FIRE IN THE DANAU SENTARUM LANDSCAPE:

HISTORICAL, PRESENT PERSPECTIVES

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This paper presents a quantitative analysis of the extent of forest and scrub burning in the Danau Sentarum area, West Kalimantan, Indonesia. Burn scar areas were detected using remotely sensed data from four dates (1973, 1990, 1994, and 1997) obtained for a 24-year period. The results show a significant increase in the total burnt area in the 197,000 ha study site, from 5,483 ha in 1973 to 17,941 ha by mid-1997. Of the area burned by 1997, 8,021 ha, or 45% of the total burnt area, was tall forest (fresh-water swamp, peat swamp, or riverine) in 1990. This indicates a considerable role of forest destruction in the burning process. Another trend that was found was an increase in the maximum size of burn scars between 1973 and 1997, from 581 ha to 1,339 ha. It is still too early to fully explain these trends in terms of underlying causes, but field data suggest three main factors lie behind the burning and interact in a way that is not yet fully understood. These are environmental factors, resource extraction activities, and increasing human population pressure. An another potential factor, with a yet unclear role in fires, is conflicts within and between villages. Further in-depth research is required to investigate the underlying causes of fire in Danau Sentarum.

Introduction

Fire is and has been part of the Danau Sentarum landscape for a long time. The oldest evidence of fires at Danau Sentarum comes from the analysis of pollen and charcoal records carried out recently by Anshari *et al.* (in press). The record provides a picture of changing vegetation over the past 30,000 years and charcoal is present throughout the record. The analysis identified increased burning levels and indicators of forest disturbance during the past 1,400 years (Anshari *et al*, in press).

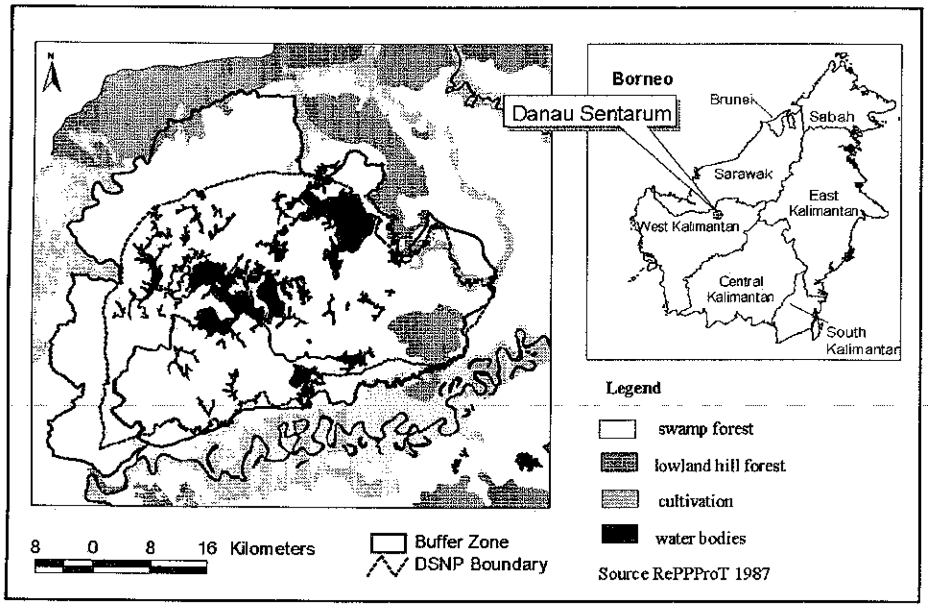

Figure 1. Location of study area.

