Vegetation and environmental change in the early – Middle holocene at a tropical peat swamp forest, Central Kalimantan, Indonesia

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ABSTRACT A pollen and charcoal record from a 153 cm peat swamp forest core in Central Kalimantan provides a picture of environmental change and fire history from 8440 yr BP to 6540 yr BP. The existence of charcoal in all sample layers indicates that fire occurred in the tropical peat swamp forest throughout the period. In the earliest period, from ca. 8440 to 8000 yr BP, there was a Camnosperma comp.-Cratoxylum forest. Palaquium comp. and Sandoricum comp. were also important constituents in this forest. Subsequently, dry climatic conditions prevailed between 7240–8000 yr BP. These climatic conditions increased the fire frequency and intensity causing vegetation change, i.e. the encroachment of Palaquium comp. and the replacement of the Camnosperma comp.-Cratoxylum forest with a Palaquium comp.-Cratoxylum forest. A Camnosperma comp.-Cratoxylum forest with more prominent representation of Elaeocarpus, Ilex, Randia, Rubiaceae and Sterculiaceae returned to the site when wet climatic conditions prevailed again at ca. 7240–6540 yrs BP. Returning wet climatic conditions reduced fire frequency, prevented intensive fires and allowed for more extensive growth of Camnosperma comp., Elaeocarpus and Ilex, but limited the growth of Palaquium comp. and Sandoricum comp.

Keywords: fire, Holocene, pollen, vegetation change

INTRODUCTION

Fires have greatly changed the vegetation of the peat swamp forests of Central Kalimantan in the last decade (Page et al., 2002). An ecological study has provided evidence that fast growing species with a high tolerance to open and dry peat soil conditions, such as Mangifera, Cratoxylum arborecens, and Combretocarpus rotundatus, dominate areas burnt by the huge 1997 forest and peat fire (Saito et al., 2003). This study indicates a particular pattern of vegetation succession following fire events. However, ecological studies are only suitable for studying short-term post-fire vegetation changes. Direct observation of the full range of post-fire vegetation changes is hardly possible (Finegan, 1984), because fire affects species composition at scales of years to centuries (Sugita et al., 1997). Palaeoecological tools, such as high-resolution pollen and charcoal analysis, can overcome this difficulty, thereby providing important clues about the long-term effects of fire on ecosystems (Birks, 1997; Bradshaw et al., 1997).

Yulianto et al. (2004) reported that fire frequently occurred in tropical peatlands of Central Kalimantan, Indonesia, during their formation. The results of an organic geochemistry analysis of one peat core from Kalampangan site indicate that fire may have resulted in significant changes, including nitrogen loss from the ecosystem and replacement of plant communities. This study aims to examine the relationship between fire and vegetation change with the pollen and charcoal record found in a peat core.

STUDY SITE

Peatland of Central Kalimantan is distributed in the lowland area, about 5–35 m above sea level, and stretches approximately 200 km inland (Fig. 1). It holds nearly 27% of the total peatland on Kalimantan Island (Shimada, 2001). Some large rivers, such as the Kapuas, Barito, and Katingan, flow from the mountains north of the peatlands through the peatlands to the Java Sea. Peat thickness varies among peatland types, from approximately 0.5 to 9.7 m (Shepherd et al., 1997; Shimada et al., 2001).

Central Kalimantan has a wet tropical climate with a mean annual precipitation between 2300–3000 mm and a mean annual temperature between 25–27 °C (Boerema, 1931; Asdak, 1995; Takahashi & Yonetani, 1997). During
the 5–6 month wet season the monthly precipitation exceeds 200 millimeters. In the short dry season (2–3 months) the monthly precipitation is less than 100 mm (MacKinnon et al., 1996). The water table remains high throughout the wet season (about 10–20 cm above the ground surface) and is lower in the dry season (about 10–40 cm below the ground surface) (Takahashi et al., 2000; Takahashi et al., 2003). Occasionally, there is a long dry season, which may be related to El-Ninó Southern Oscillation (MacKinnon et al., 1996). During one El-Ninó year the dry season was longer, precipitation much lower, and the water table dropped to more than 80 cm below the ground surface (Takahashi et al., 2000).

