Late Quaternary Vegetation and Environments in the Lake Sentarum Wildlife Reserve, West Kalimantan, Indonesia

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ABSTRACT

This thesis examines long term historical vegetation and environmental change in the humid tropical Lake Sentarum Wildlife Reserve, West Kalimantan, Indonesia, using proxy data derived from pollen and micro-charcoal analysis. The reserve embraces a large fluvio-lacustrine system dominated by a mosaic of semi-permanent lakes, peat swamp and riparian forests with some lowland rainforest. It is situated in the upper reaches of the Kapuas River, at an altitude of below 50 m ASL and straddles the equator. Four sediment cores were analysed from the southeast part of the reserve; two from the bed of Lake Pemerak that was exposed during the severe drought of 1997 and two from peat swamp forests surrounding the lake. In addition, a number of surface pollen samples were taken from described forest plots to assist in interpretation of the fossil records. A total of 23 conventional or accelerator mass spectrometry radiocarbon dates were used to provide ages for the fossil records.

Although the cores for pollen analysis were only 1.5 m or less in length, they generally covered a substantial period of time. The establishment of ages for each sequence was complicated by radiocarbon date inversions and discontinuity in sediment accumulation, while record correlation was made difficult by the distinctive nature of pollen assemblages in each of the records. However, it is considered that evidence for much of the last 40,000 years is recorded. At no site did coring reach to the base of unconsolidated sediments and it is anticipated that longer records can be retrieved with more robust sampling equipment.

In contrast to previous studies on the history of peat forests, undertaken in coastal parts of the Indonesian region where the bulk of peat accumulation has taken place in association with rising and high sea levels during the Holocene, the major phase of peat accumulation around Lake Pemerak appears to date to the last glacial period before the Last Glacial Maximum (LGM). At this time precipitation appears to have been relatively high but less variable than today while temperatures were slightly lower than those of the Holocene.

The LGM is not fully represented in sediment sequences but available evidence suggests that rainfall may have been somewhat lower than today during this period but was still sufficient to allow the maintenance of a rainforest cover. The degree of representation of predominantly montane/submontane taxa is sufficient to suggest that these made up a component of lowland vegetation during the LGM and that temperatures may have been up to 6° C lower than today. These results on the nature of LGM vegetation and climates are consistent with recent data from other humid tropical lowlands. There is no sediment dated to the very late glacial and early Holocene periods and this period may, for some unknown climatic reason, have not been conducive to the accumulation or preservation of lake or peat sediment. Climatic conditions appear to have been similar to those at present through the last 3000-4000 years.

The presence of charcoal throughout all records indicates that fire has been an environmental factor over at least the last 40,000 years. Radiocarbon dating of the archaeological site of Niah caves suggests that people have been in the interior of Borneo for this length of time and therefore could have been totally responsible for the fire signal. However, it is considered more likely that a natural low level fire regime was operational until about 30,000 years ago when there is evidence for an increase in fire activity. Burning may have further increased during the LGM with somewhat drier conditions and a slightly more open vegetation, but has been highest in the late Holocene, particularly the last 1,400 years. It is considered that these highest levels of burning activity are associated with the development of slash and burn agriculture although increased climatic variability may have been a contributing factor.

I hereby declare that this thesis contains no material which has been accepted for thee award of any other degree or diploma in any university or other institution, and that, to the best of my knowledge, this thesis contains no material previously published or written by another person, except where due reference is made in the text of the thesis

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ACKNOWLEDGMENTS

Chapter 1: Introduction

1.1. Rationale of the study

There is a rapid deforestation occurring in the tropics as a result of human influences and natural disasters. At present, anthropogenic impacts on tropical forests are very obvious on short time scales of a few calendar years. In Indonesia, the World Bank (1990) indicates that possible major agents of deforestation are smallholder agriculture, slash and burn cultivation, logging, timber plantation, estate crop and other development projects (i.e. transmigration), and anthropogenic fire. Recent deforestation is mainly related to human activities and is driven to some degree by government policies (Barber 1989; Barber *et al.* 1994; Blakie 1985; Brookfield and Blakie 1987; Chambers 1983; Colchester 1994; Peluso 1992).

Causes of deforestation in Indonesia may also be related to other driving forces, such as population pressure, indigenous culture, imbalances in international trade of timber and agricultural products, and natural forest fire. Determination of major agents and causes of deforestation in Indonesia is clearly difficult and complex (Sunderlin and Resosudarmo 1996). From the 1970s, anthropogenic activities causing deforestation have converted between about 30% and 50% of natural closed forests in Sumatra and Kalimantan into open woodlands, grasslands, and crop cultivation sites. During 1990s, the average rate of deforestation over the Indonesia region was estimated to be at least 20,000 km^2/yr (Myers 1991).

In addition, substantial natural deforestation can result from volcanic eruptions, natural fire, and other natural phenomena. In August 1883, for instance, the eruption of Krakatau with the force of more than ten thousand Hiroshima-type atom bombs cleared all forested land together with its unique flora and fauna from Krakatau island in Sunda Strait, claimed at least 36,000 lives, and destroyed about 160 human settlements. It is estimated that this eruption lowered the global air temperature by 0.5°C (Thornton 1995). In prehistoric times, natural fires have changed the landscape. According to Goldammer (1989), natural fires in East Kalimantan, Borneo, have taken place regularly over at least the last c. 17,500 years BP. Natural disasters can be devastating but it seems that tropical forests are well designed to cope with natural disturbances over long time scales in contrast to the present, where there is a very rapid loss of forested lands induced by humans in combination with natural disturbance.

The implications of deforestation are many. Since tropical forests support more than 50% of the flora and fauna species on the Earth, loss of biodiversity is a major issue of current global concern. This fear has stimulated a world-wide movement, and this issue has become important on political agenda. But, many efforts to conserve, protect and wisely manage tropical forest resources never get past the paper stage. In practice, the majority of present management practices of tropical forests are still far away from the idea of sustainable use of tropical forest resources.

Further, loss of tropical forests may also increase the amount of CO_2 released into the atmosphere. In the case of the destruction of peatland forests, methane (CH_4) is released, exacerbating greenhouse effects, and contributing to changes in global climate. Such changes would ultimately affect all living creatures on Earth, including humans. The loss of forests degrades the life support system on Earth, and according to some, may finally lead to habitat destruction and the extinction of the human species. However, others would argue that humans would be able to create tools and technology to solve this problem in the near future. The first is a fairly conservative, environmentalist's approach and the latter is a more economic rationalist approach. These two schools of thought are likely to remain in disagreement.

The governments of tropical countries tend to treat forests resources as natural commodities that can be easily converted to dollar values. Timber is commonly a major earner of foreign exchange in the tropics. This short-term economic goal creates the problem of cut and run logging schemes in major tropical forest countries. Following exploitation, many logging companies just leave the forest in its altered state in order to maximize profits, while conservation efforts are minimized. The opening of closed forest frontiers gives easy access to people to log secondary, less valuable timber, which is intentionally left by legal, timber concessionaires. This so-called illegal logging causes further damage to the forest ecosystem. It is a complex, vicious cycle, and strongly associated with inequality and poverty due to mismanagement of forest resources.

As an illustration, lowland dipterocarp forests in Indonesia have been intensively extracted to pay the costs of economic development in the era of New Order (the Suharto regime), beginning in the 1970s. Since late 1997, Indonesia has suffered from an economic crisis, which caused the fall of President Suharto from power in May 1998 and the degradation of the status of Indonesia from the developing, prospective economic tiger of south east Asia to one of the poorest countries in the world. In the last three decades, Indonesia has lost probably more than 50% of its natural, lowland dipterocarp forests, while the majority of Indonesian society remains in poverty. Mismanagement of Indonesia's forested lands does not generate social welfare for the country, but creates environmental problems in the form of poverty, loss of natural forested lands and its biodiversity, hydrological impacts, and possible global climate change. Indonesia is now under-going major reform to become a democratic state. This sudden change has brought about political and economic uncertainties. Local people have colonized national parks, clearing the forest and planting the land with agricultural crops. These people claim that the land within the national parks is their traditional property. If inequality, political instability, and poverty remain a problem, the future of Indonesia's primary forests is not promising.

The loss of tropical forests directly influences global climate by increasing carbon flux and possibly other trace gases to the atmosphere, and regional hydrology by affecting local rainfall. At present, the destruction of tropical forests is thought to be the second highest contributor to the release of

carbon, after the combustion of fossil fuel (Houghton *et al.* 1985). Carbon is liberated when the tropical forests are cleared, logged, burnt or left to decay (Brown *et al.* 1991). Values of carbon flux from the removal of forest cover are poorly understood. Based on a preliminary estimate, the mature, lowland moist tropical forests of Borneo may have biomass carbon densities of greater than 250 Mg ha^{-1}, while the biomass carbon densities of the tropical forests of India and Thailand are estimated to be less than 100 Mg ha^{-1}. Soils of lowland tropical forests of Borneo store $\leq$120 Mg ha^{-1} except the peat soils that may store up to 675 Mg ha^{-1} of carbon (Brown *et al.* 1993).

Clearly, problems resulting from deforestation are multi-faceted and difficult to solve. Further, attempts to overcome deforestation in Indonesia are impeded by limited knowledge of the parts played by ecological, economic, and social variables in this problem. In particular, our ecological knowledge on how the tropical forest ecosystem changes and responds to disturbance is still very restricted. A majority of studies on tropical forests discuss the present economic values of the resource. Many studies barely address short-term ecological values of tropical forests. Only a few studies address historical longer-term change in tropical forest vegetation.

This study is an attempt to provide ecological knowledge on the long-term dynamics of a peat swamp forest and associated systems in the Lake Pemerak area of Lake Sentarum Wildlife Reserve in West Kalimantan. This study aims to reconstruct past vegetation of the peat swamp forest in this region and provide some information on how this complex ecosystem has responded

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to natural and anthropogenic disturbances. This ecological knowledge, it is hoped, will provide base line data for the development of a conservation plan for wise use of the natural resources in the Lake Sentarum region. In a regional context, this understanding should make some contribution to the development of sustainable management schemes for other peat swamp forests in this biodiverse region.

A common approach to the study of long term, historical change in forest composition is palynology, or pollen analysis. Several such studies have been undertaken in the Indonesia region, but mainly in the highland areas. These studies have mostly retrieved late Pleistocene and Holocene records and explored the influence of temperature change on the dynamics of tropical montane forests. This project is one of the few to attempt historical analysis of vegetation change in lowland Indonesia.

The Lake Sentarum region lies between 25 and 50 m ASL (Giesen 1996) and contains seasonal lakes and extensive peat swamp forests. In contrast to lowland, dipterocarp forests, these lowland swamp forests are less disturbed and exploited. There are a few factors that restrict human impact on the peat swamp forests in the region. First, Lake Sentarum is located in the upper, inland Kapuas Basin. Consequently, it is difficult to gain access to this region. Second, commercial timbers are not as abundant as in the lowland, dipterocarp forests. A large-scale operation of forest exploitation at Lake Sentarum would be very costly. Third, Lake Sentarum is very rich in species of fish, many of which have high economic value. The total number of fish species in the Lake

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Sentarum region is estimated to be about 300 species (Giesen 1987, 1996), and approximately two thirds of freshwater fish supplies in West Kalimantan Province come from this region. This natural bounty of water resources in the Lake Sentarum region is much more attractive and intensively exploited than the resource of peat swamp forests.

The ecological integrity of the Lake Sentarum region is directly and indirectly very important not only for villagers dwelling in the lake region but also for other peoples in the Province of West Kalimantan. As a natural archive, the Lake Sentarum region stores information on the dynamics of the forested wetland in this lowland region, providing proxy data for global climate change, and impacts of past human activities on this wetland. Further, Lake Sentarum is globally acknowledged as a unique, natural wetland with an international value. In April 1994 the Lake Sentarum Wildlife Reserve became the second site in Indonesia to be under the Ramsar Convention on Wetlands (Giesen 1996).

1.2. Aims of study

The main purpose of this study is to reconstruct the history of Late Quaternary vegetation change in the Lake Sentarum Wildlife Reserve, West Kalimantan, Indonesia. Originally the intention was to focus primarily on a high resolution study of past vegetation and environments through the last few thousands years from what were hoped to be continuous sediment sequences preserved in those lakes that were historically documented to retain water through the dry season. Reconnaissance study demonstrated the feasibility of

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this aim, through sediment sampling, and ecological studies of the different vegetation types in association with collection of surface pollen samples from peatland forests were undertaken, to provide a basis for interpretation of the records.

However, the main fieldwork period coincided with the height of the major El Niño event of 1997, which restricted access to identified potential sites. As a result, research was restricted to the western margin of the lakes, where there was limited sediment accumulation in recent times. Consequently the project was refocused on longer-term environment change involving some limited landscape development as well as broader scale climate and vegetation change. This study provides a contribution to the understanding of Late Quaternary environmental and vegetation change within the Kalimantan region.

1.3. Thesis structure

This thesis contains nine chapters. This introductory chapter presents the rationale, and aims of the study and structure of the thesis. Chapter two provides a general context for this study, with a brief, general overview of the climate, general geology, tropical forests, human use of forested wetland resources, and forest fire in the Indonesian region and in Borneo particular. Chapter three then reviews existing pollen studies in Indonesia (northeastern Sumatra, central Kalimantan, and West Java), Malaysia and Singapore (Nee Soon Swamp) to provide a framework for analysis of the Lake Sentarum study. In chapter four, the study site and the region of Lake Sentarum Wildlife Reserve are described. There are specific descriptions of the geography of the

study site, the river system of the Kapuas and its connection with the group of seasonal lakes in the Lake Sentarum region, the ever wet climate of West Kalimantan, a brief discussion of the geology of the Lake Sentarum region, the peat swamp forests found in the Lake Sentarum region, and human activities in the Lake Sentarum Wildlife Reserve and its vicinity.

Chapter five discusses the variety of field, laboratory and numerical methods used in this study. In particular, data collection and analysis procedures are outlined. Finally, this chapter explores the techniques used for data presentation and numerical analyses.

Chapter six presents and discusses the relationship between present vegetation and modern pollen rain in the Lake Sentarum region. A brief overview of common habitat types in the Lake Sentarum region is explored prior to the analysis of data collected on the present vegetation and its modern pollen rain.

The next chapter presents the results and the interpretation of the analysed sediment cores. In this study four sediment cores are described and presented in the form of pollen and ordination diagrams. Results of radiocarbon dating are compiled in this chapter.

The general history of vegetation change is drawn together in chapter eight. It includes core correlation and chronology, based on Ward's classification, and a general discussion of environmental and vegetation change in the Lake Pemerak region over the last 40,000 years BP.

The last chapter presents major conclusions derived from the study, addresses the limitation of the study, and offers recommendations for future research in this complex, important and interesting region.

Chapter 2: Regional Setting

2.1. Introduction

This chapter presents relevant information on the broader region centred on the island of Borneo with specific data on the Lake Sentarum area, where appropriate. This base of knowledge is used to assist the interpretation of palynological records obtained as part of the present study and to place the results into a general, regional context. The primary focus is the present climate patterns in Kalimantan, tropical dipterocarp and peatland forests in Borneo, and forest fire.

2.2. Borneo

Borneo is located between longitudes 109°E and 119°E and between latitudes 7°N and 4°S. The island of Borneo (746,305 km^2) is the third largest island in the world after Greenland (2,175,600 km^2) and New Guinea (808,510 km^2), and is administratively divided into three countries. In the north and northeast, Sarawak and Sabah of East Malaysia and Brunei Darussalam, cover about 27% of Borneo's landmass, while Indonesia controls the other 73% (MacKinnon *et al.* 1996) under the name of Kalimantan, incorporating the provinces of West Kalimantan, Central Kalimantan, South Kalimantan, and East Kalimantan. The South China Sea has a substantial coastline along the northwest side of Borneo and separates Borneo from southern China, the Java Sea in the

south separates Borneo from Java, and in the east the Strait of Macassar separates Kalimantan from Sulawesi.

Topographically, Borneo is predominantly low lying, with beaches, large rivers, lakes, swamps and lowland forests. Most land lies below 150 m ASL, and river water can be tidal up to hundreds of kilometres inland. The highest peak is Mount Kinabalu (4,101 m) in Sabah, while other mountains such as the primary ranges of the Kapuas Hulu Mountains in the northwest, and the Schwaner Mountains and Muller Mountains in the centre rarely reach 2,500 m ASL. The Merratus Mountains in the south are a secondary range, with an average peak height of 1,000 – 1,500 m (MacKinnon *et al.* 1996). The major rivers are the Kapuas (1,143 km), which drains much of West Kalimantan, the Barito (900 km) in South Kalimantan, the Mahakam (775 km) in East Kalimantan, and the Rejang and Batang Lupar in Sarawak. Geographic location, forest cover, rivers and mountain ranges have significant impact on local rainfall patterns in Borneo.

2.3. The present climate

The present climate of Borneo is ever-wet with no clear distinction between wet and dry seasons, but the island periodically suffers from seasonal droughts, which are thought to have a strong correlation with ENSO (El Niño Southern Oscillation) events through their impact on the intensity of the southeast monsoon. The effect of the monsoons, which have a major control over the distribution of rainfall in much of the Indonesian archipelago, is less pronounced in Kalimantan than in East Java, Madura, Bali, Lombok and Nusa Tenggara.

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A major factor controlling rainfall production in Indonesia is the convection of air masses in a broad zonal trough of low pressure, known as the Intertropical Convergence Zone (ITCZ). The ITCZ forms a belt of tropical thunderstorms and affects the formation of cumulus clouds that frequently produce heavy rainfall (Jackson 1989; Verstappen 1975). The position of the ITCZ in northern hemisphere winter (January) is approximately parallel to the equator at about 10 - 12°S. The ITCZ in northern hemisphere summer (July) creates an irregular band around 23°N near the Himalayas and the Gulf of Bengal, extends up to 32°N along the south coast of Honshu, Japan, and descends to the equator near east Papua (Christopherson 1992; Sturman and Tapper 1996; Verstappen 1980). If the ITCZ in the northern winter is situated to the south of its mean position, high precipitation falls in Borneo, Sumatra, Java, Sulawesi, Nusa Tenggara, and Papua New Guinea. On the other hand, if the ITCZ in the northern summer is situated further to the north, heavy rains fall on India and South China. At this time, most parts of Indonesia experience a dry season, but moderate rains still fall on Borneo (MacKinnon *et al.* 1996).