Providing a more recent description of fire, from the mid-19th century up until present time, there are many written accounts of visits to the Danau Sentarum area that provide a wealth of fire descriptions. One of the first explorers to mention the evidence of swamp forest fires at Danau Sentarum was Pfeiffer (1856) who visited the area in January 1852. She described extensive areas of burnt standing trees in the swamps to the north-west of the lakes. Gerlach (1881) visited the area in March 1881 and commented on both drought and fires. He mentions the pronounced drought of 1877; a year that is now known to have exhibited a strong El Niño Southern Oscillation (Trenberth and Hoar, 1997; Brookfield *et al.* 1995; Harger, 1995a; 1995b). In 1877, the lakes were almost completely dry with only small trickles of water in the channels, and one could walk for miles on the dry lake bed (Gerlach, 1881). As to the cause of the fires, Gerlach blamed the Dayaks for setting fire to the forests during the dry season for sheer enjoyment. Further visits by Bock (1882), Molengraaff (1900), Enthoven (1903) provide interesting, albeit somewhat anecdotal descriptions of fires in Danau Sentarum around the turn of the 19th century, suggesting that the use of fire was common, although the underlying reasons for burning remained unclear. Helbig (1937) who described much burned land in the northern hills of the Danau Sentarum area confirmed this picture.

Some visitors to the lakes did not encounter evidence of fires. Polak (1949) did not report any traces of burnt forests, even though she looked for them. Vaas (1952) who accompanied Polak suggested that the lack of fires was due to the absence of fishing activities during the Second World War.

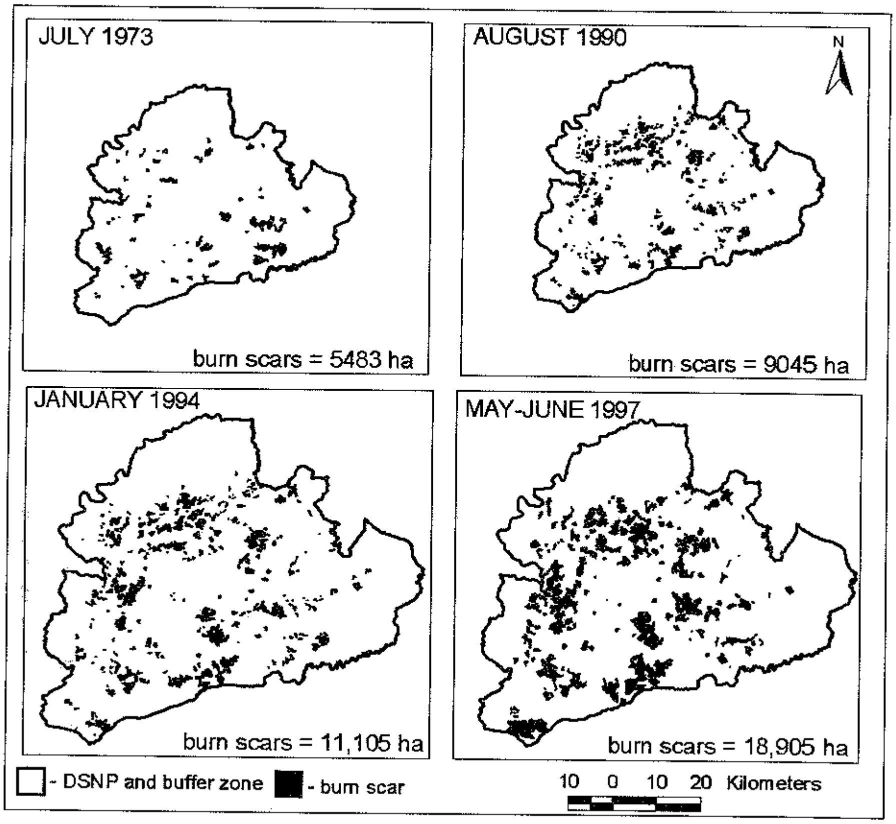

Figure 2. Distribution of burn scars (1973-1990-1994-1997).