Tropical peat swamp forest occupies most of the Central Kalimantan area. Part of the forest has been either cleared for cultivation and logging or destroyed by peatland fires. Combretocarpus rotundatus was the dominant species in a Kalampangan forest after the devastating fires in 1997 (Tuah et al., 2003). In a pristine forest of the Sebangau River area, Palaquium comp., Syzygium densinervium, Xanthophyllum palembanicum, Hydnocarpus and Shorea guiso dominate the forest (Simbolon and Mirmanto, 2000).

The study site is located in the Kalampangan forest. A large part of this forest has been degraded both by cultivation and human settlement and by the enormous forest and peat fires of 1997. The core site is in an irrigation channel that connects the Kahayan and Sebangau Rivers (Fig. 1). The core site is approximately 4 km from the Kahayan River and 14 km from the Sebangau River. The core was taken in March 2002. The initial stage of vegetative growth after the fire event was observed: ferns extensively covered the ground surface, whereas the forest stand was dominated by the sprouting species, Combretocarpus rotundatus.

**MATERIALS AND METHODS**

The field study is at a channel connecting the Sebangau and Kahayan Rivers (Fig. 1). Outcrop observation was done to identify visible charcoal layers (macro-charcoal) prior to coring. A 153 cm core was taken from a site close to the edge of the channel using a half cylinder type, Eijkelkamp peat core sampler (cf. Neuzil, 1997). Charcoal samples were taken from 12 charcoal layers in the outcrop for radiocarbon dating. Samples for micro-charcoal and pollen analyses were taken from the core at 2 cm intervals. There were no samples available from 27

![Fig. 1. Map of the study site (after Yulianto et al., 2004).](image-url)
Fruit and frugivore assemblages in Thailand

to 41 cm, because of the presence of wood.

Samples for pollen and charcoal analyses were treated with 10% KOH before a mixed-acid treatment (HCl:HNO₃ 1:1). The residue was then treated with heated 10% KOH before sieving to remove larger fragments. The remaining organics were then separated from mineral matter using the heavy liquid, ZnCl₂. HF (40%) treatment was done to remove silica. Dissolution of cellulose substances was accomplished with 1-minute acetolysis. The remaining organic matter was then washed with distilled water and 15 μl of residue was mounted on microscope slides.

Pollen counts were done using a LOMO Microscope at X 400 magnification. Initial identifications were verified using the 100X oil immersion objective, giving a magnification of 1000X. Pollen was examined to determine the genera and, when possible, the species. Several pollen types may have been derived from more than one taxon. The suffix "comp." is added to these. All pollen grains observed on the slide of each sample were counted. Pollen and spore frequencies were calculated as a sum of the total pollen and presented in a pollen diagram. The diagrams include the frequencies for all taxa.

Radiocarbon dates were obtained using the ¹³C AMS method. Dates were calibrated to calendar years using the program CALIB ver.4.3 (Stuiver & Reimer, 2000). For the samples between the dated points, ages were estimated by linear interpolation.

Micro-charcoal analysis was conducted using the pollen-slide method. In this method, charcoal particles are counted on slides prepared for pollen analysis. All particles that were black, opaque, angular and >10 μm in size were counted as charcoal. The results of this micro-charcoal analysis were presented as a charcoal/pollen (C/P) ratio. The C/P ratio is defined as the percentage of charcoal particles to pollen grains. Fluctuations in the C/P ratio reflect relative fire intensity (the amount of fuel consumed) and severity (temperature).

RESULTS & DISCUSSION

Stratigraphy and chronology

Fifteen charcoal layers, ranging from 1 to 5 cm, could be identified in the outcrop. Macro-charcoals were found in every layer. Radiocarbon dates of these charcoal layers have been reported and interpreted elsewhere (Yulianto et al., 2004). Briefly, radiocarbon dates show that the core encompasses a period from ca. 8440 yr BP to ca. 7624–6540 yr BP (extrapolated age). The age/depth relationship of those charcoal layers indicates a coherent sequence of increasing age with depth and relatively constant accumulation rates of ca. 0.08 cm/yr throughout the sequence (Fig. 2). The sampling interval of 2 cm results in a temporal resolution of about 25 yrs.

![Age/depth relationship of macro charcoal layers. The straight lines are the regression linears (after Yulianto et al., 2004).](image)
Fig. 3. Results of palynological analysis of Kalampangan core, presented with C/P diagram and radiocarbon age. All taxa are shown as percentages of the total pollen sum.

