

Causes of Indonesian Vegetation/Land Fires and Terrestrial Carbon Emissions

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Abstract

There was a widespread misconception about the sources and causes of fire incidences. At a certain point, the public perceived that wildfires and the associated haze were primarily from smallholders agricultural activities. In fact, there was a variety of sources including a substantial contribution from large-scale land clearing activities following deforestation for further land development. The availability of satellite images of hotspots is particularly important to show the distribution of fire and evaluate the underlying causes. In tropical Southeast Asia, however, where population pressure on lands and forests is prominent fires are deliberately lit for land clearing and no natural wildfires are reported. El Nino and Southern Oscillation (ENSO) provide the climatic conditions suitable for open biomass burning but it is hardly the underlying cause. An underlying cause neglected in the early discourse on vegetation fire was the forest and land development policies. Legitimizing massive forest conversion in Indonesia amounted 20-30 million ha in the early 1980s was one of the policy-driven strategies leading to various complex environmental problems.

One of the consequences of forest and vegetation fires is the changes in terrestrial carbon (C)-stocks. The amount of carbon stored in the vegetation of 160,000 ha Berbak National Park, Sumatra and the surrounding areas was estimated to be 306 Mg ha⁻¹ for natural forests, 93 Mg ha⁻¹ for secondary forests, 22 Mg ha⁻¹ for crops, and 2 Mg ha⁻¹ for early stage of plantation. These figures are within the range of 10-15% standard deviation, which were derived from several replicates from different sites in the upland having similar vegetation structure. Based on the fire scars obtained from the satellite imageries the amount of carbon released to the atmosphere was estimated around 7 Mt C during the 1997 fire event alone (Murdiyarso *et al.* 2002a).

By using the same satellite imageries combined with ground measurements within a 2.5 Mha study area in Central Kalimantan Page *et al.* (2000) determined that 32% (790,000 ha) of the area burned, of which peatland accounted for 91.5% (730,000 ha), releasing 190-230 Mt C to the atmosphere through peat combustion. They also estimated that between 810-2,570 Mt C were released to the atmosphere from Indonesia's peatlands in 1997 as a result of burning peat and vegetation. This is equivalent to 13-40% of the mean annual global carbon emissions from fossil fuels and contributed greatly to the largest increase in atmospheric CO₂ content detected since records began in 1957. Moreover, the 11.6 Mha vegetation fires in 1997 are estimated to exceed the IPCC's annual CO₂ growth of 1.5 ppmv.

Keywords: ENSO, Sumatra, Kalimantan, policy-driven deforestation, ecosystem services

Introduction

The 'big fires' raged in Indonesia in 1997. Most of them are deliberately lit to clear land, for tree crops produced a blanket of smoke or haze that spread and persisted over Indonesia and neighbouring countries for months. Fires are used every year to prepare land and burn waste

wood and crop residues but the big fires and widespread haze episode in 1997 resulted from the combination with dry conditions during which the El Nino is strongly associated with Southern Oscillation Index (SOI). Another useful indicator to demonstrate inter-decadal variability is the anomaly of Sea Surface Temperature (SST), which indicates the difference between the current temperatures and the temperature averaged over a long period. Meanwhile, the anomaly of Outgoing Long-wave Radiation (OLR) may be used to identify the increase of sensible heat in terrestrial ecosystems, hence, inter-annual changes of surface temperatures and droughts.

The question is whether this climatic variability has been the cause of fires or there are underlying causes that have been enhanced by dry weather conditions. It was obvious that during a decade after mid 1980s extensive land-use change occur in Indonesia because of government policy that attempted to convert tropical forests into timber plantation, oil palm plantation, and transmigration settlement. Fires have been extensively used as tool to clear land before new activities were established. The massive land development often conflicted with local inhabitants and smallholders. Hence, fires are often used as weapon wherever tenure systems are unclear. Inevitably, fires escaped and became uncontrolled wildfires since blames and claims cannot be easily attributed.