Much of the more recent analysis of fires in Danau Sentarum was carried out during the DFID-funded Conservation Project (1992-1997) (also see Wadley *et al.*, 2000). During his initial study of Danau Sentarum in 1986, Giesen described extensive tracts of burnt swamp forest in the north, along the Sumpa River, and also an active fire near the village of Nanga Leboyan (Giesen, 1987). He found that fires were fairly common in the dwarf and stunted swamp forest types where high litter amount and open canopy increase fire risk during dry conditions (Giesen, 1996). Giesen (1987) postulated that an increase in commercial logging and the activities of fishermen were the main underlying causes of fires at Danau Sentarum. It was found in some areas that fishermen clear swamp forest with fire to increase the area of open water for placing fixed gill-nets (Giesen, 1987).

Giesen also hypothesised that much of the dwarf and stunted forest at Danau Sentarum is fire-induced.

In 1994, Luttrell (1994) carried out the first study specifically on fires in Danau Sentarum. The outcome of this research was that the underlying causes of burning were complex and results of the fieldwork were inconclusive. In general, it was found that local people attributed fires to neglect (of cigarettes, campfires, and fish-drying fires) or jealousy over resources. Blaming another ethnic group (Malay or Iban) or outsiders (loggers) was also common. One new cause, not mentioned by previous observers, was that fires were ignited to facilitate the capture of the red-phase Arowana fish (*Scleropages formosus*), a valuable, and now rare, ornamental fish. Burning created shallow, open waters at the forest edge, where the Arowana could be lured at night by lamps and scooped up by nets (Luttrell, 1994).

Giesen (1996) carried out vegetation studies in 27 recently burnt areas in June 1994. These showed that the species that most often survive a fire are: *Shorea balangeran (kawi)* (in 80% of fires), *Crudia teysmannia (timba tawang)* (65%), *Mesua hexapetalum (kamsia)* (51%) and *Syzygium* sp. (*tengelam)* (51%). This does not mean that many trees survive a fire: for a given fire this may vary between 0–25 percent of all trees. On average, however, about 1–3 percent of all trees appear to survive a typical fire. Survival is important for recruitment, and relatively fire-tolerant species such as the aforementioned four are most likely to form an important element in the recovering vegetation. Of these four species, *kawi* survives in the greatest numbers. A second important element in areas recovering from fires are the pioneer species; i.e. those species that newly establish themselves from propagules (seeds, fruit). The most important pioneer species observed at burnt sites at DSNP are shrubs *Croton* cf. *ensifolius (melayak), Ixora mentanggis (mentangis), Timonius salicifolius (kerminit)*, and the herbs *Polygonum* spp. *lembung* and *kumpai* (various grasses). For more detail on the vegetation characteristics of burned areas in Danau Sentarum refer to Giesen (2000).

Since 1992, fires in the Danau Sentarum have also been studied using remote sensing and Geographic Information System (GIS) techniques. Dennis *et al.* (1998; in press) conducted a forest cover change study in three village territories for the period 1973–1990–1994. The study showed that fire had affected all three areas to varying extent with the impact being most severe in swamp forest. However, the results showed that within this small sample there was great variability in the pattern of fires. Two of the sites were fishing villages located within swamp forest with fairly similar characteristics. However, one of the areas, located in the middle of the Park had experienced little fire damage between 1973 and 1994, whereas the other had experienced a 5-fold increase in fires over the same period. Interviews in 1996 with this community about the causes of these fires focused on motivations of jealousy or revenge and on inadvertent wildfire caused by insufficiently extinguished cooking fires. Another possible source, reported to Dennis in 1997, was the burning of waterhyacinth *Eichhornia crassipes*, which cause problems for navigation by small boats. Apparently, people thought that by burning this plant in dry season they would prevent its re-growth when the area became inundated again. Overall, the researchers remained dissatisfied with these explanations, despite considerable efforts on several occasions to understand the picture more fully. What the study did show was the potential of combining remote sensing/GIS with socio-economic and ethnographic data for understanding the causes and impacts of burning.

Based on the above sources of information, two general fire regimes appear to be present in the area. One is seen in the upland areas and along the larger rivers, where fire has been used for centuries as part of the swidden agriculture system. The other is seen in the low-lying swamp forests in and around the lakes where fire has been present for centuries but not for any apparent use like cultivation. The causes and impacts of these swamp forest fires are still poorly understood and this paper describes how remote sensing and GIS techniques were used to contribute to an understanding of the trends and patterns of swamp forest fires within the Danau Sentarum National Park between 1973 and 1997.