Fig. 3. Continued
The pollen diagram

The KA 2 pollen diagram (Fig. 3) is characterized by the prominence of *Camnosperma* comp., *Cratoxylum*, *Elaeocarpus*, *Sandoricum* comp., *Palaquium* comp., and *Saxifragaceae*. Among the ferns, *Asplenium* is well represented. *Neoscortechinia, Eugenia, Ilex, Randia, Stemonurus, Sterculiaceae* and *Euphorbiaceae* have conspicuously high and irregular representation. The diagrams were zoned with aid of a stratigraphically constrained classification cluster analysis (ConsLink) contained within the POLPAL program. Three pollen zones were recognized in the pollen record: Zone KA 2-1, Zone KA 2-2 and Zone KA 2-3.

**Zone KA 2–1 (114–165 cm; ca. 8000–8440 yr BP)**

Zone KA 2–1 is characterized by the prominence of *Camnosperma* comp., *Cratoxylum* with *Palaquium* comp. and *Sandoricum* comp. *Aglaias, Neoscortechinia, Calophyllum, Lithocarpus, Combretocarpus rotundatus, Elaeocarpus, Engelhardia, Eugenia, Saxifragaceae, Macaranga/Mallotus, Randia, Rhizophora comp.*, *Saxifragaceae* and *Trema* values are low, mostly below 5%. Non arboreal pollen types are ubiquitous and represented by *Ardisia*, *Compositae* and *Sandoricum* comp. The only Mangrove component is the pollen of *Rhizophora* comp. which is present irregularly in low abundance. Montane pollen types, such as *Podocarpus, Phyllocladus* and *Quercus*, are present in very low abundance. Of the herbs, *Compositae* is consistently present in low values. Pteridophytes are present in low values, represented mainly by *Asplenium*. *Asplenium* is particularly uncommon in the upper levels. Charcoal layers were found at 116, 121, 131 and 150 cm depths. Overall, micro-charcoal counts are low with peaks at depths of 137, 150 and 155 cm.

**Zone KA 2–2 (54–114 cm; ca. 7240–8000 yr BP)**

This zone is characterized by the prominence of *Cratoxylum* and *Palaquium* comp., and substantial representation of *Camnosperma* comp., *Elaeocarpus* and *Sandoricum* comp. In this zone other pollen and spores are present in low abundance, mostly below 5%. Montane pollen types, *Podocarpus, Phyllocladus, Quercus*, and the mangrove pollen type, *Rhizophora* comp., are present in low abundance. *Asplenium* is less abundant in this zone than in those zones below and above it. Charcoal layers were found at 67, 85, 94, 101, 116 and 121 cm depths.

A peculiar phenomenon occurs at 101 cm depth (ca. 7600 yr BP). At this depth, *Palaquium* comp. and
Sandraicum comp. values peak and reach about 70% and 20% of the pollen assemblage, respectively. Camnosperma comp. and Cratoxylum are least abundant at this level. Most taxa are absent at this level. Asplenium, which suddenly increases below this level, is absent. It is less abundant from above this level toward the top than those of Zone KA 2-1 and Zone KA 2-2. Cratoxylum abundance increases above this level and Camnosperma comp. abundance is low. A relatively thick charcoal layer was observed at this level. The micro-charcoal count also peaks at this level. Micro-charcoal peaks also appear at 91, 95 and 101 cm depths.

Zone KA 2-3 (12–54 cm; ca. 6540–7240 yr BP)
This zone includes peat from 26 to 42 cm in depth. Camnosperma comp., Cratoxylum, Elaeocarpus, Neoscorthechinia and Palaquium comp. are important taxa and they show equal abundance at the base of this zone. Camnosperma comp., Cratoxylum, Ilex and Asplenium values increase and appear to be more abundant at the middle and upper levels of the zone, while Palaquium comp.'s value decreases significantly toward the top of the zone. Sterculiaceae values significantly increase at the middle level of the zone and decrease toward the top. Neoscorthechinia has increased abundance at the base (56–62 cm depth) of the zone. Other pollen types are present in low abundance. Montane pollen types, Podocarpus and Quercus, are present in low abundance.