Fires and the transboundary haze pollution are just symptoms of structural problems that can only be solved by addressing policy, institutional, and legal issues. Attempts to set up early warning systems, fire prevention, and extensive monitoring are only justified to slow down further damages of properties, short and long-terms human health related issues and loss biological diversity which are global commons. In line with the last aspect, global climate is also threatened as more carbon is released in vast rates. If biological diversity and climate change have increasingly become global concerns, it is worth exploring global market-based mechanisms. This paper attempts to quantify the extent and significance of terrestrial carbon losses due to recurring vegetation/land fires.

Climatic Variability and Vegetation/Land Fires

SST anomaly

The warming SST in the equatorial Pacific Ocean is the signature of El Nino which signify drought in Indonesian archipelago. The correlation is particularly high for SST anomaly in the central equatorial Pacific known as Nino 3 and 4 regions. As oceanic process, the anomaly in these regions causes a massive transport of water vapour from the archipelago, hence, cancels the formation of precipitable clouds. The upper part of Figure 1 shows the spikes of SST in 1982, 1987, 1991 and 1997 that range between 2 and 3 °C. This indicate that El Nino is an inter-decadal variability. Furthermore, these years may be considered as El Nino years, however, 1982 and 1997 are categorized as strong El Nino, while 1987 and 1991 are weak El Nino. The opposite phenomenon of cooling Pacific Ocean or La Nina causes Indonesian archipelago to experience high precipitation or wet weather.

SOI

SOI represents atmospheric processes and is characterized by air pressure difference between Tahiti and Darwin (Pittock 1974). The larger the difference the larger the SOI. Negative SOI or low pressure in Tahiti is associated with El Nino events or often termed as El Nino Southern Oscillation (ENSO) during which most of Indonesian archipelago experience dry weather. These are also demonstrated in 1982, 1987, 1991, and 1997 as shown in the lower part of Figure 1. The variability of SOI is more pronounced than SST anomaly, however, the patterns of SOI and SST are consistent. Most of the ENSO events occur between May and

November with the peak around September. It is also indicated that strong El Nino is associated with SOI smaller than minus five (-5). This climatic variability, however, is difficult to predict but it is indicated that the frequency and intensity of ENSO is increasing in the past 20 years (Trenberth and Hoar 1997).