Methods

The aim of this particular study was to quantitatively assess the changing pattern of burning between 1973 and 1997 using remote sensing and GIS techniques. Dennis and Kurniawan (2000) analyzed forest cover change using remote sensing and GIS for an area of 425,000 ha centering on the Park. This study was carried out as part of the Joint Research Centre of the European Commission's TREES Project on tropical forest cover monitoring. The change analysis was carried out for the period 1990–1997. Building on the results of the TREES Project, the Center for International Forestry Research (CIFOR) and the International Centre for Research in Agroforestry (ICRAF) included Danau Sentarum as one of its eight sites for the study of underlying causes and impacts of fires in Indonesia.

Remote sensing provides a valuable source for quantitative measurement and monitoring of burned areas (Trigg and Flasse, 2000; Antikidis *et al.*, 1999; Hoffmann *et al.*, 1999; EUFREG, 1998; Liew et al, 1998; Siegert and Hoffmann, 1998; Pereira et al, 1997). Recent burns have a high composition of charred material and a spectral reflectance that is very distinct from vegetation. Over time the spectral reflectance of the burn scar changes, as pioneer and eventually secondary vegetation grows back. Interpretation of satellite imagery, with a good knowledge of field conditions, allows burn scar maps to be created. Unless collateral information on the exact date of burning is known it is not possible to date burn scars precisely from satellite imagery alone.

For this study, the term burn scar does not exclusively refer to fresh burns. It includes areas that were recently burnt (within a few months of the image date), areas of charred woody-vegetation with some young, vigorous growth of pioneer species, such as grasses, and areas that may have patches of scrub, grass and burnt woody vegetation (see Figure 3). The important factor is that all the areas identified as burn scars still had the characteristics of having burned at some time in the recent past, it should also be added that most areas were checked on the ground. These areas had not regenerated to the extent that they would be classified as swamp scrub or forest. Using time series of remote sensing data also enabled backwards and forwards checking of burn scars and facilitated the creation of a fire history. In addition to information on the location and size of burn scars, information on the land cover types that are being affected by fire can also be obtained.

This particular study is confined to the Danau Sentarum National Park including the buffer zone (see Figure 1). The area comprises open lakes, seasonally flooded peat and freshwater swamp forest, and lowland hills. In this study satellite imagery or aerial photography for 1973, 1990, 1994 and 1997 was used to gain an insight into the size of the area affected by fire, and trends in land cover change associated with fire. Table 1 provides details of the data used.

Type	Date	Source
Landsat MSS	14 July 1973	DFID Conservation Project
Landsat TM	28 August 1990	DFID Conservation Project
B/W air photo	2 January 1994	DFID Conservation Project
SPOT XS	31 May, 11 June, 12 July	TREES/CIFOR Project

Table 1. Remotely sensed data used for the study.

Ideally, change detection procedures should involve data acquired by the same (or similar) sensor and be recorded using the same spatial resolution, viewing geometry, spectral bands, time of day and period/season of acquisition (Richards, 1986). During the period in which we intended to assess change, 1973 to 1997, the choice of sensors for the early period (1970s) was limited to Landsat MSS. By the 1990s, a wider choice of sensors was theoretically available. However, we were ultimately limited by the availability of cloud-free imagery and photography. In this case, we were forced to compare Landsat MSS with a spatial resolution of 80m x 80m, with Landsat TM with a spatial resolution of 30m x 30m, SPOT with a spatial resolution of 20m, and 1:35,000 black and white aerial photography.

