Current fire regimes, impacts and the likely changes – IV: tropical Southeast Asia

Book Section

7 Current Fire Regimes, Impacts and the Likely Changes – IV: Tropical Southeast Asia

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Abstract

The Southeast Asian region is experiencing some of the world's highest rates of deforestation and forest degradation, the principle drivers of which are agricultural expansion and wood extraction in combination with an increased incidence of fire. Recent changes in fire regimes in Southeast Asia are indicative of increased human-causd forest disturbance, but El Niño–Southern Oscillation (ENSO) events also play a role in exacerbating fire occurrence and severity. Fires are now occurring on a much more extensive scale - in part because forest margins are at greater risk of fire as a result of disturbance through logging activities, but also as a result of rapid, large-scale forest clearance for the establishment of plantations. Millions of hectares have been deforested and drained to make way for oil palm and pulpwood trees, and many plantation companies, particularly in Indonesia, have employed fire as a cheap land clearance tool; uncontrolled fires have entered adjacent forests or plantation estates, and burnt both the forest biomass and, in peatland areas, underlying peat. Forest fires cause changes to forest structure, biodiversity, soil and hydrology. Repeated fires over successive or every few years lead to a progressive decline in the number of primary forest species. Fire leads to reduction in both aboveground and below ground organic carbon stocks and also changes carbon cycling patterns. In non-peatland areas, losses of carbon from fire affected forest vegetation exceed greatly soil carbon losses, but on carbon-rich substrates, e.g. peat, combustion losses can be considerable. Peatland fires make a major contribution to atmospheric emissions of greenhouse gases, fine particular matter and aerosols and thus contribute to climate change as well as presenting a problem for human health. The scale of emissions is unlikely to reduce in coming decades, since climate modelling studies have predicted that parts of this region will experience lower rainfall in future and greater seasonality. Protecting the rainforests of this region from further fire disasters should be at the top of the global environmental agenda, with highest priority given to peatland areas.

Keywords: Peatland fire, lowland tropical forest, land clearing, carbon cycling, Mega Rice Project

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Introduction

The Southeast Asian region is currently experiencing some of the world's highest rates of deforestation and forest degradation (Achard et al., 2002; Langner et al., 2007). Forty percent of the forests existing in Indonesia in 1950 had been cleared by the end of the millennium (Global Forest Watch, 2002) and an average annual clearance rate of 1×10^6 ha during the 1980s, has increased to an average of 2×10^6 ha per year since 1996 (Global Forest Watch, 2002). The principle proximate drivers of this rapid deforestation are agricultural expansion and wood extraction (Geist and Lambin, 2002), but forest disturbance has also increased the risk of fire, leading to further loss and fragmentation of the region's remaining forests (Siegert et al., 2001). During 1997-1998, for example, large-scale wildfires occurred throughout Southeast Asia; these were linked to rapid land use changes, further exacerbated by an extended ENSO-related drought (Page et al., 2002). This fire episode (Tacconi et al., 2007), led to an increased awareness of the wide-ranging impacts that uncontrolled fires in this region have on biodiversity, economy, human well-being and climate (Schweithelm, 1999).

Fires are not a new phenomenon in the tropical forests of Southeast Asia. Occasional wildfires have occurred over several millennia (Goldammer and Seibert, 1989, 1990; Goldammer, 1992, Hope et al., 2005) but, prior to human-induced modification of the forest, rainforest fires were relatively rare events. Even when they did occur, the long interval between fires would have provided adequate time for recovery of pre-fire forest structure and biodiversity. In recent years, however, rainforest fires have become both more frequent and extensive, with human activities implicated in fire ignition as well as the changes in land cover which enable fires to establish and spread. Langner and Siegert (2009), for example, demonstrated that ~21% of land in Borneo was subjected to fires during 1997-2006, with 6.1% (4.5×10^6 ha) of the forest affected more than once. They noted that some of the most extensive fires occurred in areas of peat swamp forest, particularly in Kalimantan and Sumatra.