The development of the ITCZ is affected by global mechanisms of heat transfer from the tropics to higher latitudes. This global circulation of ocean and atmosphere includes north-south heat transport, ie, the Hadley cell, and east-west heat transport, the Walker circulation (Sturman and Tapper 1996). The intensity of the Walker circulation fluctuates and varies over time. The Southern Oscillation Index (SOI), the pressure difference between Tahiti and Darwin, is used to

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measure the strength of the Walker circulation (Allan *et al.*, 1991). When the SOI is positive, the pressure is high in the southeastern Pacific, but low in Indonesia. This is also called the La Nina phase of the Southern Oscillation, resulting in strong Walker circulation, trade winds, and maximum convection of air masses that likely result in heavy rainfall over Indonesia and northern Australia but drier conditions off the coast of South America. When the SOI is negative, the Walker circulation and trade winds weaken, and the reverse effect occurs, with drought in Indonesia and northern Australia, but heavy rains in South America. This anomaly is known as El Niño, which has been associated with the occurrence of seasonal droughts in Australia, Indonesia, and Malay Peninsula (Allan *et al.* 1991; Quinn *et al.* 1978; Quinn 1992; Sturman and Tapper 1996) and forest fires in Borneo (Goldammer *et al.* 1996; Goldammer 1999; Malingreau and Zhuang 1998; Salafsky 1994). The relationship between El Niño and Indonesian droughts is particularly pronounced during the period normally associated with the southeast monsoon, from May to October (Quinn *et al.* 1978), and sometimes until November (Ropelewski and Halpert 1987). In Borneo, seasonal droughts associated with El Niño are marked by lower than average rainfall in July, August and September.

2.4. Rainfall patterns in Kalimantan

While the temperature in the lowland regions of Kalimantan is relatively constant and warm (> 20° C), the distribution of rainfall may vary, depending on geographical position, the global circulation of ocean and atmosphere, topography,

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and land cover. In general, Kalimantan receives a large amount of annual rainfall, between 2,500 and 7,000 mm (Giesen 1987; Oldeman *et al.* 1980), which is fairly evenly distributed through the year. As a consequence, the average monthly rainfall is normally very high (> 200 mm), but a few months, especially June, July, August and September, may receive less rainfall than other months. In some areas, such as Balikpapan and Tarakan, rainfall below 200 mm per month is rarely observed. Balikpapan receives higher rainfall than Samarinda, which has a coastal location, and the effect of the southeast monsoon on this region is blocked by Sulawesi. In general, the rainfall becomes more intense towards the mountains (Oldeman *et al.* 1980) such as in the upper Kapuas basin of western Kalimantan. Fluctuations in annual and monthly rainfalls of up to 60 % are regularly observed, and reduced levels of rainfall associated with El Niño may lead to regional, seasonal droughts and water shortage, even though the microclimate in closed-generalised rainfall patterns for the provinces of Kalimantan.
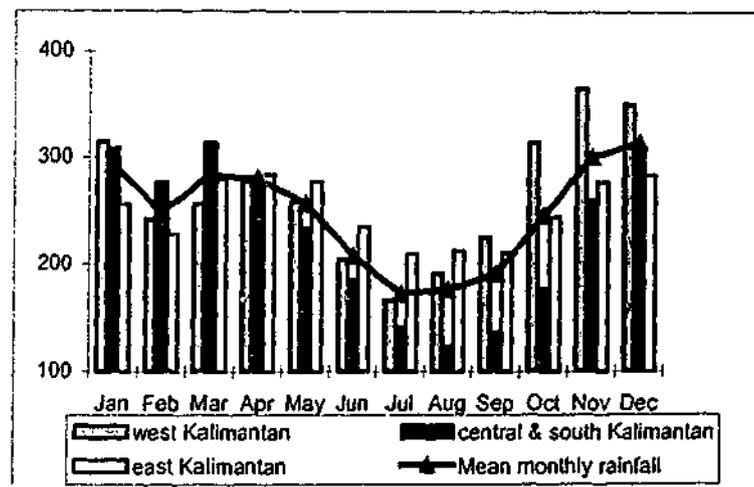
Figure 2.1. Generalised monthly rainfall patterns for Kalimantan and its individual provinces (Modified from Oldeman *et al.* 1980; Kirono *et al.* 1999a, 1999b).

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2.5. Rainfall in West Kalimantan

Since the effect of monsoons is not easily defined in West Kalimantan, geographical position appears to be a major contributing factor in the regulation of the pattern of regional rainfall in this province. West Kalimantan appears to lie within the maximum convective activity of the ITCZ both during southeast (dry)
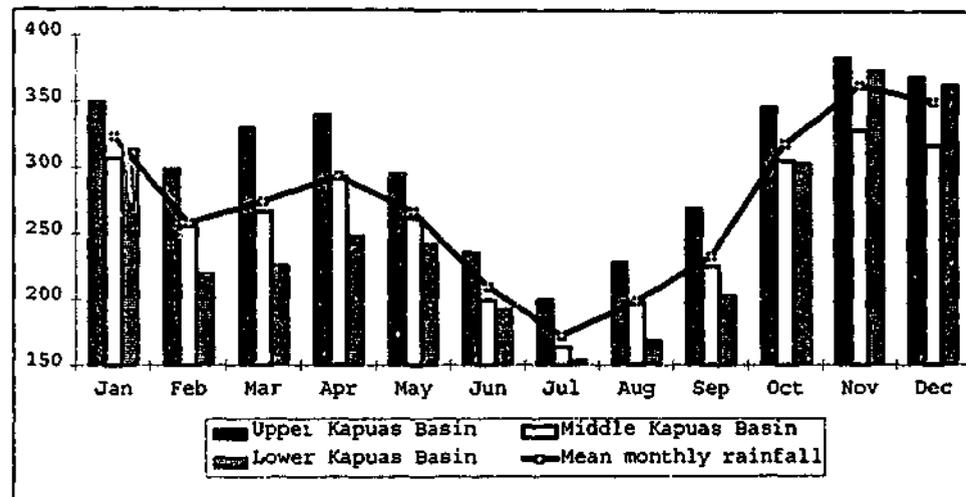
Figure 2.2. The monthly rainfall pattern in West Kalimantan (After Oldeman *et al.* 1980).

and northwest (wet) monsoons. Heavy rains fall all year. June, July, August and September may receive less rainfall than the average (Oldeman *et al.* 1980). El Niño events during these months may cause seasonal droughts, resulting in an extreme drop of water levels of the Kapuas river, the intrusion of sea water, water shortage for people and crop plants, and widespread forest fires. The average monthly rainfall pattern in West Kalimantan from 13 rainfall stations is illustrated in Figure 2.2.

In West Kalimantan, the rainfall in the upper Kapuas basin is a little higher than in the middle Kapuas basin. In Putusibau, the average annual rainfall is about

4,000 mm, while in Sanggau it is about 3,000 mm (Giesen 1987). The rainfall both in Putusibau and in Sanggau may reach 7,000 mm in some years. In the middle Kapuas basin, months possibly receiving rainfall below 200 mm are commonly June, July, and August (Oldeman *et al.* 1980), while, in the upper Kapuas basin, rainfall below 300 mm may occur in July, August and September (Giesen 1987). The rainfall pattern in West Kalimantan suggests that the monthly rainfall is evenly distributed, on average up to 350 mm, but the months of June, July, August, and September may receive a relatively small amount of rainfall, ranging from 0 mm to 100 mm. West Kalimantan is likely to suffer seasonal droughts if the El Niño phenomenon is active in the southeast monsoon (Kane 1999; Quinn *et al.* 1978) as is shown in Figure 2.3. The droughts associated with El Niño episodes in Kalimantan usually start in July and end in October. In general, El Niño does not change the rainfall pattern in West Kalimantan, but this global phenomenon may be associated with excessive rainfall decline between July and September. One year before El Niño events (Year-1), and one year after (Year+1), the amount of rainfall remains high.
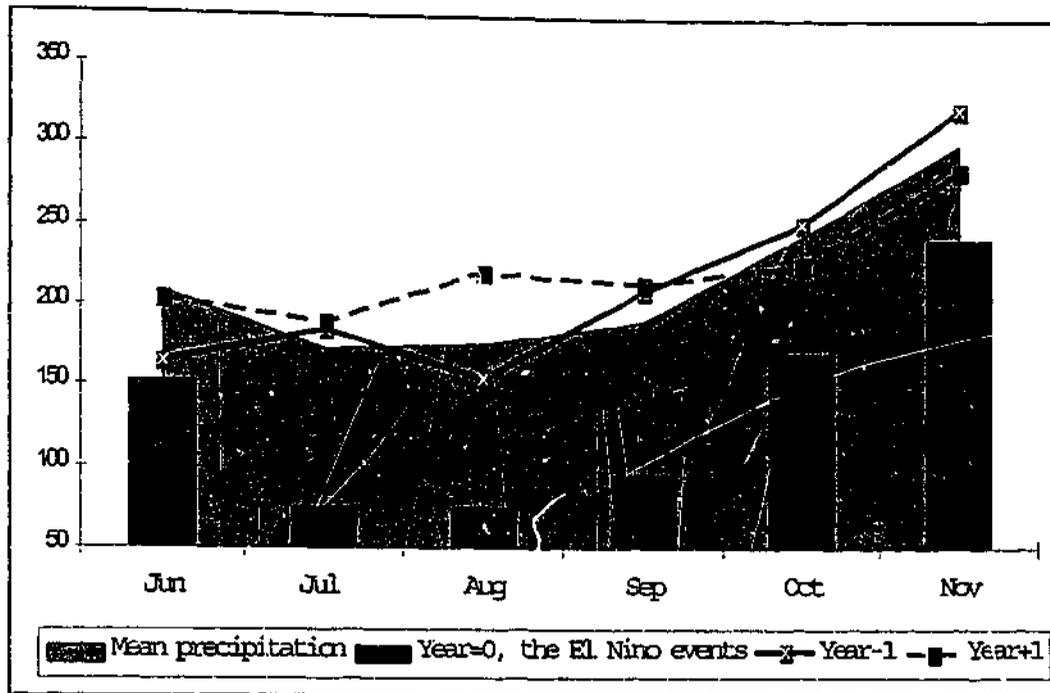
Figure 2.3. The impact of El Niño on the variability of monthly rainfall in selected months in West Kalimantan (Modified from Kirono et al. 1999a, 1999b)

2.6. Geology

The geology, the ratio of land and sea, the climate, and the distribution and dispersal of plants and animals are substantially affected by the movement of tectonic plates (Hall 1998; Metcalfe 1998; Morley 1998). The island of Borneo is presently located in the centre of the Sunda Shelf on the Eurasian plate, but is also affected by the movements of the Indian-Australian Plate and the Pacific Plate (Metcalfe, 1998). The present geographic position of Borneo was achieved around 10 Ma when its counter-clock wise rotation was completed (Hall 1998). Table 2.1 depicts major geological events, which might have important impacts on the biogeography of Borneo.

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Table 2.1. Major geological events associated with the biogeography of Borneo

Epoch	Approximate time span in millions years (Ma)	Major geological events
Miocene to Pliocene	20-10 Ma	The clockwise rotation of the Philippine plate; The counter clockwise rotation of Borneo; Delta formation in Borneo; The elimination of the Proto South China Sea; The emergence of Central Kalimantan Ranges
Oligocene to Miocene	30-20 Ma	Plate collisions and rotations; Rapid northward movement of Australia; The formation of the Indonesia archipelago
Eocene to Oligocene	40-30 Ma	The spreading of the marginal basins of the west and south west Pacific
Eocene	50-40 Ma	Collision of Indian plate and Eurasian plate; The separation of Sundaland from Eurasia; Australian plate drifts north; India and Australia became one plate in Middle Eocene; Rift basins formed throughout Sundaland

Source: Modified from Caratini and Tissot (1988); MacKinnon *et al.* (1996); Metcalfe (1998); Moss and Wilson (1998)

Borneo is thought to be the product of marginal basin fill, island arc material, continental crust, and Mesozoic accretion of oceanic crustal material (Moss and Wilson 1998). The Schwaner Mountains, and much of inland Borneo, originated from continental crust (MacKinnon *et al.* 1996; Hall 1998; Moss and Wilson 1998), while the oceanic crustal material (ophiolite) was largely deposited in the Barito Basin within the Meratus Mountains of South Kalimantan, and Pulau Laut (Moss and Wilson 1998). Figure 2.4 presents a simplified geological map of Borneo.
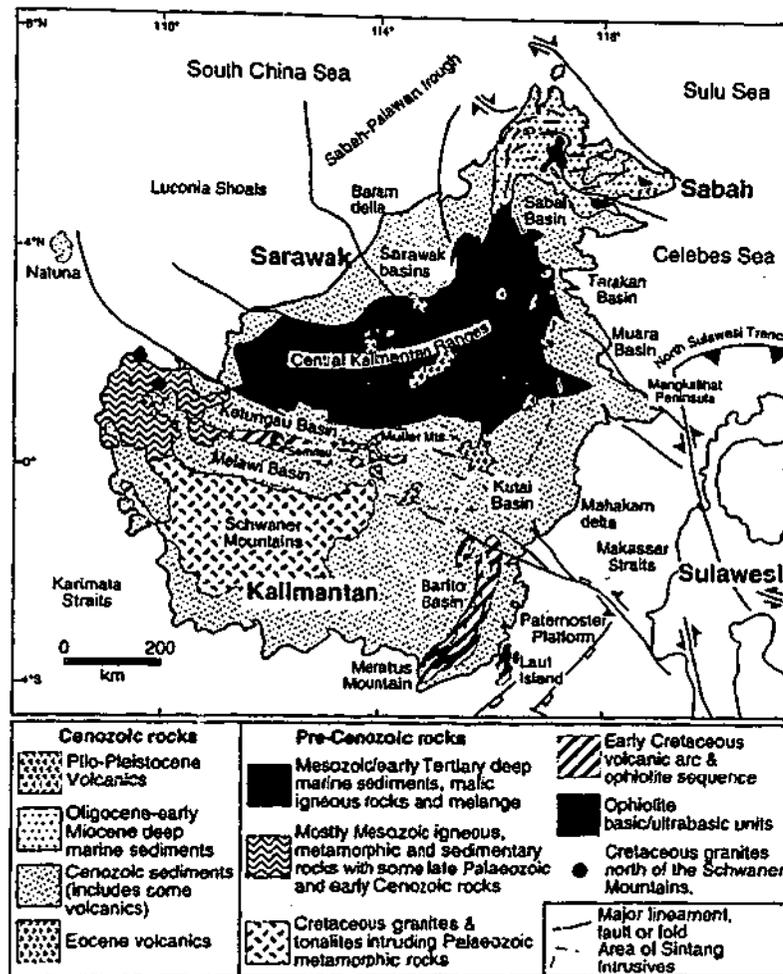
Figure 2.4. A simplified geological map of Borneo (Adopted from Moss and Wilson 1998)

This map clearly shows that the majority of sediments in Borneo were deposited in the Tertiary. Cretaceous granites and tonalites are largely confined to the Schwaner Mountains and limited parts of northwest Borneo, while some old volcanic rocks associated with Palaeozoic volcanic activity in Indonesia are found in southwest and eastern Kalimantan (RePPProt 1990). Late Pleistocene to Holocene sediment is common, particularly near the coasts, in the form of alluvial fans and peat (RePPProt 1990).

2.7. Tropical forests of Borneo

Borneo is characteristically known for its deep jungle, with high structural complexity and floristic and faunal diversity. Unfortunately, few mature, natural tropical forests remain in Borneo as extraction of tropical timber has been occurring very rapidly. In Kalimantan, timber has been commercially extracted over the last 30 years, starting around 1967 after the enforcement of the law on forestry (Manning 1971). Mature tropical forests now occur only in remote areas, inaccessible for commercial logging operations, while an enormous area of the lowland evergreen tropical forests has been converted to tree plantations supporting different kinds of introduced species such as *Elaies guinea*, *Hevea brasiliensis*, *Acacia* spp, *Eucalyptus* spp, and *Gmelina* spp. The conversion from natural, diverse rainforests to exotic monoculture and intensive agriculture has occurred very rapidly.

The following sections will briefly address the major formations of Borneo's natural vegetation occurring on dry land and in freshwater swamps. In general, tropical forests of Borneo share some similarities with other tropical forests in the ever-wet zones of west Java, northern Sumatra, and the Malay Peninsula. The ever-wet climate controls the formation of evergreen vegetation occupying the various habitat types. The vegetation types include lowland evergreen rain forests, lower and upper montane rain forests, subalpine forests, heath (kerangas) and kerapah forests, mangroves, freshwater swamp forests, and peatland forests.

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2.7.1. Lowland Evergreen Rain Forests

Lowland dipterocarp forests commonly occur on acidic and infertile soil (Ultisols) and are prone to surface erosion (Ohta and Syarif 1996), but the forests are extremely diverse. Dipterocarpaceae is widely known as the dominant family in the lowland forests of Borneo, which has the highest number of endemic species (155), while Sumatra and Papua New Guinea have approximately 11, Java has 2, Peninsula Malaysia has 28, and the Philippines has 21 (Ashton 1982). 180 tree species belong to the Dipterocarpaceae (Ashton 1989). *Shorea* spp, *Hopea* spp, *Dipterocarpus* spp, *Dryobalanops* spp, and *Vatica* spp are included among the limited selection of high demand, commercial timber. The ecological and commercial attributes of non-dipterocarp taxa are little known and probably undervalued.

It is estimated that the number of non-dipterocarp families in Borneo amounts to at least 100, incorporating 360 genera, and *c.* 2,000 tree species (Kessler 1996). These lesser known species occur in families such as Anacardiaceae, Annonaceae, Bombacaceae, Burseraceae, Euphorbiaceae, Guttiferae, Lauraceae, Moraceae, Meliaceae, Myrtaceae, Sapotaceae, Sterculiaceae, Tiliaceae, and Thymelaeaceae to mention but a few. Families producing distinctive trees such as Araucariaceae *(Agathis)*, Casuarinaceae *(Gymnostoma* and *Casuarina)*, Podocarpaceae *(Dacrydium)*, and Arecaceae are also widely distributed in the lowland evergreen rainforests of Borneo. These non-dipterocarp families do not only produce good timber but also non-timber forest

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products, which are very important to the wildlife, forest peoples, and the environment.

Herbs are poorly represented in the lowland rainforests of Borneo. Ground herbs are more common in the open and frequently disturbed sites than in the mature, closed rainforests. Two years after the Borneo fire of 1982-1983, herb biomass substantially increased, but then sharply declined afterwards (Nykvist. 1996). Repeated burning results in the colonisation of *Imperata cylindrica* (alang-alang grass). In one hectare of the lowland dipterocarp rainforest in the Batu Apoi forest reserve in Brunei, Poulsen (1996) found only 12 families of ground herbs, *c.* 67 species. In contrast, the mature, closed lowland dipterocarp forest of Borneo usually has ≥ 200 tree species per ha. The family Dipterocarpaceae dominantly occurs in the lower altitudes, up to 800 m ASL (Proctor *et al.* 1988; Pendry and Proctor 1997). Above 800 m, the dipterocarps are rare and are replaced by other families in montane forests.