In general, Rhizophora comp. is present in low abundance and slightly increases at the upper levels. Charcoal layers were found at 12, 19, 26, 29, 56 cm depths, and micro-charcoal counts are, overall, low with peaks at 12, 19 and 26 cm depths.

Vegetation and environmental reconstruction
The KA core does not go through to the basement of the peat deposit. Accordingly, it does not provide a thorough record of vegetation change within the initial phase of peat swamp development. Radiocarbon dates and the pollen diagram show that the peat swamp forest developed ca. 8400-6500 yr BP, with the main components of Camnosperma comp., Cratoxylum, Palaquium comp. and Sandraicum comp. present throughout the record. Presence of these taxa indicates that the site has been a mixed peat swamp forest from the early to middle Holocene. There is only little variation in the composition of the peat swamp forest since its initial development as indicated by general uniformity of the pollen assemblage.

The earliest period, indicated by the Zone KA 2-1, covers a period from ca. 8440–6540 yr BP. A Camnosperma comp.-Cratoxylum forest developed at the site, as evidenced by the moderate pollen values of Camnosperma comp. and Cratoxylum. Palaquium comp. and Sandraicum comp. Several taxa, such as Elaeocarpus, Ilex, Lithocarpus, Combretocarpus rotundatus, were present as minor components in the forest.

The presence of montane pollen types, such Podocarpus, Phyllocladus and Quercus, and the mangrove pollen type of Rhizophora comp., indicates that the site has been a depositional environment for both local and regional pollen grains. Their presence in low abundance and irregular representation indicates that their sources were not local vegetation. They were transported long distance, likely by wind or water. Podocarpus, Phyllocladus and Quercus are not present in thepeat swamp forest of Central Kalimantan. Presently, they are confined in Kalimantan to altitudes above 1000 m (Morley, 1981). Therefore, their pollen must have been derived from mountainous areas about 300 km to the north of the study area. Likewise, much higher values of Rhizophora would be expected if they had derived from local sources. Their presence reflects the fact that the site used to be closer to the former coastline or nearest tidal channel, probably the old Kahayan River.

Significant environmental changes must have occurred at the site ca. 7240–7800 yr BP that had allowed the encroachment of Palaquium comp. and the replacement of Camnosperma comp.-Cratoxylum forest by Palaquium comp.-Cratoxylum forest. Dry climatic conditions may have prevailed at this time as indicated by the reduction of Asplenium abundance. This condition resulted in an increase in fire frequency and intensity, as indicated by the intensive charcoal layer and micro-charcoal peak. Results of a geochemical study provides evidence for an increase in fire intensity in the Zone KA 2-2 as indicated by a significant decrease in total nitrogen, together with more negative δ13N values (Yulianto et al., 2004).

The sudden increase of Asplenium, and Euphorbiaceae shortly after ca. 7760 yr BP may be related to a fire event, since it occurs simultaneously with a slightly increase in micro-charcoal counts. Pterydophytes are pioneer species in peat swamp forests of Central Kalimantan. They grow extensively on wet or waterlogged forest floors immediately after peatland fires. They cover forest floors for a couple years prior to further forest recolonization. Accordingly, reasons for the low abundance of Asplenium at layers with charcoal and micro-charcoal peaks are unclear, but they may involve fire intensity and soil wetness.
Table 1. Radiocarbon dates from Kalampangan peat core (Yulianto et al., 2004). Calibrated ages were calculated using CALIB 4.3 (Stuiver and Reimer, 2000), calibrated age in years B. P. and 2 σ range are given.