Fire and Land Use Change

Recent changes in fire regimes in Southeast Asia are indicative of increased forest disturbance, but ENSO events also increase fire occurrence and severity. The ENSO-fire relationship is not a new one. There are, for example, accounts of extensive fires in the 15th and 16th centuries (Dennis, 1999; Taylor et al., 1999), when land use conversion activities would have been far less intensive than today, which appear to have been linked to ENSO droughts. Berlage (1957) demonstrated that ~93% of all droughts during 1830-1953 occurred during ENSO events. This pattern was repeated during the second half of the 20th century, with some of the worst fires associated with strong ENSO episodes, including the fires of 1972-73, 1982-83 (the 'Great Fire of Borneo'), 1994, 1997-98, 2002 and 2006 (Aiken, 2004; Baker et al., 2008; Fuller and Murphy, 2006; Malingreau et al., 1985; Tacconi et al., 2007; Wyrtki, 1975). The 1982-83 fires were estimated to have burnt 3.2×10^6 ha, of which 2.7×10^6 ha were forest (Schindele et al., 1989), including 0.55×10^6 ha of peat swamp

(Lennertz and Panzer, 1984). The 1997-1998 fires affected a much larger area estimated to be 11.7×10^6 ha of forest in Indonesia alone, of which approximately 2.4×10^6 ha was peat swamp forest (Page et al., 2002).

Analysis of recent land cover change has underscored the close link between land management and fire activity (Langner and Siegert, 2009). There has been an expansion in the use of fire over larger areas and for longer periods of time than would have previously occurred using traditional slash and burn techniques. The latter are sustainable if the time period between the burning events is long enough and burning is practiced on a small scale, enabling forest regeneration, but fire is now occurring on a much more extensive scale. In part this is because forest margins are at greater risk of fire as a result of disturbance and forest fragmentation through intensive logging activities, but there has also been rapid, large-scale forest clearance for the establishment of large plantations, particularly replacing peat swamp forests, which are now the last remaining extensive areas of lowland rainforest in equatorial Southeast Asia.

Peat swamp forests, which formerly covered 25×10^6 ha of Southeast Asia (Page et al., 2008a), are characterized by the presence of thick peat deposits that are acidic, nutrient-poor and waterlogged and thus present a problematic agricultural environment. Nevertheless, millions of hectares of peatland in Southeast Asia, especially Indonesia and Malaysia, have been deforested, drained and burned to make way for agriculture and settlement, especially oil palm and pulpwood (*Acacia*) estates which produce raw materials for the vegetable oil, biofuel, pulp and paper industries. Many plantation companies, particularly in Indonesia, have employed fire as a cheap and rapid land clearance tool to clear thousands of hectares of logged-over forest; many of these fires have run out of control, entering adjacent forests or drained plantation estates, where they have burned both forest biomass and surface peat.

The risk of fire on peatland is increased greatly by drainage, which lowers the water table, exposing a greater volume of dry peat to combustion. This effect is demonstrated by a study of the fire regime in the former Mega Rice Project (MRP) area on peatland in southern Central Kalimantan (Hoscilo, 2008a) (Fig. 7.1). During 1973-1996, fires affected 24% of a 450,000 ha study area. Most burn scars were located along forest edges (i.e. disturbed forest), usually in close proximity to human settlements which provided a source of ignition. More remote, intact forests were unaffected by fire, even during extended ENSO droughts. This situation changed markedly in the next decade. Following construction of an extensive canal network in 1995-96, the fires of 1997 affected about 34% of the area, i.e. 10% more than had burned during the previous 23 year period (1973-1996) whilst, in 2002, fires affected 22% of the area. In total, more than half of the study area burnt during 1997-2005, with many locations experiencing multiple fires. This was a consequence of deforestation, peatland drainage and increased human access; drainage increased fire risk, whilst people provided the fire ignition source.