2.7.2. Montane Tropical Forest

The tropical forests of Borneo occur continuously from the lowlands to the altitudinal forest line, without a non-forested zone as occurs in the tropical African and Andean mountains. However, differences in stature between the lowland forests and the lower and upper montane forests are fairly clear. The lower and upper montane forests are relatively stunted (≤ 20 m tall) although still high in species richness and tree density (Pendry and Proctor 1997). By contrast, the

Table 2.2. An idealised floristic zonation of tropical forests of Borneo

Altitude (m)	Forest Formation	Floristic Zone	Mean Annual Temperature (°C)	Major Genera
≥ 3,600	Conifer forest/ericoid scrub/ alpine	Ericaceae, Podocarpaceae, Casuarinaceae, Myrtaceae, and Symplocaceae	≤ 13	*Vaccinium, Rhododendron, Dacrycarpus, Myrica, Leptospermum, Symplocos.*
2,000 to 3,600	Upper montane	Ericaceae, Fagaceae, Podocarpaceae, Myrtaceae, and Symplocaceae	16 – 13	*Vaccinium, Rhododendron, Lithocarpus, Podocarpus, Dacrycarpus, Phyllocladus, Leptospermum, Symplocos.*
1,200 to 2,000	Lower montane	Dipterocarpaceae, Fagaceae, and Podocarpaceae	25 - 16	*Shorea, Quercus, Lithocarpus, Podocarpus, Dacrycarpus*
0 to 1,200	Lowland	Dipterocarpaceae	≥ 25	*Shorea, Hopea, Dipterocarpus, Vatica, Dryobalanops*

Sources: Smith 1980; Whitmore 1984; Proctor *et al.* 1988; Kitayama, 1992; Pendry and Proctor, 1997

mature lowland dipterocarp forest has three storeys of vegetation, with a top canopy (≤ 60 m tall). The change in forest composition with altitude takes place on Borneo's small peak ranges and the highest mountain, Mount Kinabalu (4010 m) in Sabah.

The forest line on Mount Kinabalu occurs approximately at 3,400 m ASL. The lowland dipterocarp forest is generally found up to 1,200 m ASL, the lower montane forest between 1,200 and 2,000 m ASL, the upper montane between 2,000 and 2,800 m ASL, and the subalpine above 2,800 m ASL (Whitmore 1984; Proctor *et al.* 1988; Kitayama 1992; Pendry and Proctor 1997). Above 700 m, and on the small mountains up to 1,000 m in Borneo, the stature of the forest clearly changes, from a closed lowland dipterocarp forest into a stunted, non-dipterocarp forest.

On Mount Kinabalu, the lower montane forest occurs between 1,200 m and 1,800 m (Kitayama 1992; MacKinnon *et al.* 1996). The major families in the lower montane forest are Elaeocarpaceae, Euphorbiaceae, Guttiferae, Fagaceae, Lauraceae, Leguminosae, Myrtaceae, and Theaceae. However, some families have a characteristically wide altitudinal range such as Euphorbiaceae, Fagaceae, Lauraceae, Leguminosae, Myrtaceae, and Sapotaceae (Kitayama 1992; Proctor *et al.* 1988). Families occurring in the upper storey of lowland forests may appear in the understorey within the upper zones, eg., Moraceae and Myrtaceae (Kitayama 1992). Some families, however, including Fagaceae, Podocarpaceae, Rutaceae, Epacridaceae, Ericaceae, and Escalloniaceae, are largely restricted to higher altitudes, and may become dominant there (Smith 1980; Whitmore 1984; Proctor *et al.* 1988; Kitayama 1992). Families likely to be absent in the upper montane zones (above 1,500 m) are Bombacaceae, Burseraceae, Dipterocarpaceae, Leguminosae, Meliaceae, Sapindaceae, Rubiaceae, Thymelaeaceae, and Xanthophyllaceae (Kitayama 1992). By contrast, a few families such as Ericaceae,

Fagaceae, and Podocarpaceae, which are mainly restricted to the lower and upper montane forests, can grow scattered in the lowland forests. A simple model of the floristic zone of tropical forests of Borneo is presented in Table 2.2.

Factors affecting the low stature of montane tropical forests in Borneo are very complex. The reduction of temperatures with increased altitude is considered to be a major cause (Pendry and Proctor 1996), while Kitayama (1992) concludes that an interaction of soil and temperature may have a significant role in the altitudinal zonation of vegetation change on Mount Kinabalu. Nevertheless, vegetation in the tropics is extremely well adapted to poor and acidic soils. Potential toxic elements of tropical forest soils, droughts, and water logging may not have an important effect on the stunted nature of vegetation on the higher altitudes in the Malayan mountains (Pendry and Proctor 1996; 1997). Flenley (1998) suggested that, in addition to reduced temperatures, an increase of UV-B radiation at higher altitudes, particularly over 3,000 m ASL, may suppress the growth of vegetation, leading to plant speciation (Lee and Lowry 1980). In reality, the low stature of high altitude vegetation may be the result of a combination of many factors. Permanent water logging, poor nutrient supply, high UV-B radiation above 3,000 m ASL, soil types, and water stress may lead to the formation of stunted vegetation at high altitudes, while changes in global temperatures and atmospheric CO_2 concentrations may promote change in vegetation composition through time. At local and regional scales, oligotrophy, inundation, droughts, and edaphic factors have been proposed as having significant influence on the

formation of stunted vegetation or pole-like forests in the lowlands ($\leq$ 1,500 m ASL), particularly the heath (kerangas), kerapah forest, and the inundated peatland forest.

2.7.3. Kerangas and Kerapah Forest

Heath (kerangas) has formed on podsolised white sands, which are extensively distributed in Borneo (Whitmore 1975; Whitmore 1998; Bruenig 1990; MacKinnon *et al.* 1996). Sometimes, the distribution of kerangas is not extensive, but forms a mosaic within mixed lowland dipterocarp forests. Kerapah forest is related to heath, and only occurs in waterlogged environments within peatland forests. Commonly, kerapah forest grades gradually into the peat swamp forests, and is dominated by Dipterocarpaceae, Guttiferae, and Sapotaceae (MacKinnon *et al.* 1996).

The major structural features of the kerangas and kerapah are the presence of a single, stunted canopy ($\leq$ 30 m), small diameter poles, and small sclerophyllous crystalline leaves. Kerangas is a Dayak Iban term to describe a heath forest type, which is not suitable for slash and burnt cultivation of dryland paddy (Whitmore 1975). The development of the peculiar stunted structure and sclerophyllous leaves of kerangas forest is considered to be a response to periodic water stress due to seasonal droughts (Bruenig 1974; MacKinnon *et al.* 1996; Whitmore 1998). In the Mandor reserve, West Kalimantan, a preliminary date for the formation of the white sands associated with the kerangas is around 50,000

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years BP, and the deposition of the white sands in this province is thought to have occurred during drier and cool climates of the Pleistocene (Thorp *et al.* 1990).

Oligotrophy or poor nutrient supply is no longer considered as the single major factor controlling the structure of the stunted vegetation in the kerangas and kerapah. Factors controlling vegetation development in these forests are soil type, inundation period, and fire. The soil of the lowland dipterocarp forests is also poor in nutrients, but is able to support tall forests. In fact, on favourable sites, the flora of heath forests is similar to that of the lowland dipterocarp forests, with a top canopy up to 40 m, while at the other extreme condition of nutrient deficiency, the canopy is as low as 5 m. An important factor seems to be that, that having developed the sclerophyllous and waxed leaves and the stunted vegetation, kerangas and kerapah forests are able to minimise water loss during seasonal droughts (MacKinnon *et al.* 1996).

Major taxa of large trees that may occur in the heath forests are *Shorea* spp, *Hopea* spp, *Cratoxylum* spp, *Tristaniopsis* spp, *Dactycladus* spp, *Eugenia* spp, *Ilex* spp, and *Cotylelobium*. In the shrub layer, *Barringtonia* spp, *Calophyllum* spp, *Shorea* spp, and *Vaccinium* spp are commonly found (MacKinnon *et al.* 1996). Palms, pandans, and pitcher plants (*Nephentes*) are also abundant. *Casuarina nobilis*, *Dacrydium*, and *Podocarpus* are also present in the kerangas forests.

A single species such as *Dacrydium elatum*, *D. pectinatum* or *Casuarina nobilis* may become dominant in the kerapah forest (Bruenig 1990). On the forest floor, sedges and *Pandanus* can be abundant. In addition, trees growing in the kerapah forests tend to develop pneumatophores, and xeromorphic leaves with

high concentrations of tannins. As a consequence, the organic decomposition rate in the kerapah forest is extremely slow, and this might facilitate the process of peat accumulation (Bruenig 1990; Whitmore 1998).

2.7.4. Lowland Peat Swamp Forest

Waterlogged environment and oligotrophic water are two related features of lowland peat swamp forests. Peat retains a lot of water and only develops under waterlogged environments, which halt the process of decomposition. If the water is drained from peat deposit areas, peat will rapidly decompose. In extremely dry conditions, peat will suffer total water loss, causing an irreversible phenomenon of peat shrinkage. Oligotrophic water slows the rate of decomposition (Richards 1996), and the release of various chemical compounds under anaerobic conditions, such as carboxylic and phenolic acids, high concentrations of Sulphur (S) and free Aluminium (Al), have toxic effects on the growth of decomposers and may have allelopathic effects (Andriesse 1988; Bruenig 1990). This mechanism further decreases the rate of decomposition and possibly leads the accumulation of peat, while the allelopathic effects, low nutrient levels, and waterlogged environment cause the lowland peat swamp forest ecosystem in the tropics to be unique and have a distinctive vegetation composition.

Tropical peats are mainly composed of fibric materials of woody plants, particularly tree roots (Brady 1997) and have very low ash contents (between 1 and 5%), low soil pH (between 3 and 4), and are deficient in essential nutrients, especially Phosphorus (Whitmore 1975; Anderson 1983; Page et al. 1999).

Occasionally, the base of the peat is a mineral soil, which when oxidised, will release pyrites (Fe), a potential toxic element for plant roots. The peat commonly has a domed shape, reducing flooding of the centre of the peat deposit.

The vegetation composition of lowland peat swamp forests is variable. There are some similarities and differences across peat swamp forests in the South East Asian region. A few species are found to be endemic or to become purely dominant. *Gonystylus bancanus* is endemic to Borneo, and *Shorea albida* is commonly found as pure stands in the coastal, peat swamp forests from the Sambas River in the West Kalimantan province to the Tutong River in Brunei (Anderson 1983).

For two and half decades, the development of the Malayan peatland forests was perceived as following a classical model proposed by Anderson and Muller (1975). The authors describe six vegetation associations of the peat swamp forests found in the coastal regions of northern Borneo. This vegetation classification is based primarily on the distribution of species associations from the perimeter towards the centre of peatlands. A floristically most diverse swamp forest commonly occurs at the perimeter of the peatland, while an open, stunted and less diverse forest formation occurs in the centre, suggesting the decline of nutrient pools from the perimeter to the centre of the peatlands. The six vegetation communities according to this classical model are detailed below.

Phasic community 1, according to Anderson and Muller (1975) or mixed peat swamp forest (Bruenig 1990), is an association of *Gonystylus-Dactylocladus-Neoscortechinia*. This community is considered to represent an initial phase of

peat swamp forest development, and extensively occurs at the perimeter of the peat deposit or close to a river. The forest canopy ranges from 40 to 58 metres in height. The emergent taxa are *Gonystylus bancanus*, four species of *Shorea*, *Dactylocladus stenostachys*, *Dryobalanops rappa*, and *Copaifera palustris*. In the middle storey, common taxa are *Palaquium*, *Ganua*, *Calophyllum*, *Garcinia*, *Eugenia*, *Horsfieldia*, *Gymnacranthera*, *Knema*, *Myristica*, *Combretocarpus rotundatus*, and *Dyera lowii*. In the lower storey, *Neoscortechinia*, *Alangium havilandii*, *Stemonurus secundiflorus* var., *lanceolatus*, *Tetractomia parviflora*, *Cephalomappa paludicola*, and *Ganua curtisii* may form important components. In the shrub layer, the sedge *Thoracostachyum bancanum*, *Pandanus*, and *Nepenthes* may become dominant. The fern, *Stenochlaena palustris* can be locally very common. In this association, common families are Guttiferae, Euphorbiaceae, Myrtaceae and Sapotaceae.

Phasic community 2 or Alan forest occupies a transitional zone between phasic community 1 and 3, and is less extensive and diverse than phasic community 1. The common emergent taxon in the top storey is *Shorea albida*, a large tree with often a 3 m girth (Anderson and Muller 1975). In the lower strata, *Gonystylus bancanus* and *Stemonurus secundiflorus* var., *lanceotus* are common. Herbs and terrestrial ferns are poorly represented in this community type (Anderson and Muller 1975; Bruenig 1990).

Next, phasic community 3 or Alan Bunga Forest forms a consociation of *Shorea albida*. The main feature of this community is the dominance of a single species, *S. albida*, with an average height between 50 and 60 metres. *Gonystylus*

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bancanus, Combretocarpus rotundatus, and *Dyera lowii* occur scattered in the lower storey. The number of species in the under-storey is very poor, and a single species can be dominant, such as *Tetractomia parviflora* in the Baram valley, *Cephalomappa paludicola* in the Rejang delta, and *Ganua curtisii* in Badas swamps of Brunei. In the shrub layer, *Pandanus andersonii* is very common, forming a dense, thorny bush, with several species of *Nepenthes.* Herbaceous taxa, ferns, rattans and other climbers are not prolific (Anderson and Muller 1975; Bruenig 1990).

Phasic community 4 may be a combination of two dominant associations, Padang Alan Bunga Forest with *S. albida* as an emergent taxon, and Padang Medang Forest with *Litsea crassifolia* as an emergent taxon (Bruenig 1990). This community, also known as the *Shorea albida-Litsea-Parastemon* association, occurs in the centre of the peatlands. The canopy height is approximately 36-40 m, but the trees are commonly pole size, rarely larger than 40 and 60 cm dbh. Other major taxa in the can   are *Calophyllum obliquinervum, Litsea crassifolia,* and *Combretocarpus rotundatus,* while *Parastemon spicatum* and *Tristania obovata* may be abundant in the lower storey (Anderson and Muller 1975). Sedges and herbs are rare, but *Ficus deltoidea* var. *motleyana, Euthemis minor,* and *Nepenthes* spp are common, indicating low nutrient levels in the bog plain (Anderson and Muller 1975; Bruenig 1990).

Phasic community 5 or Padang Selunsor forest represents a low pole forest type with an association of *Tristania-Parastemon-Palaquium,* occurring as a transition forest among phasic communities 3 and 4 and 6. The canopy height

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ranges from 15 to 20 metres. Other major taxa in this community type are *Tristania obovata, T. beccarii, Parastemon spicatum, Palaquium cochleariifolium, Combretocarpus rotundatus,* and *Dactylocladus stenostachys.* On the forest floor, *Pandanus sigmoideus* and the sedge *Thoracostachyum bancanum* occur abundantly (Anderson and Muller 1975; Bruenig 1990).

Finally, an association of *Combretocarpus-Dactylocladus* in phasic community 6 or Padang Keruntum woodland occurs in the raised-bog plain. The forest is open and stunted, and the trees with sclerophyllous leaves rarely achieve 12 metres in height (Bruenig 1990). The tallest and the biggest tree is *Combretocarpus rotundatus.* Several other tree species occur as shrubs, such as *Litsea crassifolia, Ilex cymosa* and *Garcinia cuneifolia,* while *Pandanus, Nephentes* and the sedge *Thoracostachyum bancanum* occupy the shrub and ground layers. Ferns are not common in this forest, and a unique feature of this habitat is the occurrence of *Sphagnum junghuhnianum* at low altitudes in Sarawak (Anderson and Muller 1975). At the centre of the peatland where this Padang Keruntum woodland occurs, the depth of the peat deposit may achieve up to 20 metres (Bruenig 1990).

However, the development of the peat swamp forests in Borneo does not always follow this pattern (Oh *et al.* 1999; Page *et al.* 1999). In the Sebangau catchment, Central Kalimantan, the forested wetlands change from riverine forest through mixed peat swamp forest (beyond the flooding regimes, more than 1.5 km away from the river), stunted or low pole swamp forest (6 and 11 km from the river) to tall swamp forest on the peat dome (about 12 km away from the river). A

very low canopy forest is found in discrete areas on the highest elevations of the peat dome (Page *et al.* 1999). Although the development pattern of the peat swamp forests in the Sebangau catchment has similarities to the development of the peat swamp forests in Northern Borneo, Page *et al.* (1999) report the occurrence of the tall swamp forest in the centre of the plain bog, where peat depth is up to 13 m. The replacement of the low pole peat swamp forest by the tall, relatively diverse peat swamp forest in the peat dome in this catchment is unexpected since thicker peat in the plain bog is expected to be poor in nutrients, unable to sustain the development of the tall peat swamp forest. This anomaly has not yet been explained (Page *et al.* 1999). Morley (2000) suggests that the age of peat has a major influence on the development of peatland vegetation. Pleistocene peat may support tall trees, while Holocene peat may support vegetation phases described by Anderson and Muller (1975).

In the mixed swamp forests near the Sebangau River, and in the tall peat swamp forest, important taxa are *Calophyllum hosei, C. lowii, C. sclerophyllum, Combretocarpus rotundatus, Gonystylus bancanus, Dactylocladus stenostachys, Dipterocarpus coriaceus, Shorea balangeran, Shorea teysmanniana, Vatica mangachopai, Palaquium cochlearifolium, Palaquium leiocarpum, Dyera costulata, Koompasia malaccensis, Agathis dammara, Xanthophyllum spp,* and *Gymnostoma sumatrana.* Forest understoreys in both the mixed swamp forest and the tall peat swamp forest are relatively poor in ferns and *Pandanus.* Trees with pneumatophores are more common in the mixed swamp forest than in the tall peat swamp forest (Page *et al.* 1999).

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Common taxa in the low pole or stunted swamp forests are *Combretocarpus rotundatus, Calophyllum fragrans*, and *C. hosei*, while *Dactylocladus stenostachys, Litsea, Cratoxylum* spp, *Tristania* spp and *Ploiarium alternifolium* are commonly found in the very low canopy forest. Pneumatophores are abundant in both forest types. The sedge *Thorachostachyum bancanum, Nepenthes* and *Pandanus* are common on the forest floor (Page *et al.* 1999).

2.8. Forest fire in Borneo

Although the climate in Borneo is ever wet, forest fires associated with strong El Niño Southern Oscillation (ENSO) episodes regularly occur in this region. The 1982-1983 ENSO induced drought was the worst on record to that date, probably resulting in more than 5 million ha of biomass burning in Borneo (Goldammer 1993). Areas affected by the fire included conservation forests, estate crop plantations, logged forests, secondary forests, and alang-alang (*Imperata cylindrica*) grassland. Secondary, logged forests and estate crop plantations are usually more prone to fire than primary forests (Goldammer *et al.* 1996; Nepstad *et al.* 1999). Recurrent fire episodes potentially replace tropical forests with alang-alang (*Imperata cylindrica*) grassland.