<table>
<thead>
<tr>
<th>No.</th>
<th>Laboratory</th>
<th>No. Sample</th>
<th>Depth (cm)</th>
<th>Radiocarbon age (years B. P.)</th>
<th>Calibrated age range (cal. yr B. P.)</th>
<th>δ¹³C (%)</th>
<th>Remarks</th>
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<tbody>
<tr>
<td>IN-1</td>
<td>KLB-2</td>
<td>19</td>
<td>6650 ± 81</td>
<td>7624 – 7424</td>
<td>-26.93</td>
<td>AMS date</td>
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<td>IN-2</td>
<td>KLB-3</td>
<td>26</td>
<td>6972 ± 101</td>
<td>7964 – 7654</td>
<td>-31.41</td>
<td>AMS date</td>
<td></td>
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<tr>
<td>IN-3</td>
<td>KLB-4</td>
<td>29</td>
<td>6814 ± 107</td>
<td>7844 – 7474</td>
<td>-30.99</td>
<td>AMS date</td>
<td></td>
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<tr>
<td>IN-4</td>
<td>KLB-6</td>
<td>53</td>
<td>6979 ± 103</td>
<td>7970 – 7613</td>
<td>-29.59</td>
<td>AMS date</td>
<td></td>
</tr>
<tr>
<td>IN-5</td>
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<td>61</td>
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<td>8221 – 7917</td>
<td>-30.65</td>
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<td></td>
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<tr>
<td>IN-6</td>
<td>KLB-8</td>
<td>73</td>
<td>7320 ± 104</td>
<td>8344 – 7943</td>
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<tr>
<td>IN-7</td>
<td>KLB-9</td>
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<td>7364 ± 101</td>
<td>8364 – 7998</td>
<td>-28.79</td>
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<td>IN-8</td>
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<td>7608 ± 102</td>
<td>8563 – 8274</td>
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<td>8203 ± 103</td>
<td>9472 – 8981</td>
<td>-30.68</td>
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</table>

A Camnosperma comp.-Cratoxylum forest with more prominent representation of Elaeocarpus, Ilex, Randia, Rubiaceae and Sterculiaceae returned to the site ca. 7240–6540 yrs BP. Wet climatic conditions must have prevailed at this time as indicated by the increased presence of Asplenium. The wet climatic conditions may have reduced fire frequency, prevented intensive fire and allowed for more extensive growth of Camnosperma comp., Elaeocarpus and Ilex, while reducing the growth of Palaquium comp. and Sandoricum comp. Although fires are also evident at this time, they may have been small in scale with almost no influence on vegetation community, as indicated by the absence of significant pollen assemblage changes. The consistent δ¹⁵N value in this interval, as reported by Yulianto et al. (2004), indicates minor nitrogen loss and thus provides evidence for this interpretation.

Reasons for the sudden increases of Neoscortechinia at ca. 6980 yr BP and Sterculiaceae at ca. 6800 yr BP are unclear. Their patterns of change appears to be independent from other forest elements, indicating individualistic behavior.

CONCLUSION
The presence of charcoal layers in the peat, as well as micro-charcoal particles in all samples, proves that fire has been a component of tropical peat swamp forests of Central Kalimantan in the Early-Middle Holocene. This provides evidence that even tropical peatland forests located in swampy areas are not fire-impervious. It seems that the climatic conditions did play a significant role in controlling the frequency and intensity of fire and thus influence vegetation communities. This study shows that although fire occurred frequently during the Early to Middle Holocene, only one fire event, which occurred at ca. 7600 yr BP, caused significant vegetation change. The development of wet and warm climatic conditions during the Early-Middle Holocene (Haberle et al., 2001) may have prevented destructive fires. The destructive and frequent peatland fires of Central Kalimantan from 5000 yr BP to the present may be due to the strengthening of the El-Niño Southern Oscillation (ENSO) climate phenomena from around 5000 yr BP (Haberle et al., 2001).

It is evident that Palaquium comp., Camnosperma comp. and Ilex are fire-related species. Palaquium comp. is well represented in the layers that also have a lot of charcoal and micro-charcoal, likewise it is poorly represented in secondary forests a couple of years after fire events, as reported by Saito et al. (2003). This indicates that Palaquium comp. is not a post-fire pioneer species. Twenty five years temporal resolution of sampling intervals of this study suggests that Palaquium comp. recolonization may commence within 10–20 years after a fire event. Accordingly, Palaquium comp. may be classified as a long-term opportunist. In contrast, poor representation of Camnosperma comp. and Ilex during the high frequency fire period of the Zone KA 2–2 indicate that these taxa are fire-sensitive species.
Although this study clarifies the role of fire in plant succession, it should be noted that the 2 cm sampling interval used does not provide adequate temporal resolution for the all post-fire vegetation succession in the peat swamp forests of Central Kalimantan. In addition, high fire frequency in the past may have resulted in peat loss, thereby destroying sections of records of vegetation succession. Assuming a sedimentation rate of 0.08–1 cm/yr, a 0.5 cm sampling interval of a continuous core from lake sediment is required for a thorough study of the vegetation succession.

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REFERENCES


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