In addition to the differences in sensors and spatial resolution, the seasonal variability within the dataset added to the difficulties of maintaining a consistent level of interpretation. Danau Sentarum is a seasonally flooded forest area with a complex and fluctuating hydrological cycle (Klepper, 1994; Giesen, 1996). From week to week, the water levels fluctuate, submerging or exposing vegetation in the process. The Landsat MSS imagery is dated July 1973 and showed high flood levels, thus much of the dwarf swamp forest and burnt swamp areas were submerged. This contrasted sharply with the Landsat TM imagery dated August 1990, which was at the height of the dry season, clearly showing areas of dwarf swamp forest and recent (within a few months) and older swamp forest burning. On the Landsat MSS imagery, burn scars were not easily identified because the area was flooded. Areas that showed a sparse covering of shrub vegetation or appeared to shows remnants of woody vegetation were considered burn scars. Experience of comparing recent imagery with field observations supports this assumption. The aerial photography, dated January 1994, represents a typical picture of medium-to-high water levels. On the air photos charred trees and the lack of woody vegetation easily identify this burn scar class. In flooded areas, burnt areas are identified by areas of water dotted with patchy vegetation and single standing trees, as distinct from clear open water.

The SPOT imagery covers 3 dates (May, June and July) in 1997 just as water levels are beginning to fall. The SPOT imagery pre-dates the extremely dry conditions of the 1997 El Niño. On the TM and SPOT there is quite a broad range of spectral values for this class, ranging from highly reflective (no woody vegetation) to less reflective with a mixture of burnt/woody and non-woody vegetation. Information from field checks improved interpretation of this class.

All image processing was carried out using the PC ERDAS software (ERDAS, 1991) and PC ER Mapper. Classifications and subsequent spatial analyses were achieved with PC ArcView. Ensuring that the four different data sets overlay exactly (co-register) is critical for valid change analysis. Without this, spurious results will occur. The Landsat TM was geometrically corrected using ground control points obtained from 1:50,000 scale topographic base maps and GPS surveys. The Landsat MSS and the SPOT images were then co-registered to the Landsat TM image. The registration between images was then checked visually. The correspondence was deemed sufficient for the change analysis. On-screen digitizing, using the digitizing methodology developed by TREES (Dennis and Kurniawan, 2000; Feldkoetter, 1999), was chosen as the method of forest cover classification for the Landsat MSS, Landsat TM, and SPOT.

Figure 3. Burn scar area at Danau Seriang, 1997 (this area burned in 1990-91, and again in 1997).

Despite the great amount of user interaction in the classification process problems were still encountered. The Landsat MSS image is one of the early products of the Landsat mission and the quality of the image, even after image restoration, was not good. This plus the limited number of spectral bands (four: green, red and two near infrared) meant that the results of the classification were variable. The inclusion of a mid-infrared band is generally favored for discrimination of natural vegetation types. Inaccurate classification was particularly apparent in areas of heterogeneous vegetation and areas of steep topography. By comparison the classification of the Landsat TM and SPOT were easier because of the excellent quality of the image and higher spatial and spectral resolution of the image than the MSS.

Finally, conventional accuracy assessment of the classification was not carried out. However, the interpreter of the imagery already had 8-years field experience of the site and with a wealth of material such as GPS located site photos it was felt that the accuracy was very high. Also, the results of the change analysis did not detect any spurious changes, such as burn scars becoming dense swamp forest on the subsequent date. Further research will involve quantitative accuracy assessment.

Results

Cumulative change in burn scars

The results of the burn scar analysis show that there was a significant increase in the area of burnt swamp forest in Danau Sentarum between 1973 and 1997 (see Figure 2). Within the 197,000 ha study area, the area classified from satellite imagery as burn scars in swamp areas increased from 5,483 ha in 1973 to 18,905 ha by mid-1997, this equates to a 245% increase (see Table 2).

	July 1973	**Aug. 1990**	**Burnt area increase 1973-1990**	**Jan. 1994**	**Burnt area increase 1990-1994**	**May-July 1997**	**Burnt area increase 1994-1997**
Burn scars in swamp forest (ha)	5,483	9,045	+ 3,562 (+ 64.9%)	11,105	+2,060 (+22.7%)	18,905	+7,800 (+ 70.2%)
Burn scars as % of total land area	3.3	5.6	-	6.8	-	11.7	-
Area of swidden agriculture (ha)	5,910	7,751	-	5,890	-	7,658	-

Table 2. Burn scar area 1973–1997 (size of study area: 197,000 ha; size of total land area: 162,000 ha).