Ecological and environmental (atmospheric) impacts

Forest fires cause changes to forest structure, biodiversity, soils and hydrology, as well as increasing greenhouse gas, particulate and aerosol emissions to the atmosphere. Natural fires in undisturbed, old-growth rainforest in this region have, until recently, been rare (Goldammer and Seibert, 1989), but there is evidence that, given a sufficiently long fire return period, these forests have a natural recovery response. Goldammer and Seibert (1989), for example, provided evidence by ^{14}C ages of charcoal that the now diverse rainforests of East Kalimantan were subject to fires between 13,500 and 350 years ago. Given the recent increased incidence of fire in this region there is a pressing requirement to understand the vegetation response to intensive and repeated fires. To date there have been only a few ecological studies examining post-fire vegetation response in lowland forests on mineral soils and even fewer investigations in peat swamp forest. This knowledge is crucial in order to: a) understand fire regimes, b) diminish future fire risk, and c) manage degraded forest land towards a mature stage of regeneration.

Studies of lowland forests have shown that fire causes increased tree mortality, with highest losses in the understorey (trees with dbh <10 cm) (Slik et al., 2002) even at low fire intensity and flame length (Baker et al., 2008), and converts forest stands with a high diversity of primary species into ones dominated by a few fire-adapted or pioneer species (Toma et al. 2005). Since climax trees need a considerable length of time for their growth and reproduction, it is likely that repeated fires within a short time interval will lead to a decrease in their numbers. Slik et al. (2008) found that dipterocarp forest structure was strongly affected by fire but recovered quickly. In contrast, species composition showed no or limited recovery and above-ground biomass (AGB) was reduced greatly and remained at a low level even after seven years.

Secondary forest regrowth can be a carbon sink over the medium term and thus studies of post-fire vegetation recovery are important to understand changes in ecosystem carbon flux. In a long-term monitoring study of post-fire forest regrowth in East Kalimantan, Toma et al. (2005) demonstrated that if fire kills large specimens of primary forest species, the lost biomass is unlikely to be completely restored since the AGB attained by pioneer trees (such as *Macaranga* spp.) was far less than the biomass of climax species lost by burning. More rapid AGB accumulation can only occur when pioneer species are replaced by primary forest species, ie. over a long time scale. In studies carried out on post-fire vegetation response in peat swamp forest in Central Kalimantan, Page et al. (2008b, 2009) and Hoscilo et al. (2008b) have shown that peatland subject to a single, low intensity fire undergoes succession to secondary forest, achieving a biomass equivalent to about 10% of that of undisturbed forest within nine years. Compared to mineral soils, the recovery of peat swamp forest is much slower. Nykvist (1996), for example, showed that the biomass of eight-year old lowland dipterocarp forest in Sabah had recovered 24% of pre-fire biomass. Following multiple fires in peat swamp forest, the numbers of tree species and individual trees, saplings and seedlings within the secondary vegetation are greatly reduced and, at the highest levels of degradation, succession back to forest is diverted to a retrogressive succession to communities dominated