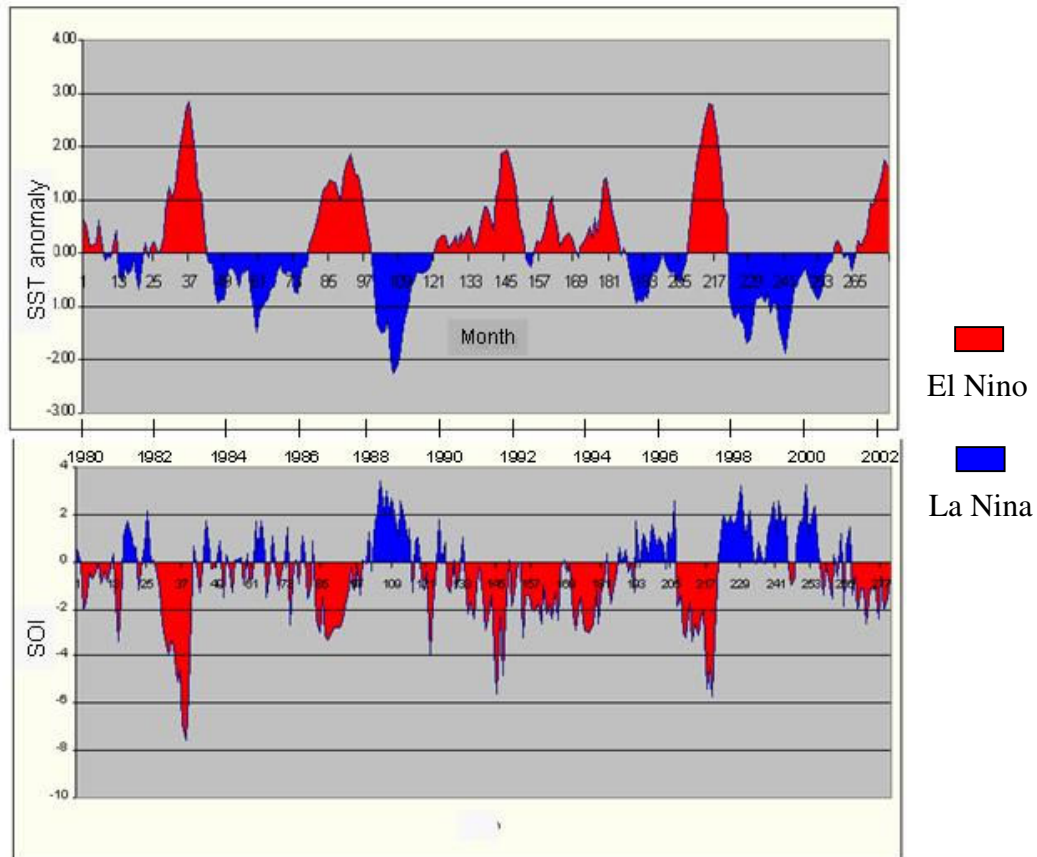


Figure 1. Sea Surface Temperature (SST) anomaly in Nino 3 and 4 and Southern Oscillation Index (SOI) that are associated with El Nino or drought events and La Nina or wet events in Indonesian archipelago

OLR anomaly

While SOI and SST are related to atmospheric and oceanic systems dynamics respectively, it is important to understand the impacts of climatic variability on terrestrial ecosystems. OLR is used to demonstrate regional distribution of potential drought overland that can be distinguished from sea surface OLR. The anomaly is indicated by the negative difference between the current OLR and the averaged long-term OLR. There are five classes of OLR differences used: very dry ($\leq -30 \text{ Wm}^{-2}$), dry (-30 to -10 Wm^{-2}), normal (-10 to 10 Wm^{-2}), wet (10 to 30 Wm^{-2}), and very wet ($\geq 30 \text{ Wm}^{-2}$). Figure 2 shows that during strong El Nino years almost all of Indonesian archipelago experienced very dry conditions, especially in the month of September. This may explain why most of vegetation/land fires occurred in September as indicated by the accumulation of hotspot frequency (Murdiyarso *et al.* 2002a).