The area classified by field work as swidden agriculture, a system which uses fires, did not change greatly over the period 1973–1997 with an increase of only 1,748 hectares or about 30% (see Table 2). The following results only deal with burnt swamp areas not associated with swidden agriculture.

The increase in burning can be analyzed for 3 time periods 1973–1990, 1990–1993, and 1993-1997. Between 1973 and 1990, the area of burn scars increased by 3,562 hectares (+64.9%) from 5,483 hectares to 9,045 hectares, see Table 2. An annual increase was not calculated because burning did not occur every year. During this 17-year period there were three El Niño events (Trenberth and Hoar, 1997; Brookfield *et al.* 1995)—1976/77, 1982/3, and 1987—one every 5.6 years, which produced prolonged dry periods. In addition there were approximately 5 dry years—1975, 1976, 1979, 1986, and 1989—in which fires could also occur. Assuming there were only 8 years in which the swamps were dry enough for fires to take place, the annual increase in burnt area, allowing a correction for years in which no burning occurred, was 8.1%.

Between 1990 and early 1994, the area of burning increased by 2,060 hectares or 22.7%. During this three-year period there was one El Niño event in 1991 (Trenberth and Hoar, 1997; Brookfield *et al.*, 1995), and two dry years (1990 and 1992). Based on this data the annual corrected increase in burning is 7.5%, which is just lower than during the 1973-1990 study period.

The final period in the study is mid-1994 until mid-1997. During this period the burnt area increases from 11, 105 ha to 18, 905 ha, equating to an increase of 70.2%. One El Niño (in 1994) and no other dry years were observed during this period, the 1997 El Niño occurred after the 1997 image date and was not included in this analysis. Therefore, assuming one fire year the annual corrected increase in burnt area is 70.2%.

Forest change and burn scars

Using the GIS, it was possible to look at the forest types being burned. Giesen (1996, 2000) devised the forest classification scheme used here. Between 1973 and 1990, stunted swamp forest and dwarf swamp forest are affected most, with respectively 2,240 ha and 3,075 ha being completely destroyed by fire (see Table 3). It is also important to note that 27.5% of the burn scars remained unchanged or burned again during the 17-year period. Regenerating dwarf swamp forest was also badly burned, accounting for 11.9% of the pre-fire composition.

	Composition of 1990 burn scars in 1973 (ha)	Composition of 1997 burn scars in 1990 (ha)
Burn Scar	2,489	6,389
Dwarf swamp forest	3,075	2,206
Dwarf swamp forest (regeneration)	1,082	2,005
Tall (peat) swamp forest	139	1,332
Riparian forest	20	74
Stunted swamp forest	2,240	6,761
Cultivation	-	138
Total	**9,045**	**18,905**

Table 3. Burn scar forest cover composition pre-fire.

Between 1990 and 1997, the areas most affected by fires were again swamp forest, dwarf swamp forest, and regenerating dwarf swamp forest, but there was also an increase in the area of tall (peat) stunted swamp forest burned. In this period the area of swamp forest burned was 6,761 ha or 37% of the total area burned. 7% of the burn scars was previously tall (peat) swamp forest, which is a significant increase over the earlier period. 32% of burn scars remained unchanged in their appearance or burned again between 1990 and 1997. The amount of dwarf swamp forest as a percentage of the total burn scar area dropped from 46% in the earlier period to 22% in the second period.