Forest fires in Borneo have been documented since the late Pleistocene (Goldammer 1989; Goldammer *et al.* 1996; Goldammer 1999). During the Last Glacial Maximum, it is considered that drier and seasonal climates over Sundaland supported the occurrence of natural fires, which may have played an important role in evolutionary diversification of rain forest species. In the past, wildfires may

have helped gap creation, acceleration of forest regeneration, and increased natural biodiversity (Goldammer 1989). In contrast, at present natural fire rarely occurs, and the current fire regimes are commonly rooted in anthropogenic activities associated with land clearing for estate crop plantations, and slash and burn cultivation for dryland rice. Seasonal forest fires in Borneo have substantially opened forest frontiers, reduced the forested lands, caused health hazards associated with smoke, and developed regional haze over this region. Recurrent burning can have devastating consequences, changing closed forested lands into open woodlands or savanna (Kershaw 1985; Cochrane *et al.* 1999). This will occur when fire rotations are short.

The forest fires associated with El Niño events that take place at intervals of 3 to 7 years have become more frequent in this millennium (McPhaden 1999). In Kalimantan, recent forest fires associated with El Niño episodes occurred in 1982/1983, 1987, 1991, 1994, and 1997, and large forest fires were noted during the strong El Niño events of 1982/1983 and 1997/1998, only separated by 15 years. The fact that the frequency of El Niño is considered to be increasing (McPhaden 1999) may be correlated with a steady increase in greenhouse gases, particularly CO_2, CH_4, and other trace gases (Timmermann *et al.* 1999).

The annual rate of forest loss due to fires is probably between 70,000 and 500,000 ha in Indonesia. Accordingly, forested lands in Kalimantan are rapidly declining and will mostly change into open woodlands covered with pioneer species, and grasslands dominated by *Imperata cylindrica* if these seasonal fires continue to regularly take place and are inadequately controlled (Goldammer *et al.*

1996; Goldammer 1999). This change will consequently lead to a significant increase of carbon in the atmosphere. As an illustration, it is estimated that carbon release associated with forest fires in the Amazon basin is about 0.6×10^9 Mg/yr, substantially higher than carbon release due to logging operations (Nepstad *et al.* 1999). Since forest fires occur regularly and may destroy large forested lands in Borneo, it is very likely that carbon release due to forest fires in Borneo is highly significant.

Table 2.3. Possible response of major taxa/families of mixed dipterocarp forests to fire

Fire promoting taxa/families	Fire resistant taxa/families	Fire depleting taxa/families
Macaranga spp (Euphorbiaceae)	*Eusideroxylon zwageri* (Lauraceae)	Dipterocarpaceae
Ficus spp (Moraceae)	Caesalpinaceae	Anacardiaceae
Octomeles spp (Datiscaceae)	*Diospyros* spp (Ebenaceae)	Annonaceae
Leea indica (Leeaceae)	Arecaceae	Burseraceae
Anthocephalus spp, *Nauclea* spp (Rubiaceae)		Fagaceae
Trema spp (Ulmaceae)		Melastomaceae
Vitex spp (Verbenaceae)		Meliaceae
		Myristicaceae
		Myrtaceae
		Sapindaceae
		Sapotaceae

Source: Adapted from Goldammer *et al.* 1996

Charcoal records suggest that in the tropical forests elsewhere natural fires occurring at intervals of hundreds and thousands of years have negligible effects on forest ecosystems. However, a fire interval of 100 years may substantially alter the composition tree species, and a-20-year fire interval will cause forest decline

(Cochrane *et al.* 1999). However, long-term impacts of fire on tropical forests are poorly known. A preliminary study shows that species of dipterocarp forests respond differently to fire. Table 2.3 lists the possible response of major taxa/families of mixed dipterocarp forests to fire (Goldammer *et al.* 1996).

Major factors controlling tree response to fire hazards are light, bark resistance to heat, and mode of regeneration. Most fire promoting taxa such as *Macaranga* and *Trema* are shade intolerant, invasive and fast growing, while major taxa such as *Shorea* and *Palaquium* in closed mixed dipterocarp forests are likely to be suppressed by fire. These taxa are commonly shade tolerant and slow growing. A few tree species such as ironwood (*Eusideroxylon zwageri)*, the hardest timber species in Borneo's dipterocarp forests, and *Diospyros* spp are likely to be resistant to heat and may survive after the fire. The ironwood tree is also able to regenerate by coppicing, and produces very hard seeds, which are resistant to fire. Taxa which are able to regenerate vegetatively are likely to recover immediately after fire.

Chapter 3: Late Quaternary vegetational and climatic change in Sundaland

3.1. Introduction

The Sunda Shelf covers an area of 1,850,000 square kilometres, and lies under the southern part of the South China Sea and under the Java Sea (Tjia 1980). This platform acted as a land bridge, connecting Peninsular Malaysia, Sumatra, Borneo, and Java during Pleistocene low sea levels, and is commonly called Sundaland (Tjia 1980; Verstappen 1980; Hantoro *et al.* 1995).

During Pleistocene low sea levels, palaeorivers over Sundaland were active. Rivers in south east Sumatra and western Borneo such as the Mekong and the Chao Phraya drained to the same paleochannel under the present South China Sea, while rivers in south east Borneo and west Java flowed to the great Sunda river (Kottelat *et al.* 1993; Molengraaff 1900; Verstappen 1975; 1980). As a result, fish populations in the present rivers of south east Sumatra and western Borneo are similar, but different from the fish found in west Java and south east Borneo (Molengraaff 1900; Dodson *et al.* 1995). Figure 3.1 portrays the estimated glacial-ice landscape in Sundaland, showing the emergence of Sunda Shelf. The emergence of this shelf during Pleistocene ice age episodes changed the ratio between land and sea, and had significant implications for the dynamics of climate and vegetation, the distribution of forested wetlands, and human migration.
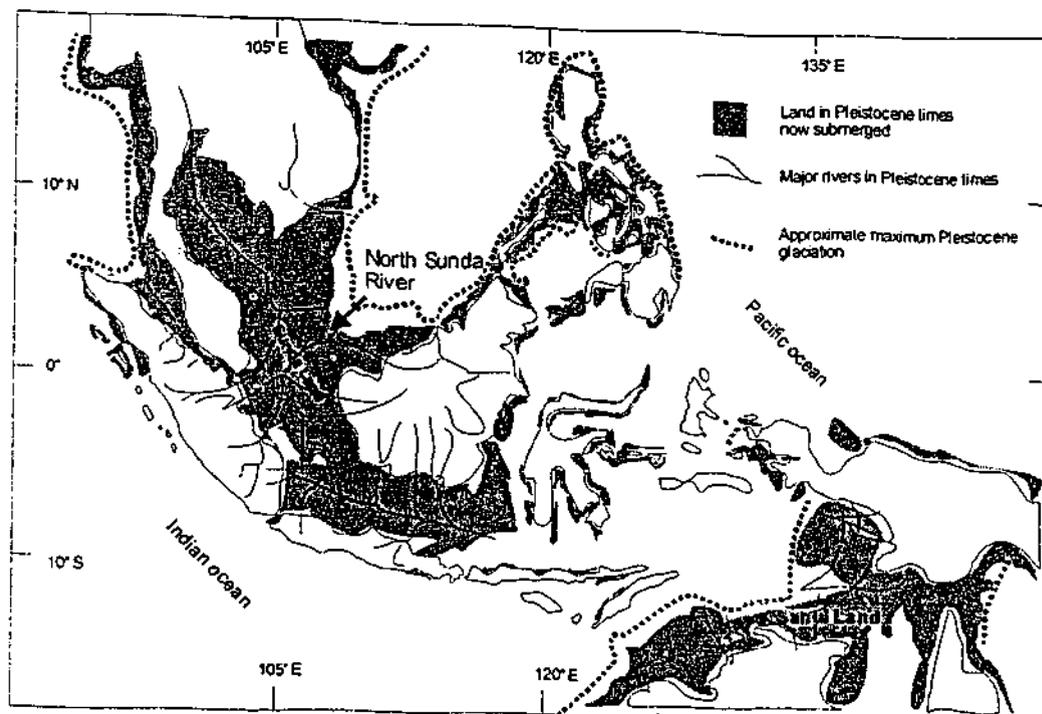
Figure 3.1. The estimated Pleistocene glacial-ice age shorelines and palaeo-rivers over Sundaland (after Kottelat *et al.* 1993; Molengraaff 1900; Verstappen 1975; and van Oosterzee 1997)

Proxy data of climatic and vegetational change over Sundaland during Pleistocene glacial episodes are mainly derived from palynological studies, particularly in the highlands of west Java, and central and northern Sumatra (Morley 1982a; Newsome and Flenley 1988; Stuijts 1993; van der Kaars and Dam 1995). The few pollen studies from Borneo do not reach back to the Pleistocene glacial episodes, and mainly discuss the development of peatland forests during the Holocene (Anderson and Muller 1975; Morley 1981a; 1982a; Haseldonckx 1977). Recent palynological studies in the lowland sites of the Sebangau peatland in the province of Central Kalimantan (Asha Thamotherampillai, pers.comm. 1999), and Rawa Danau in West Java (van der Kaars *et al.* in press) date back to the Last Glacial Maximum, and provide substantial records of past vegetational and climatic change.

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The following sections will summarise the results of pollen studies from terrestrial parts of the region that provide records extending to the Late Pleistocene. They are Situ Bayongbong, Bandung basin, and Rawa Danau in West Java, Toba Plateau, Pea Sim Sim, and Tao Sipinggan in North Sumatra, Danau Di Atas and Danau Padang in the central highlands of Sumatra, Sebangau peat swamp forest in central Kalimantan, and Nee Soon swamp in Singapore.

3.2. Pollen studies from West Java

3.2.1. Situ Bayongbong

This pollen study is based on the publications of Stuijts *et al.* (1988) and Stuijts (1993). Situ Bayongbong is located some 55 km southwest of Bandung, and lies at 107°17'E, and 7°11'S, at an altitude of 1,300 m ASL. The sediment core was collected from the small swamp, and presently is covered by tea plantations. The core is about 8 m long, with radiocarbon dates of 16,800 ± 330 years BP at the base, and 3,265 ± 35 years BP at 1 metre depth. The results of the study are summarised below.

During the late last glacial period, dating from about 17,000 years BP, *Dacrycarpus imbricatus* was a common component of the pollen record, but declined after c. 12,400 years BP *Podocarpus* was persistently found in low percentages between 17,000 and 12,400 years BP, and this tree also substantially declined after c. 12,400 years BP. Other common tree taxa were *Engelhardia, Castanopsis* comp, *Quercus, Altingia, Rapanea,* and Ericaceae, while sedges, grasses, and ferns were poorly represented.

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From the beginning of the Holocene, around c. 10,900 years BP, *Dacrycarpus imbricatus* and *Engelhardia* declined sharply, and *Podocarpus* was also found in very low percentages. Common tree taxa, such as *Quercus, Castanopsis* comp and *Altingia,* slightly increased, while *Macaranga, Melastoma, Eugenia* comp, *Dystilium, Elaeocarpus,* and *Nauclea* comp. became more common. By contrast to the late Pleistocene, sedges, grasses, and ferns were well represented.

It is possible that upper montane or alpine ericoid forests occurred around the Situ Bayongbong swamp in the late Pleistocene. *Rapanea, Dacrycarpus imbricatus,* and Ericaceae scrub could have been the major constituents of this forest, with *Quercus,* and *Castanopsis* comp. forming the oak forest at lower altitudes. According to Stuijts (1993), the presence of alpine ericoid forest at 1,300 m ASL indicates that the vegetation belt had probably descended by at least 500 m, and that temperatures were probably 2-3°C lower during the Last Glacial Maximum (Stuijts *et al.* 1988; Stuijts 1993) than at present.

However, *Dacrycarpus*, although mainly represented as scattered stands between 800 and 2,500 m altitude, may descend almost to sea level (Sunarno 1995). Most Malesian *Rapanea* species are not confined to the upper montane forest, but are also found in the lower montane forest (Boer 1998). This may suggest, by contrast, that the vegetation belt in the Situ Bayongbong area during the Last Glacial Maximum might not have been lowered substantially. The persistent occurrence of Ericaceae, *Quercus, Castanopsis* comp, *Altingia,* and *Engelhardia* from c. 17,000 to 12,400 years BP also suggests that the

forest habitat of Situ Bayongbong was similar to the lower montane forest (1,500 – 1,800 m ASL) rather than the upper montane forest or the alpine ericoid forest (2,400- 3,000 m ASL). The vegetation belt might have lowered marginally between 200 and 500 m, and the air temperatures could have been slightly reduced, but the climate remained wet. Consequently, the environment was favourable for the formation of closed tropical rain forest, but the tree composition was slightly different to the present lower montane forests in West Java.

In the period 12,400 to 10,900 years BP, the replacement of *Dacrycarpus imbricatus* by *Engelhardia,* and almost complete disappearance of *Rapanea* does suggest a rise of mean temperatures, but the rapid decline of *Engelhardia* after c. 10,900 years BP, was probably due to forest disturbance. Then, *Quercus* and *Castanopsis* comp. (Fagaceae) became dominant at c. 7,890 years BP. High values of sedges and grasses, the emergence of light demanding taxa, such as *Melastoma, Macaranga, Schima*, and *Trema,* and the decline of *Castanopsis* comp. in the late Holocene, was very likely to have been associated with forest disturbance. Anthropogenic impacts were relatively low, however, because the forest remained closed and its composition was generally maintained.

3.2.2. Bandung Basin

The intramontane Bandung Basin, about 150 km southeast of Jakarta, is located in the central part of West Java, north of the Situ Bayongbong site, at latitude 7°S and longitude 107°-108°E. The altitude of the basin is about 660 m ASL and it is surrounded by a series of volcanic highlands, such as Tangkuban

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Perahu (2,076 m ASL), Bukit Tunggul (2,209 m ASL), Malabar (2,321 m ASL), and Patuha (2,434 m ASL). The Bandung plain is relatively flat and elliptical, with an area of about 400 km^2 (Dam 1994; van der Kaars and Dam 1995). The present climate is humid, with an annual mean precipitation of 1,700 mm (van der Kaars and Dam 1995).

The history of vegetation and climate in the Bandung basin is derived from pollen studies of Dam (1994) and van der Kaars and Dam (1995). The authors analysed three sediment cores, namely DPDR-I, DPDR-II, and Lembang core 92.1.9-2. The first two cores, collected from Bodjongsoang and Sukamanah villages, are 60 m in length, and composed predominantly of lacustrine sediments, while the Lembang swamp core is very short, c. 9 m. The extrapolated dates for DPDR-I and DPDR-II cover the period from 126,000 to 16,000 years BP, and the Lembang core covers the Last Glacial Maximum. The vegetation and climate history of the Bandung basin is briefly reviewed in this section.

From 126,000 – 107,000 years BP, high percentages of *Macaranga* comp. and the persistent presence of *Carallia* indicate the presence of lowland forest, with *Barringtonia* indicative of freshwater swamp forest. Lower montane taxa, such as *Dacrycarpus imbricatus, Dystylium stellare, Engelhardia cf. spicata, Myrica, Dodonea cf. viscosa,* and *Podocarpus* were relatively rare, although *Quercus* and *Castanopsis* comp had good representation. The climate was humid and the authors suggested that the presence of *Carallia* in Bodjongsoang (660.5 m ASL) and Sukamanah (662 m ASL) during this period indicates a warmer environment than today. However,

Carallia species occur from lowland to lower montane forest up to 1,800 m ASL, and are found scattered in a variety of habitat types, such as the lowland forest, mixed dipterocarp forest, and freshwater swamp forest (Hou 1998). Consequently this evidence does not demonstrate conclusively that temperatures were slightly warmer than present.

From c. 107,000 to c. 81,000 years BP, taxa of lower montane forest, such as *Engelhardia, Myrica, Dacrycarpus imbricatus,* and *Podocarpus,* became prevalent. The climate was possibly slightly cooler. Freshwater swamp taxa, particularly *Barringtonia,* declined slightly, but the oak forests dominated by *Quercus* and *Castanopsis/Lithocarpus* were still prevalent. The rainfall remained high.

An abrupt climatic change occurred around c. 81,000 years BP. Pollen from freshwater swamp and lowland forest taxa, such as *Macaranga* comp, sharply declined, and *Barringtonia* and *Carallia* disappeared, while Cyperaceae and Poaceae values increased substantially. Lower montane taxa, such as *Dacrycarpus imbricatus, Dystylium stellare, Engelhardia,* and *Podocarpus* steadily increased. The climate at this time must have been cooler and drier than previously. Increased values of Poaceae and Cyperaceae suggest that the annual precipitation probably decreased by up to 30%, giving an annual rainfall of well below 2,000 mm. A dr' r and more seasonal climate on the Bandung plain from c. 81,000 – 74,000 years BP is also indicated by the absence of spores of the moisture-loving bird's nest fern (*Asplenium*). The re-appearance of *Asplenium* spores from 74,000 to 47,000 years BP might indicate a slight increase in rainfall before the re-establishment of a more seasonal

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climate between c. 47,000 and at least 16,000 years BP. The dominance of lower montane forest taxa in the Bandung plain at an altitude 660 m ASL after c. 81,000 years BP indicates a maximum depression of 1,200 m for the vegetation belts and suggests a reduction in temperature of between 4 and 7°C relative to today.

The short core from Lembang is located near Bandung, at an altitude of 1,200 m ASL. The Lembang swamp core covers the Last Glacial Maximum period. During this period, Lembang had closed montane forests, with the following common taxa, *Myrsine, Vaccinium, Dacrycarpus imbricatus, Dodonea cf viscosa, Engelhardia cf spicata, Myrica, Podocarpus, Quercus,* and *Castanopsis.* Fern spores were poorly represented. *Altingia* and *Asplenium* were not reported to occur at this time. The presence of montane taxa and the absence of *Altingia* and *Asplenium* may indicate that the last glacial climate in Bandung basin was cooler than today and slightly seasonal. The site does not provide a record of the very late Pleistocene or Holocene.

3.2.3. Rawa Danau

The Rawa Danau swamp is located on the northwestern tip of West Java at an altitude of 100 m ASL. This site, which is thought to be sensitive to the influence of Indonesia's monsoon climate, is considered to be an important site for pollen studies in that it provides evidence of climate and vegetation change in the terrestrial lowlands of Indonesia. The swamp is formed within a caldera. The vegetation history of the Rawa Danau is derived from a pollen study of a 17 m-long sediment core covering the last c. 16,000 years BP (van der Kaars *et al.* in press).

