times 10^9}$	$\mathbf{7.97 \times 10^9}$	**0.180**	**0.453**	**0.038**	**0.218**	**0.491**

* calculated by applying values of 57% for peat carbon content and 0.10 g cm^{-3} 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^{-1} for peat swamp forest (Diemont *et al*., 1997)
*** calculated on the basis of 25% timber left standing (same basis as above)

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, based on ERS and Landsat images.

In developed sites, CO_2 emission rates varied, depending on water level, between 216 and 404 mg m^{-2} h^{-1}, while the average emission rate was a bit over 300 mg m^{-2} h^{-1} (Vasander & Jauhiainen 2001). If this average value of 300 mg CO_2 m^{-2} h^{-1} (= 81 mg C m^{-2} h^{-1}) is used for the decomposing peat in the whole fire damaged area (796,906 ha) we get an estimate of the effect of decomposing peat on carbon losses from the degraded areas. During one year the decomposing peat would increase the amount of carbon emissions by 4.16 Mt which would still increase the total loss of peat by 1.1 – 2.5% (cf. Table 2).

Discussion and conclusions

Mapping of burnt 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 the1982/83 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 Sungai 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 mega-rice 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.

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.

Pristine PSF emiited about double the amount of CO_2 compared to degraded areas with the same water level (Vasander & Jauhiainen 2001). The explanation for the clear difference in CO_2 emission rate in these two site types may well be attributed to the differences in their ecology. As vivid natural ecosystems, pristine forests produce a lot of decomposable litter into the forest floor both from above (leaves, tree branches, dead trunks) and below (fine roots, microbial biomass) the peat surface. Also the tree root respiration produces constantly CO_2. In developed sites massive vegetation cover is removed during the land clearance for farming and no short-term agriculturally grown vegetation can produce comparable amounts of decomposable litter to the soil. Furthermore, during harvest, much of the vegetation is removed with the crops and often the remains of vegetation are burned in order to fertilize the soil. These practices comb ined with aerobic conditions in surface peat lead to the decomposition of peat. The differences in CO_2 emissions between pristine and developed PSF thus may be compared to the differences of a healthy respiring organ and a dead decomposing one. Degraded PSF is thus emitting CO_2 to the atmosphere between the fires, too.

The combination of PSF Mapping with Remote Sensing and GIS Technique, field work of peat thickness drilling and in situ determination of emissins with carbon dioxide flux rate measurements, GPS recordig and continuous field campaigns are very good tools for the research of peatland especially in the tropical area of Kalimantan.

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References

BAPPENAS (National Development Planning Agency)/ADB (Asian Development Bank (1999). Causes, Extent, Impact and Costs of 1997/98 Fires and Draught. Final Report, Annex 1 and 2. Planning for Fire Prevention and Drought Management Project. Asian Development Bank TA 2999-INO Fortech, Pusat Pengembangan Agribisnis, Margueles Pöyry. Jakarta, Indonesia.

Barber, C. and Schweithelm, J. (2000) Trial by Fire – Forest Fires and Forestry Policy in Indonesia's Era of Crisis and Reform, report of *World Resources Institute*, Forest Frontiers Initiative, in collaboration with WWF Indonesia and Telapak Indonesia Foundation, 76 pages.

Boehm, H.-D.V., Siegert, F., Rieley, J.O. and Limin, S. (1997) Land use planning and environmental monitoring in Kalimantan using remote sensing data, published in *Economic & Business Review Indonesia* No. 279, August

Boehm, H.-D.V. and Siegert, F. (2000) Application of Remote Sensing and GIS to monitor Peatland multi-temporal in Central Kalimantan, published in the proceedings of the *TROPEAT-Conference* held in Nov. 21/22 1999 in Bogor

Diemont, W.H., Nabuurs, G.J., Rieley, J.O. and Rijksen, H.D. (1997) Climate change and management of tropical peatlands as a carbon reservoir. In: J.O. Rieley and S.E. Page (eds.) *Biodiversity and Sustainability of Tropical Peatlands*. Samara Publishing, Cardigan, UK, pp. 363-368.

Fuller, D.O. and Fulk, M. (2001) Burned area in Kalimantan, Indonesia mapped with NOAA-AVHRR and Landsat TM imagery. International Journal of Remote Sensing 22: 691-697

Jaya, A., Limin, S., Rieley, J.O. and Böhm, H.-D.V. (2000) Peat depth in Block C of Mega Rice Project, Central Kalimantan prepared for the *Millennium Wetland Event and Symposium of the International Peat Society*, Quebec 2000.

Liew, S.C., Lim, O.K., Kwoh, L.K. and Lim, H. (1998) A Study of the 1997 Forest Fires in South East Asia using SPOT Quicklook Mosaics. International Geoscience and Remote Sensing Symposium, 6 – 10 July 1998, Seattle.

Liew, S.C., Böhm, H.-D.V., Siegert, F., Kwoh, L.K., Padmanabhan, K. and Lim, H. (2001) Remote Sensing and Aerial Survey of Vegetation Cover Change in Lowland Peat Swamp of Central Kalimantan During the 1997 Fire, in press, Journal of Remote Sensing.