Burn scar dimensions

Analysis of the size of burn scars between 1973 and 1997 shows an interesting pattern. In 1973, only 60 distinct burn scars were identified in the study area, the mean size of the burn scars was 91 ha, with the largest being 581 ha and the smallest being < 1 ha. By 1990, the number of burn scars had increased to 248 with the mean size dropping to 36 ha, however the range in size was much greater with the largest burn scar being 453 ha and the smallest being 1 ha. The burn scar statistics for 1994 did not differ much from 1990, but 1997 saw a large change. Although the number of burn scars did not change greatly, 174 compared to 248 in 1990, the mean size of burn scars increased from 36 ha to 108 ha and the maximum size increased dramatically from 453 ha to 1,339 ha.

Discussion

The results of the analysis show a clear increasing trend in the total area and size of burn scars between 1973 and 1997. There is a substantial increase in the total burnt area from 5,483 ha in 1973 to 18,905 ha in 1997, with a steady increase in the intervening years. In parallel with a total increase in burnt area is an increase in the overall size of individual burnt areas. Delving deeper into these changes shows that the impact of fires is worsening in recent years. Analysis of pre-fire composition of the burn scars gives an insight into the changing impact of fires on the swamp forests. In the first time period studied, 1973-1990 (see Table 3), the main types of vegetation affected are dwarf swamp forest and stunted swamp forest. This finding conforms well with Giesen's observation that dwarf and stunted swamp forest at Danau Sentarum are particularly vulnerable to fires (Giesen, 1996). There is also a strong likelihood that much of the dwarf swamp forest in the area has previously burned. This is evidenced by the fact that areas that at one point in the analysis were regenerating swamp forest became dwarf swamp forest in the next time period and then in the subsequent period burned again, repeating the cycle. Further analysis of the time series would be valuable in testing Giesen's hypothesis that much of the dwarf and stunted forest at Danau Sentarum is fire-induced (Giesen 1996). Giesen (pers. comm.) remarks that species composition of dwarf swamp forest, which is dominated by *kerminit*, *melayak* and *mentangis*, also supports this hypothesis: A few fires would lead to dominance by fire tolerant species such as *kawi*, while repeated fires would lead to a dominance of pioneer species, such as *mentangis*, *melayak* and *kerminit*. In the second time period, 1990-1997 (see Table 3), there is a shift away from dwarf swamp forest being the main victim of fire to stunted swamp forest, and more worryingly, tall peat swamp forest. This indicates that new types of forest are being burned in addition to areas that have historically burned such as the fire-prone scrub-like dwarf swamp forest. In addition to forest areas burning, on average, 30% of the burn scars in 1973-1990 and 1990-1997 period remain unchanged or are burned again. This is an important finding because it indicates the vulnerability of these areas to repeat burning.

The results of the burn scar analysis show a shift in recent years to an increase in the size of burnt area. For example, the largest single burn scar in 1990 was 435 ha but by 1997 the largest single burn was 1,339 ha. Analysis of some of the large burn scars shows that in previous years the area was composed of smaller unlinked burns but over time these burns have merged. The reason for this could be that areas that have previously burned are more prone to burning in future years. Each time an area burns the likelihood that it burns beyond the boundaries of the earlier burn is high, especially as most of these fires are uncontrolled.

Having analyzed the trends and processes of fire in Danau Sentarum, some insight can be gained in the possible underlying causes. However, as the research is still ongoing it is yet impossible to find a clear explanation of these causes. Evidence from interviews and field observation show that fires in the swamps of Danau Sentarum can be either deliberate or accidental and during El Niño years the number of fires increases considerably due to prolonged dry conditions. Identifying the underlying causes has proved difficult as evidenced by the earlier work of Giesen (1996) and Luttrell (1994). Their hypotheses on the main causes of fire, i.e. forest resource exploitation and fishing, however, still apply today. This doesn't, however, answer why there is an increasing trend in fires. Here we speculate on some of the more detailed underlying processes, which are currently being researched by the authors as part of the USFS-funded fire research by CIFOR and ICRAF. Field analysis, including detailed interviews in five villages, show that for each village area there is a specific set of reasons why certain areas were burned.