From c. 16,000 to 10,800 years BP, the record shows that the Rawa Danau swamp was colonised by lowland and swamp taxa such as *Macaranga/Mallotus*, *Moraceae/Urticaceae*, *Planchonella* type, *Rhizophora*, *Albizia* type, and *Elaeocarpus*. *Pandanus* was abundant in the understorey. Poaceae and charcoal values reached their highest values, while fern spore percentages were low. Substantial values for montane taxa, such as *Dacrycarpus*, *Dystyllium*, *Myrsine*, and *Podocarpus*, were confined to this period. According to van der Kaars *et al.* (in press), the climate during the late last glacial was substantially drier and possibly more seasonal as indicated by high values of Poaceae, and low values of fern spores. The Rawa Danau record is not considered to supply strong evidence of substantial temperature reduction in this lowland region. The high values of montane taxa are thought to have come from the surrounding mountains, via wind transfer. However, since these montane taxa disappeared after c. 10,800 years BP, a rise in mean temperature is likely to have occurred. It is possible that temperatures during the last glacial in the lowland Rawa Danau area were reduced in the highland regions but not to the same extent as in the Bandung basin.

From c. 10,800 to 3,400 years BP, the vegetation at the Rawa Danau swamp was altered substantially. Most montane taxa disappeared, and Poaceae was significantly reduced. The swamp and lowland assemblages became more diverse, with additions of *Calophyllum*, *Barringtonia*, *Bombax-Ceiba*, and *Blumeodendron*, while fern spore values were higher. It appears that the climate became wetter and at least marginally warmer.

From c. 3,400 to c. 80 years BP, the lowland swamp forest was dominated by *Elaeocarpus* instead of *Macaranga/Mallotus* type. Cultivated taxa, such as *Cocos nucifera* and *Arenga,* emerged during this stage, and Cyperaceae and Poaceae substantially increased, indicating some type of recent anthropogenic impacts on the Rawa Danau swamp.

3.3. Pollen studies from Sumatra

Palynological studies from Sumatra have mostly been derived from montane areas, particularly from the north eastern and central parts of the island. Pollen studies are from Pea Bullock (2°15'N, 99°02'E, 1,400 m ASL), Pea Sim Sim (2°10'N, 98°51'E; 1,450 m ASL) and Tao Sipinggan (2°10'N, 98°51'E; 1,445 m ASL) of the Toba Plateau (Maloney 1980; 1983; Maloney and McCormac 1995), Danau di Atas (1°04'S, 100°46'E; 1,535 m ASL) in the central Sumatra highlands (Newsome and Flenley 1988), and Danau Padang (950 m ASL) in the Kerinci area of central Sumatra (Morley 1982a). The only pollen study, to my knowledge, from a lowland area of Sumatra is that documenting the floral composition of a peat soil from the Lower Batang Hari River basin, located in the Province of Jambi, southeastern Sumatra (Sabiham and Hisao 1986). This study mainly addresses the dynamics of the Lower Batang Hari River peatland forest during the mid Holocene. Those pollen studies extending to the last glacial period from Sumatra will be briefly reviewed in this section.

3.3.1. Pea Bullock, Pea Sim Sim and Tao Sipinggan

Pea Bullock (c. 1,400 m ASL.) is located 2 km north of Siborongborong on a plateau of the Toba highlands. The site is an extinct volcanic crater, which has infilled with peat (Maloney 1994; Maloney and McCormac 1995). These authors analysed two sediment cores from Pea Bullock. The 8-m long Pea Bullock core A spans about the last 30,000 years B.P, and the 3.5-m long Pea Bullock core B covers the period from about 20,000 years BP. The cores consist of fine organic mud at the base, and fibric peat above this. The results of pollen analysis for these cores are briefly discussed below, following Maloney (1994) and Maloney and McCormac (1995).

These cores together provide a long history of vegetation and climatic change for Sumatra. The results of pollen analysis from both cores show that oak-laurel forest was common on the Toba Plateau during the Late Pleistocene. Major taxa found in this forest were *Dacrydium, Engelhardia, Castanopsis* comp., *Quercus, Altingia,* and *Myrsine.* In the Holocene, the forest composition remained essentially similar, but with substantially increased values of *Eugenia.*

High values for *Vaccinium* during the last glacial period, between 21,000 to 18,000 years BP, might indicate a general cooling over the Toba highlands. However, the magnitude of this cooling cannot be determined. Major taxa found in this study have a wide altitudinal range from lower montane to upper montane forest and no single taxon restricted to the upper montane belt is recorded. All taxa found in this study show that the

environment on the Toba highlands has remained humid since the Late Pleistocene.

Pea Sim Sim is also located on the Toba highlands, west of the Pea Bullock site, at an altitude of 1450 m ASL. Pollen data from this site were published in Maloney (1980). A 9.79 m long sediment core was raised from Pea Sim Sim swamp, and yielded a basal radiocarbon date of about 18,500 years BP.

From c 18,500 to 16,500 years BP, major pollen taxa recorded at this site were *Dacrycarpus imbricatus*, *Dacrydium*, *Lithocarpus/Castanopsis*, *Quercus*, and Ericaceae. The high values for *Dacrycarpus imbricatus* during this period must have indicated a lower temperature during the Last Glacial Maximum because *D. imbricatus* is commonly dominant at higher altitude (> 2,000 m ASL). However, Maloney (1980) asserted that the source of this podocarp was from lower altitude.

An abrupt change in vegetation occurred about c. 16,500 years BP, when *Engelhardia*, *Symingtonia*, and *Altingia* became common, and *Dacrycarpus imbricatus* substantially declined. The lower montane forest dominated by *Quercus* remained as important as before c. 16,500 years BP. A subsequent further sharp decline in *Dacrycarpus imbricatus* and a substantial increase in *Eugenia* after 12,000 years BP indicate a rise of mean temperature. All taxa found in this study require humid conditions, indicating the persistence of high rainfall on the Toba Plateau.

Tao Sipinggan is a small lake, located at a distance of 2 km from the Pea Sim Sim swamp. The lake probably formed within an extinct crater and

lies at an altitude of 1445 m ASL. A 9-m long core was analysed for pollen analysis, and the basal date was 12,000 years BP (Maloney 1981).

Around 12,000 years BP, the Tao Sipinggan highland was covered by Gymnospermae, *Symingtonia, Engelhardia, Altingia, Lithocarpus/Castanopsis*, and *Quercus*. In the Holocene the forest composition remained stable, but with substantially higher values of *Eugenia* and reduced values of Gymnospermae. The change from the Pleistocene to the Holocene indicates climatic amelioration, but the magnitude of the rise in mean temperature could not be inferred. All taxa found in this pollen study show that the environment has remained wet, confirming that effective precipitation was high on the Toba plateau throughout the last 12,000 years.

3.3.2. Danau di Atas

Danau di Atas is also located in the Central Highlands of Sumatra, at latitude 1°04'S, longitude 100°46'E, and altitude 1,535 m ASL. The lake appears to be of tectonic origin, and about 40 m deep (Newsome and Flenley 1988).

The history of vegetation and climate change from Danau di Atas is reviewed from a palynological study of a 16.5 m long sediment core, with the basal radiocarbon date suggesting that the record extends back to c. 30,000 years BP (Newsome and Flenley 1988). This pollen record is comparable with the pollen study from Pea Bullock (Maloney 1980; Maloney and McCormac 1995).

From c. 30,000 to 14,000 years BP, *Dacrycarpus imbricatus* and *Dacrydium* were extremely common in this region. *D. Imbricatus* occurs

predominantly between 800-2,500 m ASL, and sometimes forms pure stands (Sunarno 1995), and *Dacrydium* is largely confined to altitudes between 600 and 2,500 m ASL, but can be also be found at sea level (Ong 1995). Other major taxa found during this period were *Quercus, Lithocarpus/Castanopsis, Myrsine, Vaccinium, Symingtonia populnea,* and Myrtaceae.

The high values of these montane taxa at Danau di Atas was interpreted as an indication of reduced mean annual temperature relative to present of between c. 1.6° and c. 5.2°C, and a lowering of the vegetation belts between 260 m and 860 m (Newsome and Flenley 1988). After c. 12,000 years BP *Dacrycarpus imbricatus* and *Dacrydium* strongly declined, and almost disappeared in the mid Holocene. *Quercus, Castanopsis/Lithocarpus, Engelhardia,* and *Altingia* appear to have replaced the upper montane forest taxa. The decline of *D. imbricatus* must indicate climatic amelioration in the Holocene, and all taxa found in this pollen record indicate that the environment in the Central Highlands of Sumatra has not experienced drier climate conditions than today over the recorded period.

3.3.3. Danau Padang

Danau Padang is a small-drowned valley, located in the southern part of the Kerinci valley in central Sumatra, at an altitude of 950 m ASL. The lake is surrounded by small hills of the Barisan Range. The present vegetation of Danau Padang consists of herbaceous swamp, *Pteridium* swamp, *Euodia* forest, *Myrsine* forest, and *Ilex cymosa* forest. Rice paddy cultivation occurs on the margins of the site. A pollen study from Danau Padang is derived from Morley (1980, 1982a).

Prior to c. 10,000 years BP, upper montane forest taxa, such as *Podocarpus imbricatus, Symingtonia populnea*, and *Engelhardia*, were prevalent at Danau Padang, while the lowland areas were probably occupied largely by Fagaceae forest taxa, such as *Quercus* and *Lithocarpus/Castanopsis*. The persistent presence of *Podocarpus imbricatus* might indicate temperatures at least 2° C cooler than today, resulting from the depression of vegetation belts up to 350 m. Although the climate was possibly cooler during the last glacial, all pollen taxa found in this study do not show that the climate was more seasonal or drier than today. The steady values of fern spores in this pollen record also indicate a humid environment.

After c. 8,600 years BP, *Podocarpus imbricatus, Engelhardia*, and *Symingtonia populnea* sharply declined, and the oak forest became dominant. These upper montane taxa were replaced by *Altingia, Quercus*, and *Lithocarpus/Castanopsis* during the Holocene, and indicate warmer and wet climatic conditions. The swamp forests were dominated by *Elaeocarpus, Eugenia, Myrsine*, and *Ilex cymosa*.

3.4. A pollen study from Sebangau Peatland

The Sebangau peatland is located in central Kalimantan, about 200 km north of the Java Sea. The Sebangau catchment covers about 5,000 km^2 and largely comprises peatlands, with an average altitude of 30 m ASL (Page *et al.* 1999). The vegetation occurring in this peatland was briefly discussed in section 2.7.4.

The pollen study of a 10-m sediment core from this peatland is still in progress (Asha Thamotherampillai, personal comm. 1999). The radiocarbon

dates for this core provide a basal date of 18,300 years BP at about 9.5 m depth. A more general history of the peatland is provided by the undated pollen records of Morley (1981b).

It was previously thought that the majority of peatlands in the Malayan region were formed during the mid Holocene. Morley (1981b) believed that the lowland Sebangau peatland was formed around 5,000 – 6,000 years ago, and initially developed from Poaceae and *Lycopodium cernuum* swamp. In contrast, Asha Thamotherampillai's study shows that this peatland has existed since the Late Pleistocene.

From c. 18,000 to 10,000 years BP the Sebangau peatland was largely forested, with the main constituents being common peat swamp forest taxa such as *Calophyllum, Combretocarpus rotundatus, Campnosperma, Ilex, Garcinia, Palaquium, Mallotus, Lophopetalum multinervum,* and Meliaceae. Substantial values of Poaceae were restricted to basal samples, probably the height of the Last Glacial Maximum. These high values of Poaceae suggest a moderately lower moisture availability rather than cooler conditions. Further radiocarbon dates are needed to determine the time of disappearance of Poaceae.

From c. 10,000 to c. 1,500 years BP, tree composition of the Sebangau peatland forest showed substantial changes. *Calophyllum* abruptly declined around 10,000 years BP, but suddenly increased again after c. 1,500 years BP. *Palaquium* initially declined in the early Holocene, but then expanded in the mid Holocene. *Dacrydium* also showed a sudden increase in the mid Holocene. *Campnosperma* and *Ilex* showed several peaks within the Holocene but then

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sharply declined after c. 1,500 years BP. *Combretocarpus rotundatus* showed a slight increase through the record, while *Lithocarpus* values remained constant throughout the record. Local factors rather than global climate change probably influenced the vegetation dynamics over the Sebangau peatland during the Holocene.

Unfortunately, this dated pollen record does not show the presence of montane forest taxa. By contrast, Morley (1981b) recorded montane forest taxa such as *Podocarpus imbricatus*, and *Dacrycarpus imbricatus* in the Poaceae phase. He claimed that these montane forest taxa did not occur in the Sebangau basin, but were transported from the Muller Mountain, some 300 km to the north. His thinking, though, was very much influenced by a belief that the peatland was Holocene in age and the establishment of a Last Glacial Maximum age for the base of the sequence substantially changes the situation. It is likely that these montane forest taxa and Poaceae probably indicate that the lowland Sebangau river basin experienced both cooler temperatures and substantially drier conditions during the last glacial period.

3.5. A pollen study from Nee Soon Swamp, Singapore

The small Nee Soon swamp is located in northeastern Singapore (1°24'N, 103°48'E) at an altitude of 10 m ASL. A pollen study from this swamp is described in Oh *et al.* (1999).

This freshwater swamp forest has existed since the late last glacial period. Oh *et al.* (1999) analysed a 110 cm long sediment core (NS6b/2), and a 160 cm long sediment core (NS8b/2). Unfortunately, both cores are not yet well dated. The only AMS radiocarbon date on core NS6b/2 gives a result of

11,800 ± 50 years BP at about 71-75 cm depth, while the only AMS radiocarbon date on core NS8b/2 is 8,650 ± 60 years BP at 160-162 cm depth. These preliminary radiocarbon dates confirm that lowland freshwater swamps in the Malayan region have been present since the late last glacial period.

Prior to c. 12,000 years BP, according to the pollen diagram from Core NS6b/2, the forest in the Nee Soon swamp appears to have been open in character. Common swamp taxa were Myrtaceae, Podocarpaceae, Sapotaceae, *Castanopsis/Lithocarpus*, and *Ficus*. In the Holocene, Sapotaceae, *Pometia*, *Oncosperma*, *Campnosperma*, and Araceae increased, while Podocarpaceae substantially decreased. At present, Podocarpaceae occurs locally scattered in the Nee Soon swamp. The abundance of Podocarpaceae before c. 12,000 years BP, and its decline in the Holocene might indicate that the last glacial climate in the Nee Soon swamp was somewhat cooler than present.

During this glacial period, Poaceae was abundant, and ferns spores, including Cyatheaceae, were relatively common throughout the record. A similar Poaceae problem to the Sebangau peatland is encountered here. Probably, prior to c. 12,000 years BP, the Nee Soon freshwater swamp was not extensive, and the grasses flourished in favourable sites within dryland or aquatic environments. It appears that mean annual rainfall was reduced, and resulted in a seasonal climate, but there was still sufficient water to maintain swampy areas at Nee Soon. After the sea levels rose in the Holocene, Nee Soon was largely infilled with peat from the freshwater swamp forest, and Poaceae sharply declined as the climate became more humid.

In core NS8b/2, Poaceae shows high values around c. 9,000 years BP and these sharply declined in the mid Holocene. Major taxa found in this core are similar to those in the other core.

3.6. General comparisons

It is widely postulated that, during the last glacial period, the climate over Sundaland was cooler and more seasonal, resulting from the impacts of Pleistocene low sea level episodes that substantially changed the ratio between landmass and sea (Verstappen 1975; 1980). However, the magnitude of Late Quaternary climatic change over this region is difficult to define. To my knowledge, the estimates of temperature reduction during the last glacial period are still speculative, ranging from $1.5°$ to $7°C$, and pollen studies do not provide strong evidence that the Late Quaternary climate was seasonal all over Sundaland. Some parts of west Java, central Kalimantan, and Nee Soon swamp in Singapore might have experienced more seasonal and drier climates. Overall, effective annual precipitation levels during the last glacial still allowed the maintenance of closed rainforests in Situ Bayongbong, the Bandung Plain, the Central Highlands of Sumatra, and northern Sumatra. Verstappen (1975, 1980, 1994) believed that precipitation during the Pleistocene glacial episodes was reduced between 30% and 50%. This is not impossible. Since the present mean annual precipitation over most parts of Sunda Shelf is very high, 3,000 – 5,000 mm on average, a 50% rainfall reduction in the last glacial may not have caused the elimination of forest over much of Sundaland.

By contrast to precipitation, the reduction in temperature during the last glacial period appears to have been very influential. A cooler environment over

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Sundaland led to montane forest taxa, such as *Podocarpus, Dacrycarpus, Quercus, Lithocarpus,* and Ericaceae, descending to lower altitudes. When the climate became warmer in the Holocene, these montane taxa, particularly *Dacrycarpus* seem to have disappeared from lowland areas, while a few *Podocarpus* are left scattered in the lowland forests, and most *Podocarpus* occurs in mixed Fagaceous and conifer forests from lower to upper montane belts (Nasution 1995).

This review suggests that Late Quaternary climatic change resulted in limited change in forest cover over Sundaland, but that the floristic composition of the forests has been very dynamic.

3.7. Prehistory of human impact on forest from pollen analysis

Pollen and charcoal analyses also provide proxy data of past human impact on forest. This can be indicated by massive declines in, or the absence of, certain forest taxa, the appearance of undergrowth and pioneer taxa such as *Pandanus, Nepenthes, Macaranga, Trema,* and *Melastoma,* and planted taxa, such as *Ipomoea, Cocos nucifera, Arenga* and *Durio,* fern spores such as *Stenochlaena palustris* and *Lycopodium,* and weedy taxa associated with agriculture, forest clearance, and fires (Flenley 1985; Maloney 1994; van der Kaars *et al.* in press).

The history of forest disturbance over Sundaland may be as long as the history of human occupation in this region. The earliest appearance of *Homo erectus* in Java is thought to be after c. 1.3 million to 1.7 m years ago (Bellwood 1997), while *Homo sapiens* has been present in Java since c. 100, 000 years ago (Flood 1999). Modern people *(Homo sapiens)* were present in

Niah Caves, northwest Borneo, about c. 41,500 to 39,600 years BP (Harrison 1967, 1970, 1971).

The method of radiocarbon dating is limited. Samples over 40,000 years old are difficult to date because of the low quantity of ^{14}C in those samples (Flood 1995; Lowe and Walker 1997). Ever-wet climates in Sundaland lead to rapid decomposition and erosion rates that rework the geological sediments. All of these conditions may influence the precision of radiocarbon dates.

It is widely accepted that humans arrived in Australia around 50–60,000 years (Flood 1999). These people must have crossed narrow sea gaps, about 70 to 90 km wide, which isolated Asia from Australia during the late Pleistocene (Flood 1995; Hodrrige 1995). Since these people came from South East Asia and could have substantially changed Australia's landscape and vegetation (Kershaw 1985; 1994), their environmental impacts on Sundaland might have also been significant.