Neuzil, S. G. (1997) Onset and rate of peat and carbon accumulation in four domed ombrogenous peat deposits, Indonesia. In: J.O. Rieley and S.E. Page (eds.) *Biodiversity and Sustainability of Tropical Peatlands*. Samara Publishing, Cardigan, UK, pp. 55-72.

Notohadiprawiro, T. (1998) Conflict between problem-solving and optimising approach to land resources development policies - the case of Central Kalimantan wetlands. In: Sopo, R. (ed.) *Proceedings of the International Peat Symposium - The Spirit of Peatlands*. Jyväskylä, Finland, 7-9 September, 1998, pp. 14-24. International Peat Society, Jyväskylä, Finland.

Page, S.E. and Rieley, J.O. (1998) Tropical peatlands: a review of their natural resource functions with particular reference to Southeast Asia. *International Peat Journal*, 8, 95-106.

Page, S.E., Rieley, J.O., Böhm, H-D.V., Siegert, F. and Muhamad, N.Z. (2000) Impact of the 1997 fires on the peatlands of Central Kalimantan, Indonesia, prepared for the *Millennium Wetland Event and Symposium of the International Peat Society*, Quebec 2000.

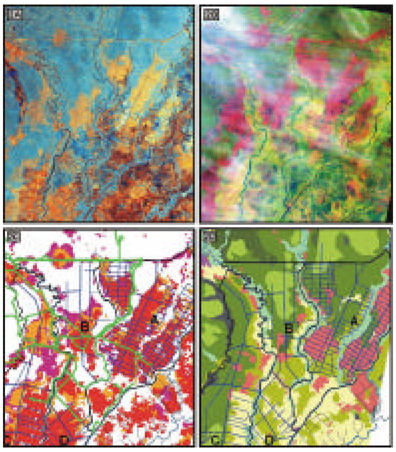
Rieley, J.O., Ahmad-Shah, A.A. and Brady, M.A. (1996) The extent and nature of tropical peat swamps. In: E. Maltby, C.P. Immirzi and R.J. Safford (eds.) *Tropical Lowland Peatlands of Southeast Asia*. IUCN, Gland. pp.17-53.

Schindele, W., Thoma, W. and Panzer, K. (1989) The Kalimantan Forest Fire of 1982-3 in East Kalimantan, *Part I: The Fire, the Effects, the Damage and Technical Solutions*. FR Report No. 5, German Agency for Technical Cooperation (GTZ)/ITTO, Jakarta.

Vasander, H. & Jauhiainen, J. (2001) Measuring of CO_2 emissions in tropical peatlands. In: Proceedings of the International conference & workshop on tropical peat swamps "Safe-guarding a global natural resource", 27.-29 July 1999, Penang. Malaysia (in press).

FIGURES

Fig. 1A: Main channel with 110 km length.
Fig. 1B: Several meters of pure peat at km 20 along main channel (here 8m deep).
Fig. 1C: Fire in selectively logged forest.
From left to right



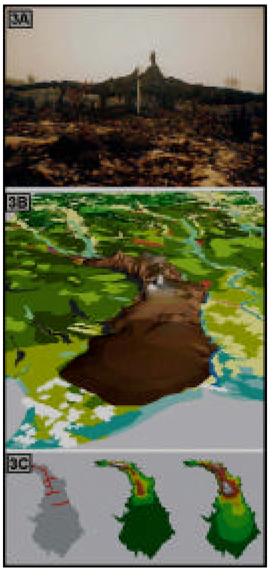


Fig. 3A: Burnt peat soil and uncovered root system.
Fig. 3B: shows a three-dimensional representation of peat volume and surrounding vegetation cover. The left panel of **Fig. 3C** shows the location of peat drillings, the middle a surface profile and the right peat depth in Block C of the MRP.

Fig. 2A: Mulitemporal ERS-mosaic before fire and after fire 1997; a subpart of the study side.
Fig. 2B: Landsat Image 6 month after the fire (acquired 28.3.1998).
Fig. 2C: Burnt scars 1997 and the MRP Blocks A, B, C, and D.
Fig. 2D: Vegetation and Land-use with main channels of MRP and some old channels derived from Landsat image May 1997.

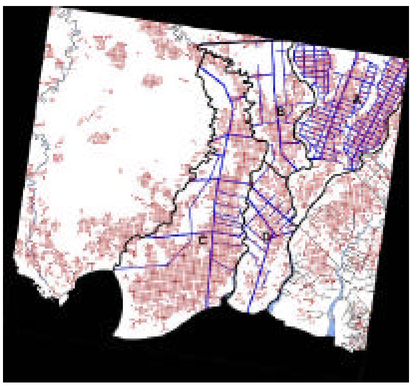


Fig. 4: NOAA-AVHRR hotspots measured between July and November 1997 of the 2.491 MHa study side and the Blocks A, B, C, D of the MRP with the new channel system.