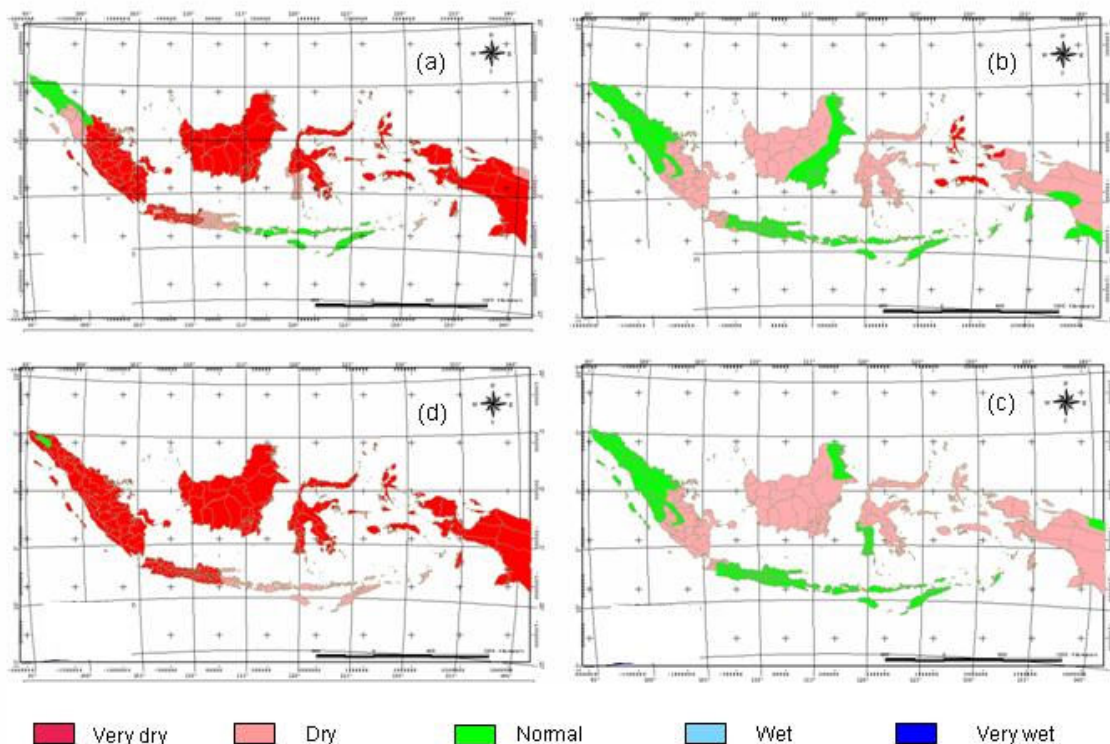


Figure 2. OLR anomaly in September during El Niño years (clockwise is 1982, 1987, 1991, and 1997) which indicates the dryness of terrestrial ecosystems. 1982 and 1997 are strong El Niño years, while 1987 and 1991 are weak El Niño years

Forestry and Land Development Policies

The above-mentioned parameters of climatic variability are hardly the cause of vegetation and land fires since no ignition has been reported as caused by this natural phenomenon. Its role in enhancing the spread of fires may be further discussed in the light of the underlying causes. An underlying cause neglected in the early discourse on the 1997 fires was that the forestland development strategies that are not sustainable and often wasteful. The process is underlined by legitimized plan to convert forests on a massive scale through the Ministerial Decree No. 682/Kpts/Um/8/1981, which designated 20-30 Mha of forestland as Conversion Forests. This national policy sparked extensive forest conversions or deforestation under the name of development to provide lands for plantations and transmigration settlements. In many cases, fires have been widely used for land preparation before the new plantations are established.

Following the Decree, the rate of deforestation of 600,000 ha yr⁻¹ in early 1980s rapidly increased up to of 1,600,000 ha yr⁻¹ in less than 20 years (MoFEC 1997, World Bank 2000). Illegal logging in the late 1990s up until now (Jepson et al. 2001) worsened the situation. Table 1 shows the ambitious forest conversion program to establish mono-species timber estates. Yet, only less than a half of the area allocated was realized. Rates of success have been very low due to poor site selection leading to abandonment of the allocated sites. These abandoned lands could lead to conflicts over land ownership and the other way around. It is not known why the 'others' category grew an order of magnitude larger over the decade.

Table 1. Timber plantation development to 1998 (ha)

	Allocated	Realized by 1998
Kalimantan	2,928,414	956,261
Sumatra	2,148,964	893,463
Sulawesi	255,791	85,455
Maluku	64,775	77,656
Irian Jaya	153,250	39,996
Others	48,730	352,215
Total	5,559,924	2,404,364

Source: World Bank, 1999

The area of oil palm plantation is more than tripled since the controversial Decree was launched until soon after the big fire. As shown in Table 2, more than 2 Mha of new plantation was established within a period of less than 10 years. More areas are pending for approval, mainly in Kalimantan and Sumatra. It is very likely that these areas will include peatlands. The economic downturn in 1997 may slowdown the expansion but the enthusiastic autonomous local governments may re-visit the applications.

Table 2. Oil palm plantation development from mid 1980s to 1998 (ha)

Island	Area in mid 1980s	Area in 1998	New area since mid 1980s	Outstanding application in 1995
Kalimantan	0	562,751	562,751	4,760,127
Sumatra	805,800	2,240,495	1,434,695	9,395,697
Sulawesi	11,800	101,251	89,451	665,379
Maluku	0	0	0	236,314
Irian Jaya	23,300	31,080	7,780	590,992
Others	1,800	21,502	19,702	1,777
Total	842,700	2,957,079	2,114,379	15,650,286