Humans could have constantly disturbed the forests for several reasons. Hunter and gatherer communities could have opened up the forest to facilitate wildlife hunting and the collection of wild foods. Subsequently, forest soils would have been used for the practice of shifting agriculture that requires nutrient inputs from biomass burning. Timber and non-timber forest products such as roots, resins and rattan would have been extracted to fulfil various human needs for houses, tools, and crafts. To disturb the forest, fire is a primitive tool that humans have forever probably widely used.

Pollen records suggest that forest clearance over Sundaland was relatively recent. Probably, small-scale forest disturbance occurred after c. 10,000 years BP in Situ Bayongbong, West Java, when there was a large decline in *Engelhardia*. In general, large-scale forest disturbances in this region were considered to appear from 5,000 to 3,000 years BP, as indicated by substantial increases in regrowth taxa such as Poaceae and Cyperaceae (Stuijts 1993). The Danau Padang pollen record reveals that major forest clearance could have occurred around the same time as that at Situ Bayongbong, around c. 4,000 years BP. This record shows that high values for *Trema*, Poaceae, Cyperaceae, *Nepenthes*, *Arenga*, and *Stenochaelena palustris* were confined to the mid and late Holocene (Morley 1982a). From Pea Sim Sim, North Sumatra, Maloney (1980) suggested that early forest clearance tentatively took place around c. 17,500 years BP, and strong evidence of substantial forest clearance appeared in the pollen record from Pea Sim Sim after c. 7,500 years BP. The closed fagaceous forests suddenly opened up at this time, and regrowth taxa, such as *Macaranga*, *Trema*, and herbs became very common. The Tao Sipinggan record indicates that substantial forest clearance on the Toba Plateau occurred around c. 2,000 to 4,000 years BP, as indicated by higher values for *Trema* and Poaceae and low values for tree pollen of closed forest taxa (Maloney 1981). An undated, 75 cm long pollen record from Pea Sijajap, North Sumatra, also demonstrates that this region was substantially deforested and regrowth taxa such as Poaceae and *Trema* became common. Newsome and Flenley (1988) suggest that massive deforestation at Danau di Atas and Telago

swamps, central highlands of Sumatra, took place after c. 1,800 years BP as indicated by high values for *Macaranga* pollen grains.

Early anthropogenic disturbance at Rawa Danau swamp forests might have occurred in the mid Holocene, when values for *Macaranga* pollen grains substantially increased in abundance while values for *Carallia* decreased. Greater human impact on this site appears to be confined to the last few hundred years. Poaceae and Cyperaceae increased substantially, and *Arenga, Cocos nucifera,* and *Durio* suddenly appeared in this pollen record around c. 400 years BP (van der Kaars *et al.* in press).

Although pollen records from Sebangau do not provide strong evidence of forest clearance in lowland areas of Borneo, at least in peatlands, substantial human influence on Borneo's rainforests could have occurred since the late glacial. Both pollen records from Sebangau peatland suggest that forest disturbance in Borneo during the last glacial was probably irregular. The abundance of Poaceae values in the basal record of Setia Alam core (Asha Thamotherampillai pers.comm. 1999), and higher values for Poaceae, *Lycopodium cernuum,* and *Pandanus* in the pollen record from core PR-2 (Morley 1981b) may have been associated with small-scale anthropogenic forest disturbance in Central Kalimantan. The persistent decline of certain types of tree taxa such as *Ilex, Campnosperma, Gonystylus bancanus, Garcinia cuspidate,* and *Dacrydium* from Setia Alam and Morley's pollen records may also indicate human activities.

Overall, pollen records suggest that regional and large-scale deforestation associated with anthropogenic influence in Sundaland might have

been significant since 4,000 to 5,000 years BP (Flenley 1985). This inference is concluded from pollen records from high altitudes rather than lowland areas, because the majority of pollen studies in this region have been undertaken in the highlands.

3.8. Evidence of prehistoric forest fires

Paleoecological records provide proxy data of past fires and can be used as evidence of the behaviour of climatic variability, forest fires and vegetation change. Fire occurs as a result of the complex interaction between vegetation, climate and human activity (Clark *et al.* 1997). A drier and seasonal climate is likely to induce natural fires, and these fires would be more intense and frequent as human activities increase and as climate becomes more variable, while climatic stability may be associated with records of low fire activity (Haberle *et al.* 1999).

The charcoal record from Rawa Danau shows that forest fires were prominent from *c.* 15,000 to 10,000 years BP, low in the mid Holocene, and then high from *c.* 1,700 years BP to the present day. Fires at Rawa Danau during the Last Glacial Maximum may have been natural and associated with a drier and seasonal climate, while anthropogenic fires could have been more prominent in the late Holocene as charcoal is associated with the appearance of cultivated crop taxa and open vegetation. A recent analysis of fire records from several sites in New Guinea shows a similar pattern and that frequent and intense fires are strongly correlated with periods of climate variability (Haberle *et al.* 1999). They demonstrate that there were repeated fires in Indonesia and New Guinea during the last glacial/Holocene transition (17,000 to 9,000 years

BP) and in the mid to late Holocene (5,000 years BP to present). Gradual increases in temperatures and possibly an unstable Southern Hemisphere Summer Monsoon during the last glacial transition played an important role in generating forest fires, while ENSO episodes associated with severe droughts promoted widespread fires over Indonesia and Australia within the last 5,000 years.

In Australia, the impacts of biomass burning, particularly by Aboriginal people, on the evolution of Australian vegetation have been widely debated over the last 20 years (Kershaw *et al.* in press). The major notion derived from the history of fire in Australia is that biomass burning is strongly associated with variable climatic conditions, of which ENSO is likely to have been a major cause. In the later part of the Quaternary, forest fires substantially increased under conditions of more seasonal and drier climates (Kershaw *et al.* in press) in line with the evidence of Haberle *et al.* (1999). Under relatively stable climatic conditions, forest fires appear to have been primarily related to anthropogenic activities.

Chapter 4: Study Area

4.1. Lake Sentarum Wildlife Reserve

Lake Sentarum Wildlife Reserve consists of a series of open, shallow and seasonal lakes, located in the upper Kapuas basin, about 700 km inland from the estuary of the Kapuas River (Figure 4.1). The lakes lie at approximately latitude 00°44'N, and longitude 112°06'E, and have varying altitudes between 25 and 50 m ASL. The reserve was designated as the second Ramsar Convention site in Indonesia on August 3, 1994 (Frazier 1999). In addition to its conservation significance, the reserve functions as a natural reservoir that regulates water levels of the Kapuas River (Mollengraff 1900). During the wet season at least 25% of the Kapuas water overflows into the lakes, while in the dry season about 50% of lake water discharges into the Kapuas River (Klepper *et al.* 1996). The Lake Sentarum Wildlife Reserve is the only remaining natural lake ecosystem reserve in Kalimantan, because other Kalimantan lakes such as the Sungai Negara lakes in south Kalimantan, and the Mahakam lakes in Central Kalimantan have been heavily disturbed, deforested, and enriched by nutrient release associated with human activities (Klepper *et al.* 1996). This reserve is probably the only major representative of freshwater swamp forest habitat in the Greater Sunda Islands (www.wetlands.agro.nl, 2000).

The lakes in the reserve are very rich in fish. At least 300 freshwater fish species, such as *Scleropages formosus, Ophicephalus micropeltes,*

Wallago miostoma, Leptobarbus hoeveni, Notopterus chitala, Myrtus nigriceps, and *Botia macrantha,* are recorded (Giesen 1987). Fish in the lakes play a very important role in the local economy. About 60% of freshwater fish traded in West Kalimantan come from the lake region. In the past, the reserve was an important habitat for waterfowl (Giesen 1987). About 200 species of birds have been recorded in the reserve.

Forests in the reserve are also very diverse, unique, and are natural habitats for wild bees which produce large quantities of honey, hundreds of bird species and other wildlife such as *Pelargopsis capensis* (stork-billed kingfisher), Anhinga *melanogaster* (Oriental darter), Ardea *purpurea* (purple heron), Ardeola *bacchus* (Chinese pondheron), *Heliastur indus* (Brahminy kite), *Sterna albifrons* (little tern), *Ketupa ketupa* (buffy fish-owl), *Anthracoceros coronatus* (the pied hornbill), *Nasalis lavartus* (proboscis monkey), *Neofelis nebulosa* (clouded leopard), *Pongo pygmeus* (orang utan), *Manis javanica* (pangolin), *Helarctos malayanus* (sun bear), *Chitra indica* (turtle), *Varanus borneensis* (water monitor), *Tomistoma schlegeli* (false gavial), and *Crocodylus porosus* (saltwater crocodile).

The size of the reserve was initially 80,000 ha. It was then expanded to 130,000 ha in 1995 in order to include some dryland habitats. About 21,700 ha of the reserve is taken up by seasonal and shallow lakes. The rest consists mainly of inundated swamp forests, riparian forest, inundated and non-inundated peat swamp forest, lowland dipterocarp forest, and heath forest (Giesen 1996).

Table 4.1. Dimensions of selected lakes in the Lake Sentarum Wildlife Reserve

Lake (Danau)	Size (ha)	Approximate average depth (m)
Luar	5,208	7
Bekuan	1,268	5.5
Genali	2,000	5
Sentarum	2,324	7
Tekenang	1,564	6
Pengembung	1,548	7

Source: Giesen (1987; 1996) and MacKinnon *et al.* (1996)

The size of individual lakes is small, ranging from < 100 ha to 5,200 ha, and the average depth of these lakes is shallow, between 2 and 7 m (Giesen 1987; 1996; MacKinnon 1996). Table 4.1 lists selected lakes occurring in the Lake Sentarum Wildlife Reserve.

4.2. Climate, hydrology and geology

The present climate in the Lake Sentarum Wildlife Reserve is equatorial and extremely wet, without clear distinction between dry and wet seasons. The average monthly rainfall is about 300 mm (Giesen 1996), with an annual rainfall about 3,600 mm (www.wetlands.agro.nl, 2000). The rainfall pattern in the upper Kapuas basin has been illustrated in chapter 2. The temperature averages 33°C during the day and 22°C at night. Water temperatures range between 27 and 30°C, and can be up to 35°C in shallow pools (Giesen 1987). The humidity is very high, between 70 and 90%.

Source: Modified from Salyadi and Permadi, 1995
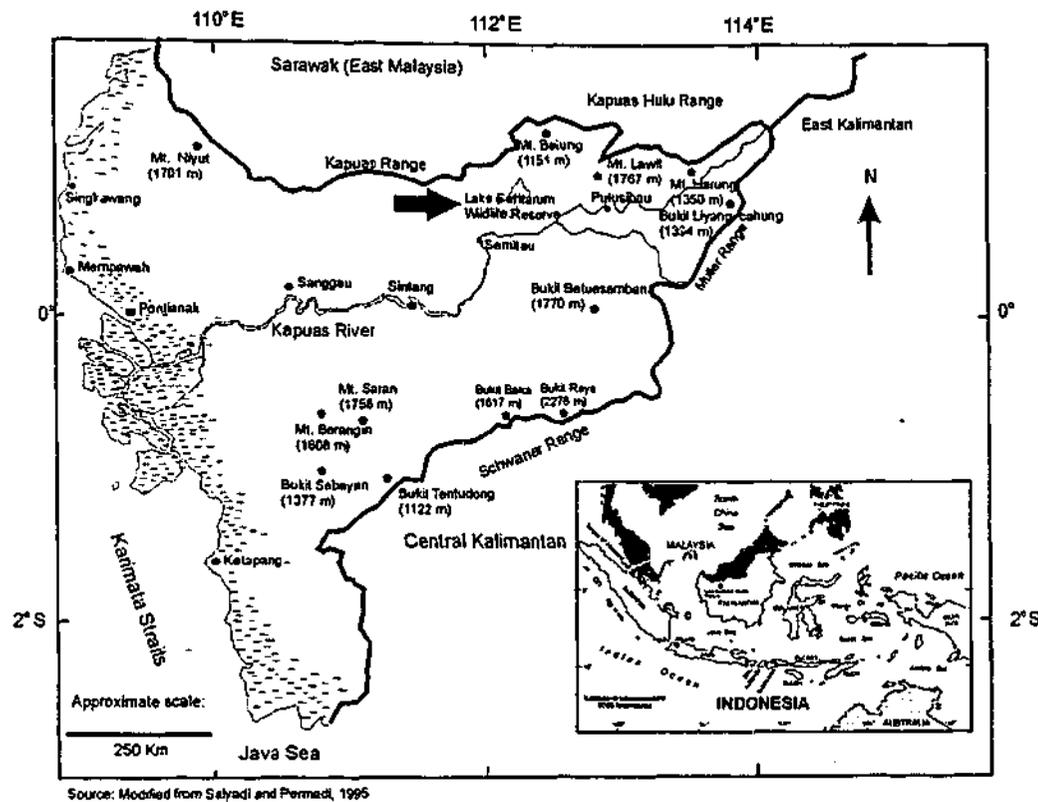
Figure 4.1. Map of West Kalimantan, showing Lake Sentarum Wildlife Reserve

Although the average water depth of these lakes is between 2 and 7 m (Giesen 1987; 1996), the water levels at the lakes can fluctuate up to 12 m (Giesen 1996). The water levels of the lakes depend mainly on the amount of rainfall in the upper Kapuas basin. During strong El Niño years, most lakes including Danau Luar, Danau Bekuan, Danau Genali, and Danau Pengembung dry, however, large rivers such as the Tawang, Sumpa, Tengkidap and Leboyan retain water. Danau Sentarum may not totally dry since it is directly connected to the Tawang river. Giesen (1987) suggests that if the monthly rainfall in the upper Kapuas basin is less than 300 mm for three consecutive months, the water levels at the lakes gradually decline. Depending on the length and

severity of dry spells, the majority of the lakes in Danau Sentarum region can dry for between 1 and 5 months.

When the lakes disappear, the beds of the lakes are invaded by seasonal grasses and sedges. There is also a network of small, winding streams with very shallow water on the lake beds. At a glance, these small streams look like a drainage canal system. It is questionable whether these streams are natural or human made. Tree stumps and peat bands have been occasionally seen in these canals, suggesting extensive widespread peat swamp forests in the past (See Plates 4.1 and 4.2). Further, these small streams and sometimes small pools, with less than 20 cm of water, are important refuge habitats for fish, turtles, and tortoises (Giesen 1996).

The lake water contains high concentrations of humic acids from the organic matter of peat (pH 4 - 5.5). The colour of the lake waters is almost black, while the colour of the Kapuas water is much lighter. Overall, the lake water is poor in nutrients or oligotrophic (Giesen 1987), but very high in suspended solids as result of present day erosion. Further, the lake water is presently polluted by domestic wastes, pesticides, cyanide and oils (Giesen 1996) and enriched by phosphates from detergents. In contrast, Beccari (1904) noted that the lake water of Danau Seriang in May 1867 was very dark and looked like tea in colour, but very clear, suggesting insignificant erosion and pollution in the upper Kapuas basin over 100 years ago.

Although Molengraaff (1900) speculated that the Lake Sentarum region was formed at least by the Jurassic, current geological data suggest that the

formation of the lakes was probably much more recent. The sediments in the Lake Sentarum region are thought to be Pleistocene to Holocene, resulting mainly from fluviatile and lacustrine sedimentation (RePPProt 1990). Apart from granite intrusives found in Pulau Melayu near the village of Lanjak at Danau Luar and the hills surrounding the lakes, the major sediments are Pleistocene and Holocene sandstones, clays, and peats (Giesen 1987). The beds of the lakes mainly comprise fine grey or yellowish sandy clay that is infertile since it comes from the decomposition of quartz, serpentines, and silicates (Molengraaff 1900).

4.3. Lake Pemerak

Lake Pemerak is a small lake (< 100 ha), with an average depth of 7 m, located a few hundred metres east from the village of Nanga Pemerak (Figure 4.2). Large lakes such as Sentarum, Pengembung, Genali, Sumpa, and Luar are situated to the northeast of Lake Pemerak. These large lakes connect with each other through large rivers within the reserve, and form extensive open water areas. By contrast, Lake Pemerak appears to be isolated from these large lakes. The major sources of water to Lake Pemerak are largely from rainfall, and the Tawang River that functions as a major inlet and outlet channel for the all lakes in the Lake Sentarum Wildlife Reserve.

The lake is "Y" shaped, with one small arm pointing southwest, and the other longer arm directed to the southeast, and its big tail pointing north and ending near the village of Nanga Pemerak. Another slim arm pointing southeast occurs at the end of the tail.

The bed of Lake Pemerak consists of sandy clay, and peat. During the severe dry season of 1997, this bed was largely dry, and had become a temporary savanna ecosystem. The clay surface was cracked, indicating water deficit conditions. Seasonal Poaceae and Cyperaceae grew on this bed, and a substantial number of stunted, arboreal plants dominated by *Barringtonia acutangula*, which are normally submerged during inundated periods, appeared like living sticks in an open savanna. These trees were sparsely distributed along the marginal slopes of the lake basin.

Small streams or channels meandered across the lake bed. The banks of the stream channels revealed predominantly sandy-clay sediment. A few tree stumps were seen in these channels, and, with the presence of some peat, suggested that a peat swamp forest may have existed in the lake basin in the past.