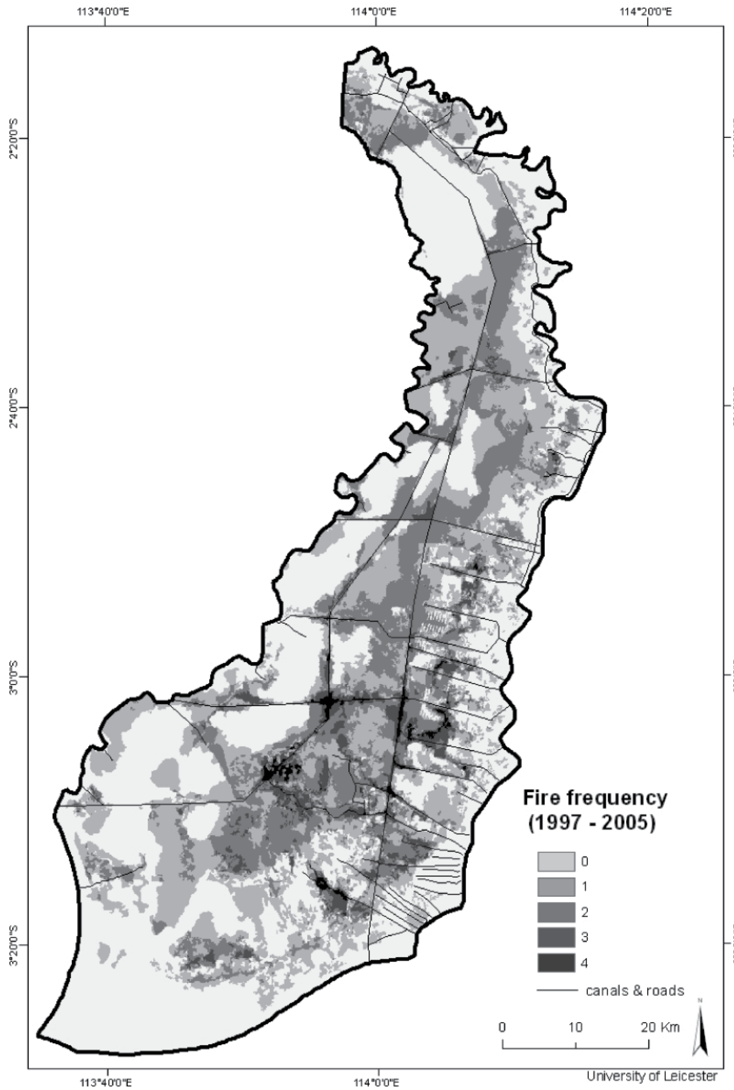

Figure 7.1. Spatial distribution of single and multiple fires over the period 1997-2005 in Block C (4,500 km^2) of the former Mega Rice Project (MRP) area in southern Central Kalimantan province, Indonesian Borneo (Hoscilo, unpublished results; see also Page et al. [2008, 2009]). This area of peat swamp forest was extensively drained during 1995-1996 as a result of MRP infrastructure development (the network of canals and roads is overlaid on the map). Peatland drainage has greatly enhanced both the risk and extent of fires, illustrated by the large number of sites that have burnt two, three or four times, particularly in proximity to canals. During ENSO-related droughts (1997, 2002 and 2006), forest and peatland fires in the MRP led to high greenhouse gas and particulate emissions to the atmosphere (Fig. 7.3).

by ferns with very few or no trees (Fig. 7.2). At this point, both biomass and hence the potential for carbon sequestration are greatly reduced.

Several studies have highlighted invasion of ferns and grasses as a particular feature of repeatedly burned forest in Southeast Asia (Cleary and Priadjati, 2005; Slik et al., 2008; Van Nieuwstadt, 2002; Woods, 1989). A high density of non-woody vegetation suppresses tree regrowth since it can overgrow and out-compete many seedlings and saplings in the early stages of their development. In addition, fire reduces seed availability and dispersal, leading to a decline in seedlings and saplings, and removes the vegetative regeneration potential of tree bases and roots, which are burned away. Van Nieuwstadt et al. (2001) reported a loss of 85% of the dormant seeds in the surface litter layer and 60% in the upper soil layer in lowland forest following fire. A further consequence of repeated fires on tropical peatland is land subsidence, a result of peat dewatering, biological oxidation and combustion losses, which lead to an increased risk of flooding in wet seasons. Van Eijk and Leenman (2004) and Wösten et al. (2006) describe post-fire vegetation trends in Berbak, Sumatra, where areas burnt only once and subject to shallow, short duration flooding during the wet season were able to undergo succession to a relatively species-diverse, well structured forest vegetation. Sites subject to multiple burns, peat subsidence and deep or prolonged flooding, however, have a much more poorly developed and less diverse vegetation dominated by flood-tolerant, non-woody vegetation.