Source: World Bank, 1999

It is obvious that the underlying causes are policy-related issues. Unfortunately, the existence of local people who often have customary “*adat*” right which is not recognized in the formal legal system has been neglected in the planning phase. Comprehensive analysis on the underlying and interacting causes demonstrates a cascade of policy problems in land-use planning and management of forest resources (see *e.g.* Tomich *et al.* 1998, Potter and Lee 1998, Goldammer *et al.* 1998, Schweithelm 1998). Furthermore, Murdiyarso *et al.* (2003) outlined a policy intervention scheme at various levels that addresses:

- inappropriate use of fire as a tool to clear land
- destructive and inefficient logging practices
- unfair system for planning and allocating use rights to forests
- questionable land development strategies emphasizing monoculture crops, few commodities and promoting rapid deforestation
- lack of an effective international (regional) environmental regime

The 1997 Indonesian Vegetation/Land Fires

Sumatra Fires

Most fires in Sumatra (Riau, Jambi, South Sumatra and Lampung Provinces) can be attributed to land-use allocation policies. The majority of converted lowland tropical forests are for oil palm plantation. As shown in Table 2, more than 9 Mha application was outstanding in 1995 (World Bank 1999). These may include logged-over forest and

secondary forest but mainly peatlands, which hold substantial amount of biomass fuels are prone to burning before new plantation was established. In addition, local community and smallholder farmers also use fire to clear land in their plots (Ketterings 2000). In the case of those who cultivate rubber for centuries in Jambi, the unproductive trees are slashed and accumulated in March-April before deliberately ignited around September-October (Ketterings *et al.* 1999). The sustainable old “shifting cultivation” practice has been accelerated by shortening the fallow cycles. There was no incident of natural ignition sources reported (Stolle 2003).

In contrary, it is widely known that fires are used as tool to clear lands and weapon when conflicts over land ownership are unresolved. In South Sumatra such incident has caused deliberately lit fires to escape and uncontrollable (Bompard and Guizol 1999). Institutional causes, such as, lack of coordination and overlapping of various administrative structure in government agencies are among the inadequate management tools. It was estimated that 1997 fire burned 786,000 ha of land, making South Sumatra the most severely affected province in the island. Although without a breakdown by vegetation types Legg and Laumonier (1999) estimated the total area burned in Lampung and South Sumatra as much as 1.0 Mha.

Kalimantan Fires

Peatland fires, especially in Central and South Kalimantan where Mega Rice Project was started in 1995, dominated the 1997 fires in Kalimantan. The scheme was to convert more than 1 Mha peat forest into rice-growing area. The project involved more than one million transmigrants from Java and squeezed thousands of local people. The complex social problems would later worsen the smouldering fire and haze. The peat is one of the oldest and deepest peats in the planet (Barber and Schweithelm 2000). Forest removal and water drainage have exposed the entire landscape susceptible to fire and other environmental disasters. It is in this heart of Kalimantan where massive amount of carbon was released into the atmosphere during 1997 fires.

Although East Kalimantan was severely damaged by the great ever recorded 1983 fires, strong El Nino in 1997 still accelerated smallholders and large-scale operators fire-related activities in the uplands. Drought and fire collided for millennia but what made the situation in 1983 a calamity was the reckless logging operation in the previous years (Schindler *et al.* 1989, Goldammer and Siebert 1990). With low intensity logging, forests could recover the damage by recurring fires. However, careless logging techniques and plantation establishment have enhanced the damage by 1994 and 1997 fires, which are severe and permanent. Logging activities several years before the fire contribute to the damage. New settlements were established following logging roads and in the frontier of the forest causing fire to re-occur.

Area burned and carbon released

It is almost impossible to determine, with precision, the total area of landscape in Indonesia that burned in the 1997 fires. There are always huge discrepancies of data when comparing official and satellite data obtained from various agencies. A report by the Indonesian Development Planning Agency (BAPPENAS 1999b), for example, provides a range from 0.16 to 9.7 Mha for the whole of Indonesia with the regional detail as shown in Table 3. The total area burned has been revised by Liew *et al.* (2001) who included 316,000 ha of burned peatland in Sumatra and 311,000 ha in Kalimantan provided by Hoffmann *et al.* (1999). These give the revised total area burned of 11.6 Mha (Tacconi 2003).