These channels form the drainage network when the lake is dry. At the beginning of the dry season, when the water level in the lakes has dropped substantially, these channels are the only places for several types of fish, such as catfish, to survive. Consequently, these fish are easy to collect. Water remaining in these channels, even during a very dry season, functions as a natural refuge for fish. When no rain falls during seasonal droughts, surrounding peat swamp forests appear to act as the main source of moisture and water for these small streams.
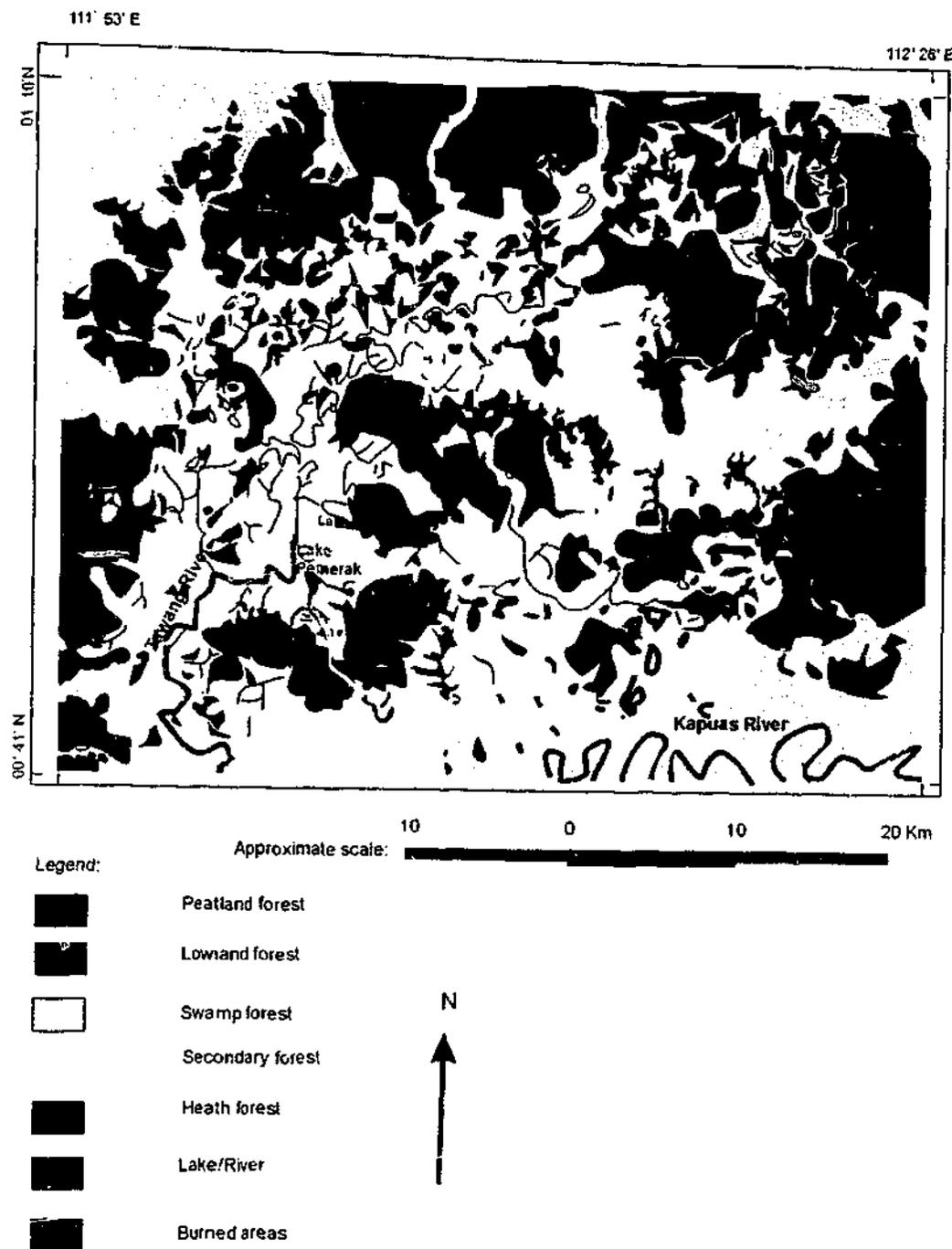
Figure 4.2 Map of lake Sentarun, showing selected vegetation types around the reserve

Source: Courtesy of Rona Dennis, based on Landst MSS (1973, Radar (1983),Landsat TM
(1990), Air photos (1994), and ground truthing (1994-1996).
All are unpublished sources. This map was redrawn by permission of Rona Dennis.

Peat swamp forest is locally called Hutan Nung, a common customary forest belonging to the Malay people of various villages, such as Nanga Pemerak, Sumpa, Pengembung, and Sekulat. About ten years ago some parts of this forest were commercially logged, but at present only locals have a right to log this forest for their own use. This rule has been established and is well maintained. Therefore, within the reserve boundary, Hutan Nung is currently regenerating and well maintained, while other swamp forest communities occurring close to the reserve margin have been extensively deforested. The majority of the present vegetation found in Hutan Nung belongs to the tall peat swamp forest as described in section 4.4.1.

4.4. Present vegetation in the Lake Sentarum Wildlife Reserve

A number endemic plant species occur within the reserve. These include *Caesaria* spp, *Croton* cf. *ensifolius, Dichilanthe borneensis, Eugeissona ambigua, Helicia* cf. *petiolaris, Korthalsella* cf. *germinans, Microcos* cf. *stylocarpus, Rhodoleia* spp, *Ternstroemia* cf. *toguian,* and *Vatica* cf. *umbronata* (Giesen 1996). Further taxonomic study is needed to find and identify other potential endemic plant species in the reserve.

Major vegetation types occurring in the Lake Sentarum Wildlife Reserve are swamp forests, which may form peat and are adapted to the seasonal fluctuations of water levels at the lakes. The seasonally and permanently inundated swamp forests within the reserve are estimated to cover more than 50,000 ha (Giesen 1996). Other vegetation types found in the reserve are riparian forest, lowland dipterocarp forests, and heath and kerapah forest.

Giesen (1987, 1996) divides swamp forests in the Lake Sentarum Wildlife Reserve into three major categories, based on the length of inundation periods, the species composition, and the substrate. They are the tall swamp forest (hutan pepah), the stunted swamp forest (hutan rawa or gelgah), and the dwarf swamp forest (rampak gelgah). The major character of the tall peat swamp forests is that they are less flooded than other two inundated swamp forests.

4.4.1. Tall peat swamp forest

The inundation period is about 2-3 months, with a water depth of between 1 and 2.5 m in the tall peat swamp forest. Major taxa commonly found in this habitat are *Dryobalanops abnormis* (kelansau), *Hopea mengerawan* (emang), *Tristaniopsis obovata* (melaban), *Gonystylus bancanus* (ramin) and *Calophyllum sclerophyllum* (mentangur kunyit). Other common taxa in the tall swamp forests are *Dichilanthe borneensis, Gluta pubescens, G. wallichii, Ilex cymosa, Shorea balangeran, Teysmanniodendron sarawakanum, Vatica ressak, Garcinia rostrata,* and *Syzygium durifolium.*

The canopy of the tall swamp forest ranges from 25 to 35 m. The tall peat swamp forest within the reserve, particularly in a small customary forest of Hutan Nung, is relatively undisturbed since no commercial logging is allowed. Hutan Nung is located south of Danau Pemerak, northwest of Danau Sumbuk, west of Danau Seliban, and southwest of Danau Pengembung. The size of this customary forest is estimated to be between 5,000 and 8,000 ha.

4.4.2. Stunted and dwarf swamp forest

The stunted swamp forest is located near the lakeshores, with an inundation period of 4 to 8 months, and average water depth of 3.5 m. The canopy of the stunted swamp forest is substantially lower, between 8 and 25 metres. Similar to the tall swamp forests, several vegetation associations can be dominant in this habitat. Kenarin-Menungau-Kamsia is a common association, consisting of *Diospyros coriaceae* (Kenarin), *Vatica menungau* (menungau), and *Mesua hexapetalum* (Mesua), while an assemblage of Kawi-Kamsia incorporates *Shorea balangeran* (kawi) and *Mesua hexapetalum* (Mesua). Other common taxa in the stunted swamp forests are *Cleistanthus sumatranus* (kertik), *Crudia teysmannii* (timba tawang), *Fordia splendissima* (limau antu), *Garcinia bancana* (sikup), *Homalium caryophyllaceum* (pekeras), *Ilex cymosa* (kayu telor), *Microcos cf. stylocarpa* (tengkurung asam), and *Xanthophyllum affine* (merbemban). The dwarf swamp forest is very low, just around 5-8 metres tall, and is located at the lakes. As the average water depth is about 5.5 m, and lasts for 11 months. The vegetation in this habitat is mainly submerged. Common taxa in this habitat are *Barringtonia acutangula* (putat), *Carallia bracteata* (kayu tahun), *Croton cf. ensifolius* (melayak), *Garcinia borneensis* (empanak), *Gardenia tentaculata* (landak), *Ixora mentangis* (mentangis), *Pternandra teysmanniana* (gelagah), *Memecylon edule* (kebesi), *Syzygium claviflora* (masung), and *Timonius salicifolius* (kerminit).

4.4.3. Riparian forest

Riparian forest in the Lake Sentarum Wildlife Reserve commonly occurs on levees of large rivers. This environment is regularly inundated with an average of 2 m of water (Giesen 1987), for 6 months. Major taxa found in this habitat are *Gluta renghas, Baccaurea bracteata, Coccoceras sumatrana, Eugenia* spp, *Diospyros coriaceae, Homalium caryophyllaceum, Vatica menungau, Mesua hexapetalum, Antidesma stipulare, Artocarpus teysmannii, Ficus microcarpa, Dillenia excelsa, Hopea dasyrrhachis, Lagerstroemia speciosa, Mallotus sumatranus,* and *Pternandra galeata.* The undergrowth consists of Poaceae, sedges, and ferns. Rattan is sometimes abundant. This habitat is heavily disturbed, particularly by shifting cultivation for rice paddy (Giesen 1987; 1996). Table 4.2 describes major characteristics of inundated vegetation types in the Lake Sentarum Wildlife Reserve.

Table 4.2. Major characteristics of inundated vegetation types in the Lake Sentarum Wildlife Reserve

Vegetation type	Inundation period (month)	Average water depth (m)	Soil type	Average canopy height (m)	Major taxa
Tall peat swamp forest	2-3	0.5-4	peat	15-30	*Dryobalanops, Hopea, Tristaniopsis, Gonystylus, Sapium, Shorea, Crudia, and Calophyllum*
Dwarf swamp forest	9-11	5-6	clay	5-8	*Barringtonia, Randia, and Timonius*
Stunted swamp forest	5-7	1.5-4	clay	8-22	*Diospyros, Vatica, Mesua Garcinia, Grewia, Homalium, Mallotus, Tristania, Coccoceras, and Shorea*
Riparian forest	5-6	2-6	clay	15-20	*Gluta, Diospyros, Vatica, Mesua, Elaeocarpus, Dillenia, Eugenia, and Baccaurea*

Source: Modified from Giesen (1987; 1996)

4.4.4. Other vegetation types

The dryland forests have a patchy distribution on the hills of Semujan (370 m), Pegah (150 m) and Menyukung (630 m), located in the southeastern part of the lake region. Lowland dipterocarp forests are found on the slopes, where soils are moist, fertile and less sandy. The major top canopy species ($\leq$ 45 m) are *Anisoptera grossivenia, Dipterocarpus gracilis, Shorea leprosula,* and *S. seminis.*

Heath (kerangas) occurs on sandy soils on the top of the Semujan and Menyukung hills (Giesen 1996). Pole-like trees of this heath forest are stunted, between 20-26 m tall, and have an open canopy. Major taxa are *Baeckia frutescens, Koompasia malaccensis, Lithocarpus* spp, *Shorea laevis, Shorea seminis, Syzygium* spp, *Tristaniopsis obovata,* and *Vatica cinera.* The undergrowth is composed of *Lycopodium cernuum,* and a few pitcher plant species such as *Nepenthes ampullaria* and *N. mirabilis,* are present.

Kerapah, a water logged heath forest, occurs extensively along the northern boundary of the reserve. As with heath forest, most trees of the kerapah are generally stunted and pole-like, although some other trees are relatively large and tall. Major taxa found in this forest are *Aporusa* spp, *Calophyllum* spp, *Gonystylus* spp, *Eugenia* spp, *Pellacalyx* spp, *Sapium* spp, *Shorea* spp, and *Vatica* spp. The undergrowth is largely composed of *Pandanus* spp and Cyperaceae since locals and timber companies, operating outside the reserve boundaries, heavily log this forest.

Another disturbed association within the Lake Sentarum wildlife reserve is ladang for rice cultivation, either on levees of the riparian forest or dryland on the hills. Taxa commonly growing in this secondary vegetation are *Macaranga* spp, *Trema* spp, and *Rhodomyrtus tomentosa. Lycopodium* spp, *Pteridium* spp, Poaceae and Cyperaceae dominate the undergrowth. Floating vegetation mats are common both within the lakes of the reserve and on several ox-bow lakes near the Kapuas river. Major herbs found on these mats belong to the Poaceae and include *Digitaria* spp, *Echinochloa colonum, Leersia hexandra, Leptochloa chinensis, Panicum conjugatum, P. repens* and *Saccharum spontaneum*. Ferns and sedges are also common on these mats, but aquatic herbs are very rare. The waterhyacinth, *Eichornia crassipes,* is mainly restricted to the Kapuas River and near villages in the reserve (Giesen 1996). When collecting plant specimens in May 1867, Beccari (1904) did not report seeing any floating aquatic plants. Table 4.3 summarises the main characteristics of other vegetation types occurring within and around the Lake Sentarum Wildlife Reserve.

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Table 4.3. Major characteristics of other vegetation types occurring within and around the Lake Sentarum Wildlife Reserve

Vegetation type	Average canopy height (m)	Soil type	Major taxa
Lowland dipterocarp forests	35 - 45 m	mineral soil, with clay	*Anisoptera, Dryobalanops, Vatica Dipterocarpus, Shorea, Palaquium, Eugenia*
Heath forest	22-26 m	sandy clay soil	*Baeckia, Koompasia, Lithocarpus, Shorea, Syzygium, Tristaniopsis, Vatica*
Kerapah forest	15-22 m	organic soil, with shallow peat	*Calophyllum, Gonystylus, Eugenia, Pellacalyx, Shorea, and Vatica*
Secondary forest	10-15 m	mineral soil, with clay	*Macaranga, Trema, Melastoma, Dillenia, and Fagraea*
Floating mat	N/A	N/A	Poaceae, Cyperaceae, and Pteridophytes

Source: Modified from Giesen (1987; 1996)

4.5. Regional comparisons of peat swamp forests

The peat swamp forests at the lakes appear to be different from those represented in the classical model of vegetation dynamics of peat swamp forests in the Malayan region illustrated by Anderson and Muller (1975). Padang forests, located in the centre of peat deposits, are not found at the lakes while dwarf and stunted swamp forests resulting from periodic and permanent floods are not currently reported to occur in the Sebangau peatland and other Malayan peatlands. Major differences and similarities among peat swamp

forests in the Lake Sentarum, the Sebangau catchment, and Sarawak are presented in Table 4.4.

The table shows that major taxa occurring in the peat swamp forests in this region are Calophyllum, Combretocarpus, Dryobalanops, Palaquium, Ganua, Hopea, Shorea, Dipterocarpus, Gonystylus, Eugenia, Cratoxylum, and Dactylocladus. Dipterocarpaceae, which is the dominant family in the dryland areas of Borneo, is not always a major component in the peat swamp forests, although it can form dominant stands such as Shorea albida in the peat swamp forest of northern Borneo (Anderson and Muller 1975). Tree growth in the peat swamp forests is relatively more suppressed than in the dryland forests. It is common for the peat swamp forests to comprise low pole and open canopy forests.

4.6. Human activities

Permanent human settlements have been established within the area incorporated within the Lake Sentarum Wildlife Reserve for hundreds of years. At present, between 3,000 and 5,000 people live within the reserve boundary, while several more thousand people live around the reserve, such as in the villages of Jongkong, Suhaid, and Selimbau, located along the Kapuas River, and the town of Lanjak at Danau Luar. The total number of people who directly or indirectly use the lake resources is possibly more than 15,000. It was estimated that the annual fish catch between 1975-1985 was about 10,000 wet

Table 4.4. Major types of peat swamp forests found in the Lake Sentarum Wildlife Reserve, the Sebangau peatland, and Sarawak

Forest Type	Location	Major taxa	Water table	Peat thickness (m)	Canopy and tree height (m)
Mixed peat swamp forest	Sebangau, Sarawak, Lake Sentarum	*Calophyllum, Combretocarpus Dipterocarpus, Shorea, Dryobalanops, Dyera, Ganua, Palaquium, Gonystylus, Knema, Myristica, Mezzetia, and Neoscortechinia*	Low	2 – 6	closed, and top canopy heights between 30 and 50
Transition forest	Sebangau, Sarawak,	*Calophyllum, Combretocarpus, Palaquium, Gonystylus, and Stemonurus*	Relatively low	3 – 5	open, top canopy heights between 30 and 45
Low pole forests	Sebangau, Sarawak, Lake Sentarum	*Calophyllum, Combretocarpus, Campnosperma, Dactylocladus, , Cephalomappa, and Parastemon,*	High	6 – 10	open and top canopy height ≤ 30
Tall peat swamp forest	Sebangau, Lake Sentarum	*Calophyllum, Tristania, Palaquium, Gonystylus, Cratoxylum, Dipterocarpus Shorea, Hopea, Gymnostoma, Koompasia, and Xanthophyllum*	Very low	8 – 13	closed and top canopy heights between 30 and 60
Dwarf and Stunted swamp forests	Lake Sentarum	*Barringtonia, Randia, Timonius, Coccoceras, Grewia, Diospyros, Carallia, Crudia, Vatica, Microcos, Ilex, and Mesua*	Above the surface (inundated)	0 – 2	very open, and top canopy heights between 5 and 25

Source: Anderson and Muller (1975); Giesen (1987; 1996); Page *et al.* (1999)

tons (www.wetlands.agro.nl, 2000). The value of fish resources is around 90% of annual gross benefits of resources harvested from the reserve, and the rest (10%) is from timber, swiftlet nests, turtles and tortoises, rattan and honey (Aglionby 1997).

For millennia, humans, animals, plants, and other creatures have established abilities and mechanisms to adjust to natural fluctuations of water level in the reserve. The good fishing season falls when the water level is moderately low, between 5 and 2 m. This normally occurs between April and October. When the water level is high, between 5 and 12 m around November to March, fishing activities appear to be less attractive than exploiting forest resources (Peters 1994; Wickham 1997). Human pressure on forest resources increases during the high water period because of poor harvest in fish. The influence of seasonality affects both natural and socio-economic systems in the reserve (Wickham 1997).

Fire regularly occurs at the lakes, particularly in the dry season. Mollengraff (1900) reported that fire was widely used to smoke fish, and believed that people at the lakes carelessly set fire to the forests. Fire is also used in widening the fishing grounds in order to increase the catch. Fire may attract the highly demanded ornamental Asian Arowana, *Scleropages formosus* to appear within burnt areas. Biomass burning in shifting cultivation is used to clear the forest, fertilise the swidden, eliminate pests, and open walking tracks.