In broad terms, the results of the village interviews showed that there are three main reasons for fires: resource extraction; increased population and greater access; and climatic conditions conducive to fire. Firstly, fires connected with resource extraction from both forest and water areas have been cited as a cause since the first reports of fires in the 1800s. Many interviewees did not admit to deliberately using fire as a tool in improving fishing areas as cited by both Giesen (1996) and Luttrell (1994). However, interviewees would blame others for such practices which leads one to believe that there is some truth in this cause. Carelessness with cooking fires in the swamps during the dry season was also often cited. Direct observations by the authors in 1994, 1997 and 1999, proved that fires can start from cooking fires which have not been properly extinguished. Over time, certain resources have played a more important role than others. One interesting example was the valuable *Arowana* fish, which was extensively sought during the 1980s, actually until it almost disappeared. As described by Luttrell (1994) fire was used in the search for the fish, many of the fires in the 1980s may have been due to a demand for *Arowana*. People also remember times when fire was used to encourage a flush of grass that would lure deer (*rusa*) out of the surrounding forests. However, deer are now very rare in the forests surrounding the lakes and hunting of the deer in this way is no longer practiced. It has further been reported that Iban use fire when hunting for soft-shelled turtles during the dry season, while honey collecting is also a possible cause of fires: harvesting involves smoking the bees out of a hive with smoldering torches, and under dry circumstances fires could easily spread.

Secondly, there is an increasing population and increasing accessibility in the Danau Sentarum area, both because of improved transportation and increased resource extraction. This is linked to a populations increase. Jeanes (1997) reports that the human population in the Danau Sentarum area has been on the increase, and in 1997, the total population of the Park had reached 8,480 permanent residents, with an additional 2,400 that migrate to the area during the dry season for seasonal fishing (Erman, 1998). A positive correlation between human population and burning is expected.

Thirdly, there may be natural reasons for an increase in burning. There is a possible trend of an increased frequency of the El Niño phenomenon, which is generally accompanied by very dry conditions in the Danau Sentarum area. Local people noticed a big increase in fires from 1991 onwards, especially in 1991, 1994, and 1997, all of which are known El Niño years. Furthermore, the ongoing deforestation in the upper Kapuas area is possibly leading to greater fluctuations in river level. In 1986, floods were already more pronounced than in the decades before, and this trend will continue if changes in land cover continue (W. Giesen, pers. comm; pers. obs.). Whether this increased flooding frequency is counter-balanced by more frequent drying out of the lakes' area is yet unknown, but as the lakes area connected with the river, such trends are possible. A final natural reason for increased fires may be the increasing amount of combustible material that is left behind after logging and also the increased fire proneness of areas that were already burned.

These three main factors interact in ways that we do not yet understand, also because they may be very site-specific. For instance, two villages may have conflicting ideas about ownership or use rights of a certain resource use area (see e.g. Dennis *et al.*, 1998). Increasing resource extraction by, for instance, improved market access, may go hand in hand with increased conflict risks, because of higher population pressure, which, in very dry times, may lead to many fires. However, on the other hand, the potential threat of a conflict may be counteracted by an agreement between villages and the expected fires might not occur.

An assessment of the impact of the devastating fires of the 1997/98 El Niño is still on going for DSNP. Anecdotal evidence from the area suggests that 1997 fires and smoke was the worst in living memory, although the smoke may not all have emanated from the proximate area. Post-1997 imagery has not yet been analyzed, but Erman (1998) identified 46 fires from 1997 ground surveys in the area. The chances are high that the burnt area has increased, and that due to the prolonged drought associated with the 1997/98 El Niño that many areas of swamp forest burned.

Before it will be possible to really understand the underlying processes in more detail, village-level fieldwork is needed. We believe that within this research the past can be a key to understanding the present and future. Suggested research therefore includes further analysis of vegetation change patterns in relation to climatological data, and village interviews investigating the underlying causes of why a certain area burned. The ultimate goal would be to gain a level of understanding that would allow one to address the true underlying causes of the fire, something that is badly needed for proper management of the fire problem.

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