In a study of peatland fires in Borneo, Spessa et al. (2009) demonstrated that the occurrence of uncontrolled fires was favored by the increased fire susceptibility of both over-drained peatland areas and previously disturbed forests. The greater the losses in tree cover between 1997 and 2005, for example, the more fire activity was observed. The results of this study, and those described above, are consistent with studies conducted in other tropical ecosystems disturbed by fire, e.g. in Amazonia, where recurrent fires transformed tree-dominated ecosystems to mostly grassy ecosystems which, in turn, promote even more fires as part of a so-called 'vicious positive feedback loop' (Cochrane et al., 1999; Cochrane, 2003). The same process is occurring in Southeast Asia, where increased fire frequency has converted forest vegetation, at low risk of fire, to fern- and grass-dominated savannah-type communities, which dry out quickly during periods of low rainfall and thus burn more easily, creating a positive feedback through increased flammability.

In addition to changes in vegetation structure and diversity, fire also leads to reductions in both aboveground and below ground organic carbon stocks and changes in carbon cycling patterns. Losses of carbon from AGB usually greatly exceed those from soil but, in regions with carbon-rich substrates, e.g. peat swamp forests, combustion losses from belowground stocks can be much greater than AGB losses. For this reason, fires in peatland areas require particular attention, since they make a substantial contribution to global greenhouse gases (Bowman et al., 2009) and, through the production of fine particular matter and aerosols, result in a wide range of human health problems (Heil and Goldammer, 2001). The devastating 1997-1998 Indonesian fires were one of the largest peak emissions events in the recorded history of fires in equatorial Southeast Asia, if not globally (Schultz et al., 2008;

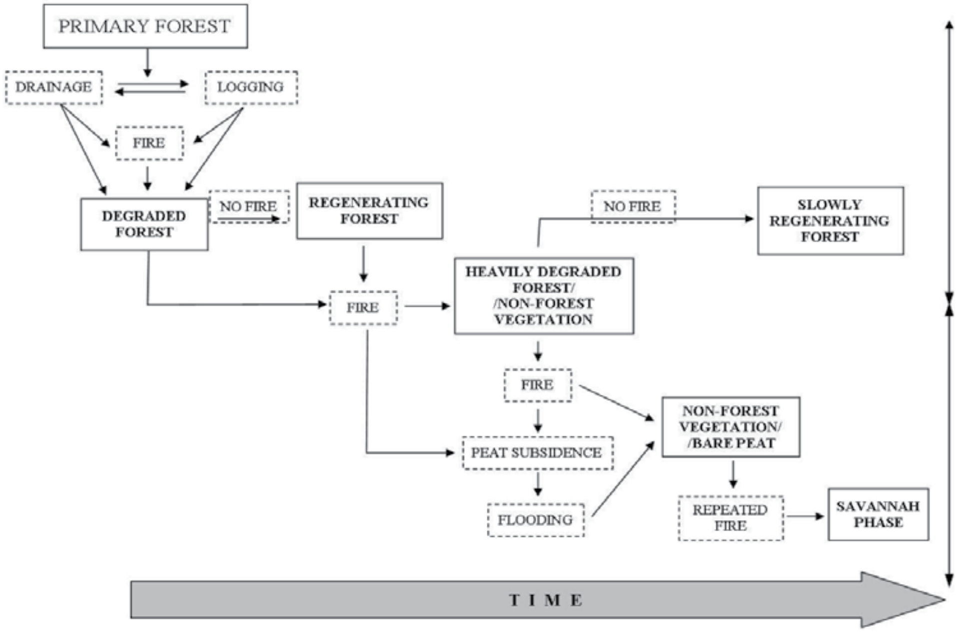

Figure 7.2. Relationship between single and multiple fires and phases of vegetation succession against time in peat swamp forest. With repeated fires, progressive succession towards forest is replaced by a retrogressive succession to 'savannah' type vegetation dominated by ferns, sedges and grasses and with few or no trees (adapted from Page et al. [2008b]).

van der Werf et al., 2006). Page et al. (2002) conservatively estimated that the Indonesian fires in 1997 released more than 870 Tg of carbon to the atmosphere, which was equivalent to 14% of the average global annual fossil fuel emissions released during the 1990s. This value was confirmed by Schultz et al. (2008), who estimated 1997 emissions from Indonesia at 1.136 Pg carbon, and van der Werf et al. (2006, 2008), who estimated 1997 emissions from equatorial Southeast Asia at 1.089 Pg carbon, over 90% of which was released from Indonesia. These emissions represent a serious perturbation in terms of climatic forcing from trace gases and aerosols. The magnitude of emissions, particularly from tropical peatland fires (Fig. 7.3), is unlikely to be reduced in coming decades, since climate modeling studies have shown that parts of equatorial Southeast Asia will experience reduced rainfall and greater seasonality in future decades (Li et al., 2007).