Table 3. The extent of area damaged in 1997 fires (ha)

Island	Lowland forest	Peat and swamp forest	Scrub/grass-land	Timber plantation	Agriculture	Estate crops	Total *
Kalimantan	2,375,000	750,000	375,000	116,000	2,829,000	55,000	6,500,000
Sumatra	383,000	308,000	263,000	72,000	669,000	60,000	1,756,000
Java	25,000	0	25,000	0	50,000	0	100,000
Sulawesi	200,000	0	0	0	199,000	1,000	400,000
Irian Jaya	300,000	40,000	100,000	0	97,000	3,000	900,000
Total	3,100,000	1,450,000	700,000	188,000	3,843,000	119,000	9,656,000

*) Fires in montane forests are not included

Source: BAPPENAS, 1999b

In order to estimate the amount of carbon released during fires, one has to bear in mind that:

- each land-use or land-cover has to be accounted for individually since they have a significant different in biomass and carbon density
- not all classified land-use necessarily covered with the said vegetation
- not all area affected by fires are completely burned, therefore, a combustion factor or burning efficiency has to be employed
- the amount of carbon (C) constitutes around a half of the biomass
- to convert the emission into gaseous phase (CO₂) another conversion factor of 3.7, which is the ratio of molecular weight of CO₂ and C, is used
- to further convert the units mass of CO₂ (gigaton, Gt) into units of concentration (ppmv), the figure should be halved.

Based on the survey of 10 land-use types in Jambi Province, Sumatra ranging from degraded grassland to undisturbed natural forest, where the carbon density varies between 39 and 254 Mg ha⁻¹ (Murdiyarso *et al.* 2002b), a median of 50 Mg ha⁻¹ is adopted to estimate carbon loss from the above-ground biomass during fire episodes. The burning efficiency was of 50% was averaged from field experiment conducted by Hairiah and Sitompul (2000). With the area burned during El Nino years in the past 20 years 'reconciled' from various sources, the estimated CO₂ release is shown in Table 4.

Table 4. Area burned in four El Nino years and the amount of CO₂ released into the atmosphere

Fire event	Area burned (Mha)	Estimated CO ₂ released (ppmv)
1982	3.60	0.33
1987	0.07	0.006
1991	0.5	0.05
1997	10.0	0.93

As shown in Figure 1, 1982 and 1997 are strong El Nino years, while 1987 and 1991 are weak El Nino years. They are also signified by the area burned, hence the amount of CO₂ released. However, although 1983 El Nino was stronger than 1997, the area burned in 1997 and CO₂ released were larger. This may be explained by the fact that the underlying policy causes have played an important in providing access to land where fuel loads was mounting.

The estimated CO₂ released from one fire episode in 1997 is two third of the annual CO₂ growth of 1.5 ppmv (Houghton *et al.* 2001). This figure may be underestimated since only

above-ground biomass burning was accounted for. It has to be born in mind that burned peat and swamp forests also released carbon from below-ground organic materials. The amount depends on the peat thickness and its flammability.

Peatland fires

Fuller and Fulk (2001) estimated that 1.45 Mha of peatland was burned in the whole of Indonesia during 1997. These included Sumatra (300,000 ha), Kalimantan (750,000 ha) and Irian Jaya (400,000 ha). The most recent assessment (Tacconi 2003) shows that the total area of peatland burned during 1997 fire was 2.12 Mha or 20% of the total area burned. This consists of 624,000 ha in Sumatra after including additional 316,000 (Liew *et al.* 2001) ha from the initial estimate by BAPPENAS (1999) and 1,100,000 ha in Kalimantan after accommodating the revised figures for East Kalimantan of 311,000 ha provided by Hoffmann *et al.* (1999), Central Kalimantan of 730,000 ha provided by Page *et al.* (2002), and other peat-covered landscape in West Kalimantan. The burned peatland area in Irian Jaya of 400,000 ha remains the same. It means that 1997 fire has burned 10% of Indonesia's total peatland of 20.1 Mha.

Based on hundreds of field drilling, Page *et al.* (2002) found that their 0.4 Mha study area within the 2.5 Mha inter-fluvial peat-covered landscape in Central Kalimantan is dome-shaped with a maximum thickness of 8 m and a mean of 4.4 ± 0.2 m, equating to a possible mean volume of peat of 14.9 ± 0.3 billion m^3 . In order to compensate for those areas where the peat was shallow or non-existent a reduced estimates of 2.3 m for mean peat thickness and mean volume of 7.8 billion m^3 were adopted. By using satellite imagery and ground measurements it was estimated that within the 2.5 Mha area, 0.79 Mha (32%) of the area burned, of which peatland accounted for 0.73 Mha (91.5%). The peat layer destroyed by the fires varied between 0.25 and 0.85 m with an average of 0.51 ± 0.05 m. These give an estimate that the peat fires in Central Kalimantan released 0.19-0.23 Gt C into the atmosphere. These values do not take into account the amount of carbon lost in biomass burning. The situation was exactly the opposite when estimating carbon loss from peat forest in Berbak National Park. The amount of carbon released due to 1997 fire within more than 124,000 ha burned area was only 7 Mt because the loss from peat underneath was not calculated (Murdiyarto *et al.* 2002a). Assuming that the carbon content for pristine peat swamp forest is 250 t C ha^{-1} (Jordan 1983) and that 50% of the trees remained standing after fire the 2.5 Mha study area released 0.05 Gt C. By applying an average value of 0.51 ± 0.05 m of peat burned away over 33.9% of the peat-covered landscape of Central Kalimantan to the 20.07 Mha of peatland in Indonesia, Page *et al.* (2002) also estimated that between 0.81 and 2.57 Gt C could have been released from burning of peat and its surface vegetation due to 1997 fires.

If the total peatland area burned is deduced from the total area burned in 1997, and the carbon density of 50 t ha^{-1} and burning efficiency of 50% are applied, the amount of carbon released from non-peatland area ($11.6 - 2.12 = 9.48$ Mha) would be 0.47 Gt. If the upper limit of the peatland fire was added to the upland fire, the estimate of carbon released from 1997 Indonesian fire would be 3.04 Gt. This amount is higher than the global annual carbon release estimated by IPCC (Houghton *et al.* 2001) of 2.9 Gt C.

Concluding Remarks

Indonesia's big fire in 1997 was very much associated and driven by national policy concerning large-scale forest conversions. Other causes were less important in terms of magnitude. Moreover, it is misleading to keep repeating to give the impression that ENSO is

the cause of fire. ENSO, of course, has accelerated the spread of wildfire but it does not ignite fire. The evidence as shown in Table 4 that although the 1982's ENSO was stronger than the 1997 one but less area was burned by 1982 fire demonstrates the fact that land-use and land management policy was the primary cause.

The contribution of peatland fires to the emission of carbon is significant. This is because beside the above ground biomass organic materials accumulated on and below the ground contribute substantial amount of fuels that are ready to be combusted during dry weather. As a result the 1997 Indonesia's fire which involved 2.12 Mha of peatland out of the total 11.6 Mha burned area released 3.04 Gt C or 1.52 ppmv of CO₂, slightly higher than the global annual CO₂ growth of 1.5 ppmv. It means that CO₂ emission from Indonesia's 1997 fire alone has doubled the global annual CO₂ growth.

Due to various contentious issues including leakage and permanence sink project under Clean Development Mechanism of the Kyoto Protocol is limited for reforestation and afforestation activities (Leining 2000, Noble and Scholes 2001). Although avoiding deforestation is not eligible for mitigating climate change, one should think about non-Kyoto market mechanisms, at least to let the peat and swamp forest ecosystems to adapt with the changing climate. Other eligibility criteria should be sought and defined, such as, ecosystem services in the form of peatland water table maintenance, peatland biodiversity conservation, and non-timber forest products to improve the livelihood.

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