Conclusions

Forest fires in Southeast Asia, and the environmental changes that they bring about, have had significant impacts on the atmosphere, the carbon cycle and ecosystem services, notably

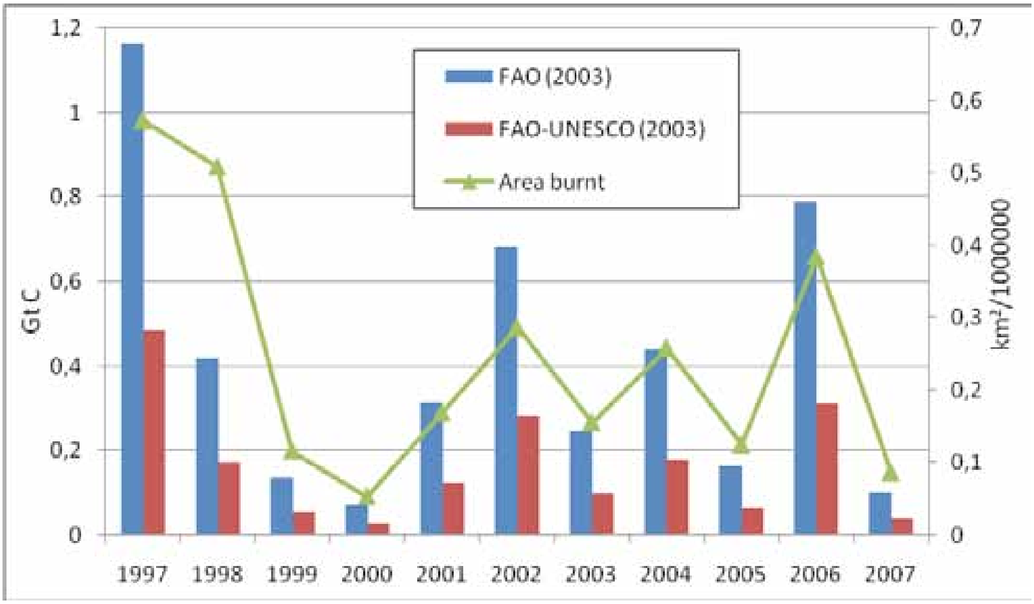

Figure 7.3: Estimated annual total carbon emissions from peat burning versus annual total area burnt for Borneo over the period 1997-2007. Peat surfaces were derived from two soil maps (FAO, 2003; FAO-UNESCO, 2003). Peat bulk density was assigned a value of 128 kg m^{-3} and the carbon fraction was assumed to equal 0.54. The depth of peat burnt in areas classed as histosols was assumed to be 50 cm (after Page et al., 2002) and in areas classed as humic gleysols to be 40 cm (Spessa et al. unpublished results). There are considerable uncertainties associated with estimating carbon emissions from peat fires; data are needed on peatland extent, which is poorly known, area and depth of peat burnt. Despite these uncertainties, the data illustrate the scale of recent fires in this part of Southeast Asia.

carbon and water storage and biodiversity. Protecting the rainforests of this region from further fire disasters should be at the top of the global environmental agenda, with greatest attention given to peatland. Not only do forest fires make a significant contribution to atmospheric carbon emissions and, consequently, to global climate change, they also cause considerable human misery and hardship. Protecting the remaining forests from logging, drainage and land conversion should be seen as a high priority, as undisturbed forests are at very low risk of combustion. Where there is an over-riding economic imperative for land development then land clearance should not involve the use of fire whilst, in peatland already converted to agriculture or plantations, improved water and land management practices, especially those that maintain a high water table, could contribute to a greatly reduced risk of fire.

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