Plate 4.1. A wet phase in the Lake Sentarum Wildlife Reserve

a. Lake Luar, the biggest lake within the reserve
b. Tekenang Hill, with secondary vegetation
c. Pak Markan, a boat driver of Jongkong village
d. Floating grassmat
e. Trees in this inundated peatland forest are equipped with aerial roots
f. Karamba, a fish cage for raising snakehead fish
g. Logging within the reserve
h. Forest fire that kills swamp vegetation
i. Timber raft on Leboyan river, a major means of log transportation (These photographs were taken in January 1997)
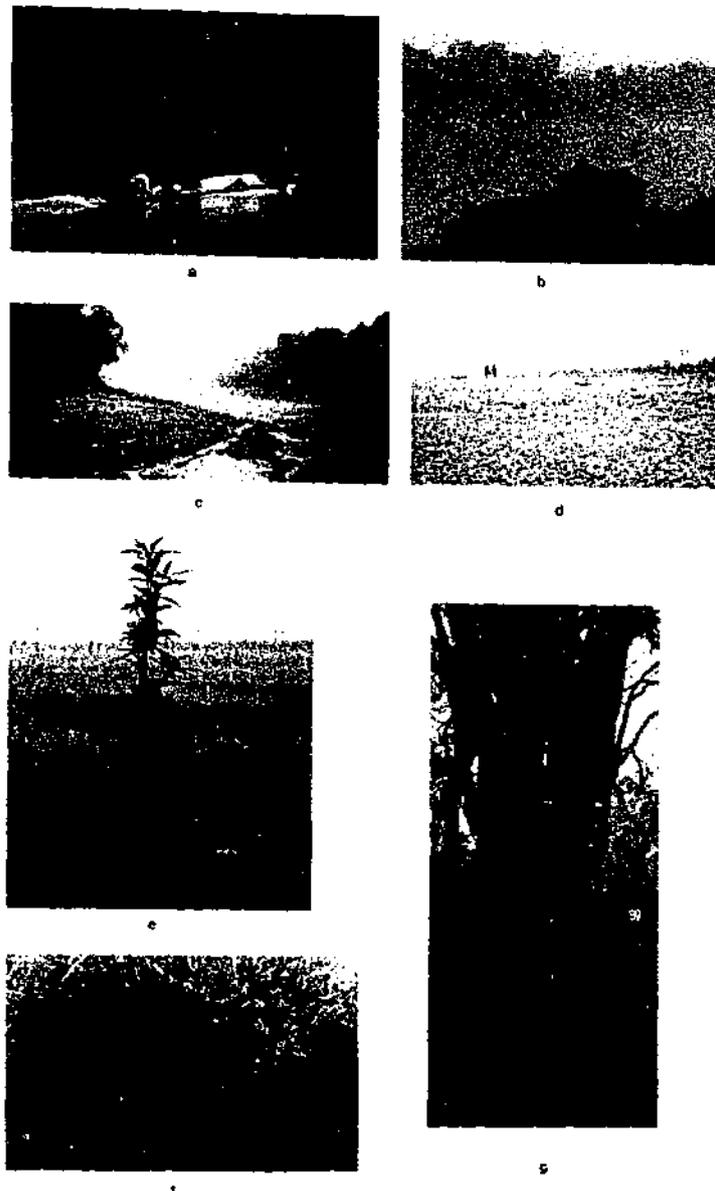
Plate 4.2. The dry season of 1997 in the Upper Kapuas Basin and in Lake Pemerak

a. Exposed Kapuas River bank during the dry severe drought o August 1997. This small boat carried supplies for fieldwork at Lake Pemerak

b. Haze over Kapuas River

c. Small channel on the exposed Lake Pemerak and peatland forest in the background

d. The dry bed of Lake Pemerak in August 1997

e. Seasonal grasses and sedges cover the moist parts of the exposed bed of Lake Pemerak

f. Inundated *Barringtonia* tree in January 1997

g. Exposed *Barringtonia* tree on the bed of Lake Pemerak in August 1997 (These photographs were taken in August 1997, except for photograph f).

Outside the reserve boundary, several commercial timber companies exploit the forest, and use the main rivers within the reserve to transport timber. As a consequence, human activities in the reserve are intensive, resulting in rapid degradation of the lake ecosystem.

At present, environmental and social change is occurring rapidly all over Borneo. In this region, development projects such roads, plantations, timber logging, and new human settlements through transmigration schemes strongly correlate with anthropogenic pressure on the sustainability of natural resources in the lakes. Overfishing has been observed (Dudley 1996). A large amount of turtle and tortoise meat (*Chitra indica* and *Testudo* spp) has been sold as delicacy in overseas markets. Logging and plantations cause forest conversion and lead to habitat loss for birds and wildlife.

An increase of human population will cause land shortage and intensify rice cultivation. This possibly threatens the peat swamp forests at the lakes by conversion to wet rice cultivation (Wadley 1998). Further, a great amount of domestic waste is dumped in the lakes and streams, and chemical pesticides used in agriculture contaminate the lake water, accumulate in fish species and may cause serious health hazards to humans. A new road connecting Lanjak, near Lake Luar to Badau, a border town between Sarawak, East Malaysia and Indonesia, has been constructed and will open the frontier that may lead to rapid socio-economic and environmental changes in this formerly isolated region.

Chapter 5: Methodology

5.1.   Sediment core collection

Three sediment cores (HN1, HN2, and HN3) were collected within the Lake Pemerak peat swamp forest, and three other sediment cores (DP1, DP2, and DP3) were taken from the bed of Lake Pemerak, and finally one sediment core (DP4) was gathered from a peat band exposed in the bank of a small stream, located near the village of Nanga Pemerak (Figure 5.1). The cores were wrapped in plastic, labeled and carefully stored in PVC tubes. The cores were transported by air to Monash University.

The site for sediment core HN1 was about 100 m from the bank of the lake Pemerak within frequently flooded peat swamp forest. The core was collected using a Russian sampler (Jowsey 1966). Penetration was very difficult as this peat deposit contains large pieces of wood. Core HN1 is 150 cm long. Efforts to obtain a longer core were prevented due to the impenetrable nature of the peat, and breakage of the sampler.

Cores HN2 and HN3 were collected with a modified Livingstone piston sampler, within less frequently flooded sites of the peat swamp forest. Core HN2 is 350 cm, and core HN3 is 124 cm long.

Sediment cores DP1, DP2, and DP3 were collected from a moist site on the bed of the Lake Pemerak. Core, DP1, was relatively easier to retrieve than cores DP2 and DP3. Core DP1 is 300 cm long, while the top parts of the core

DP2 could not be retrieved because the sediment contained too much dry sand.
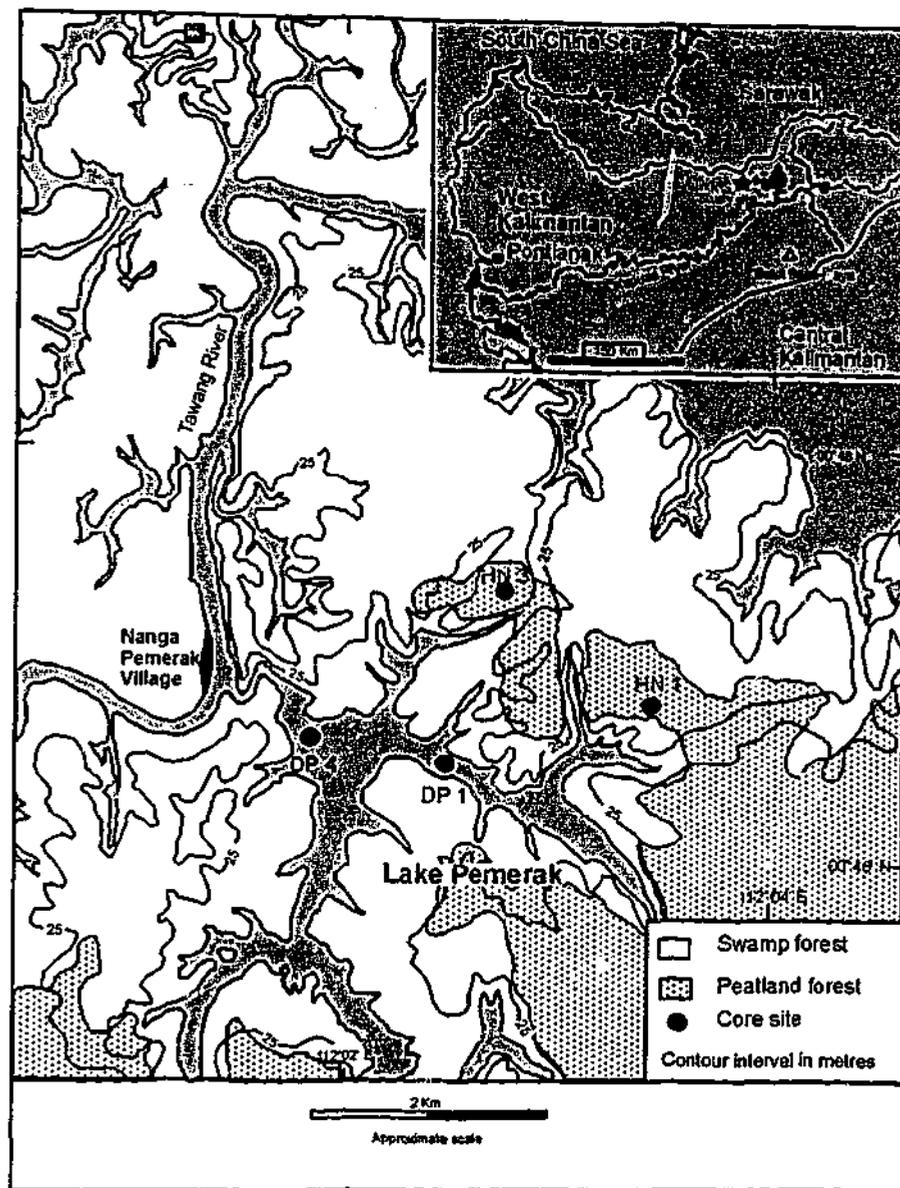
Figure 5.1. Approximate location of core sediment sites

Scale: 50 cm
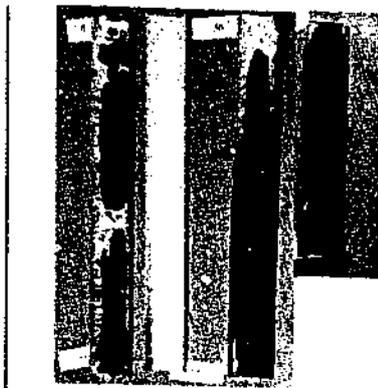
a. Core HN3
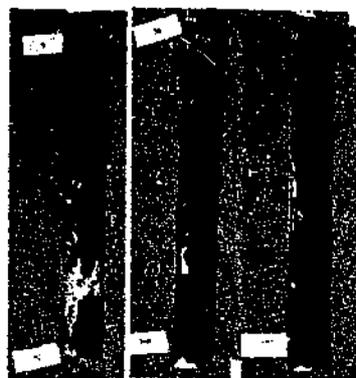
b. Core HN1

c. Core DP1

d. Core DP4

Villagers from Lake Pemerak, standing on the dry lake bed and carrying peat sampling equipment

An exposed peat band in the bank of small channel

Plate 5.1. Pictures of sediment cores, local assistants, and peat band

Core DP3 is very short, just 35 cm long, and contains mostly sand. All these cores were collected using the modified Livingstone piston sampler.

Finally, sediment core DP4 was collected from a peat band occurring in the bank of small stream located close to the village of Nanga Pemerak. This core is 100 cm long. Several attempts to obtain a deeper core failed. Pictures of sediment cores collected in this study are shown in Plate 5.1.

In this study, sediment cores HN1, HN3, DP1 and DP4 were chosen for laboratory analysis. Other cores were considered less suitable for pollen analysis since they were very sandy in the case of cores DP2 and DP3 or coarsely fibrous (consisting a lot of rootlets) in the case of core HN2. Core description and sampling for moisture content, inorganic residue estimation, pollen and charcoal analysis, and radiocarbon date determination were all carried out at the Centre for Palynology and Palaeoecology, Monash University. Samples for radiocarbon dating were sent to Waikato Laboratory, New Zealand, and the Australian Nuclear Science and Technology Organisation (ANSTO), Sydney, Australia.

5.2.   Modern pollen rain studies

An introduction to vegetation types and forest resources found in the Lake Sentarum Wildlife Reserve is provided by Giesen (1987; 1996), and Peters (1994), and reviewed in the previous chapter. This information provided the basis for selection of modern pollen samples and associated vegetation data to aid in interpretation of fossil pollen records.
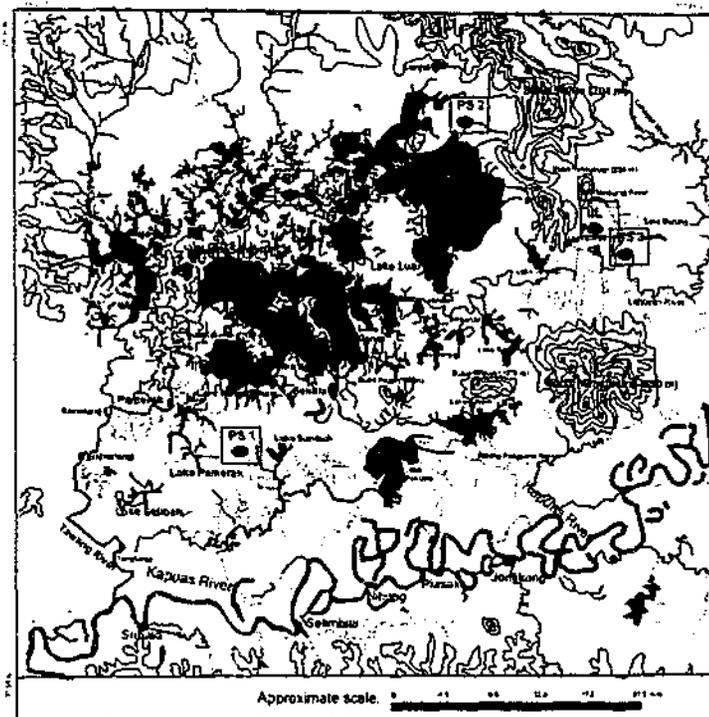
Legend.

———— Lake:river

▬▬▬ Settlement

———— Contour interval 100 m, first contour line represents 50 m

● Approximate location of vegetation plot

N
↑

Approximate scale.

Figure 5.2. Approximate location of surface sample sites and vegetation plots

Sites were selected at 100 m intervals along transects located within major habitat types. Seven study sites were selected within the preserved customary peat swamp forest (PS1 sites), eight plots were located in a previously logged peat swamp forest (PS2 sites), four plots were within a presently logged peat swamp forest (PS3 sites), eight plots were located in riparian forests (RP sites), and three samples were collected from the surface of Lake Lukuk (LL sites). The geographic location of PS1 sites is approximately 0°46′N and 112°07′E, PS2 sites about 0°01′N and 112°14′E, PS3 sites about 0°23′N and 112°54′E, RP sites about 0°59′N and 112°14′E, and LL about 0°20′N and 112°55′E. RP sites were largely deforested and abandoned by shifting cultivation practice. The locations of these transects is shown on Figure 5.2. The collection of vegetation and pollen data from plots was undertaken between November 1996 and February 1997.

Main study plots of 20 x 10 m² were constructed in PS1, PS2, PS3 and RP sites to record all trees with diameter at breast height (DBH) greater than or equal to 5 cm. Although plot sizes were small in relation to patterning within diverse vegetation, time availability inhibited construction of larger plots. The height of the recorded trees was also determined, using a clinometer. Two other small (1 x 1 m²) subplots were lain within each main plot. The presence of *Pandanus, Calamus,* Cyperaceae, Poaceae, and pteridophytes was noted within each subplot. Floristic data from LL sites were not systematically recorded because most vegetation was submerged, but major taxa were observed around the bank of Lake Lukuk. These taxa were *Barringtonia, Memecylon,* and

Pandanus.

From the centre of each site, one surface sample in the form of organic matter was collected for pollen analysis and stored in a plastic bag. The location of samples for modern pollen rain study is situated in the centre of the main plot. The method used to prepare these samples for pollen analysis is described in section 5.5.

Fresh flowers for reference slides were also gathered from the lakes, but most reference slides were made from dried flowers sampled at Herbarium Bogoriense, Indonesia and Rijksherbarium, Leiden, the Netherlands. Reference slides are stored at the Centre for Palynology and Palaeoecology, School of Geography and Environmental Science, Monash University, and Herbarium Bogoriense, in Bogor.

5.3. Core descriptions and sample processing

A modified Troels-Smith system (Kershaw 1997) was used to describe the sediment cores. Although the Troels-Smith system has been widely used in northwest Europe to describe lake and swamp sediments, many investigators from other parts of the world feel reluctant to use this method. In this modified Troels-Smith system, most Latin names have been converted into English terms, and a new component, charcoal, has been added.

The individual stratigraphies of the analysed sediment cores HN1, HN3, DP1 and DP4 will be presented in chapter 6. After description, the sediment cores were sampled every 4 cm for moisture content determination, loss on

ignition estimation, and pollen and charcoal analysis.

The determination of moisture content and inorganic residue follows standard routines. The moisture content was estimated from moisture loss after the sample had been oven dried at 105° C for 24 hours (Kershaw 1980). Inorganic residue was calculated from loss of organic matter after the dried sample had been ignited in a muffle furnace at 550° C for 2 hours (Dean 1974).

Pollen and microscopic charcoal particles were concentrated from one cm^3 uncontaminated samples, retrieved by using a clean syringe. The standard preparation procedure described by Lowe et al. (1996) was followed. First, each one cm^3 sample was transferred to a 100 ml glass beaker and dispersed in 10% Na-pyrophosphate for 24 hours. In order to speed up the process of disagregation, each sample was heated and stirred over a hot plate before sieving through a 180 µm mesh to remove larger fragments. Then, the residue was filtered through a 7 µm sieve to remove fine particles, and left undisturbed for 24 hours to allow the filtered residue containing pollen to settle on the bottom of the glass beaker. Next, the excess distilled water from the beaker was carefully siphoned, and the residue was transferred to a 10 ml plastic tube, and washed twice with distilled water, centrifuged at 3,500 rpm for 3 minutes and decanted. After washing with 100% acetic acid, a 10 minutes standard acetolysis was undertaken to break down cellulose substances. Next, the residue was washed with distilled water twice, and then the remaining organic component was separated from mineral matter using the heavy liquid, Sodium Polytungstate ($Na_6(H_2W_{12}O_{40})H_2O$) at specific gravity 2.0, and centrifuged at

2000 rpm for 20 minutes. Finally, the residue was again washed with distilled water and 90% ethanol before being mounted on microscope slides in glycerol. The amount of residue, and the amount of residue applied to microscope slides, was measured for the estimation of pollen and concentrations (Jørgensen 1967). The same method was used to estimate charcoal concentration. In addition, a ratio between total charcoal particles and total arboreal pollen grains was determined for each analysed slide (See sections 5.4 and 5.5).

5.4.   Pollen counting and identification

Pollen counts were undertaken on an Olympus BH-2 microscope at a magnification of x 750. Initial identifications were verified using a x 100 oil immersion objective, giving a magnification of x 1875. A total of 200 arboreal pollen grains per sample was counted where possible but, due to low pollen concentrations, some counts were as low as 100 arboreal pollen grains.

Pollen identification was assisted by comparison with reference slides in the collection of the Centre of Palynology and Palaeoecology. Two published pollen floras: 'The Pollen Flora of Taiwan' (Huang 1972) and 'Pollen of Wet Evergreen Forests of the Western Ghats, India' (Tissot *et al.* 1994) were also intensively consulted. Dr. W. Van der Kaars verified identifications.

The majority of taxa found in this analysis were identified to genus level, while a substantial proportion of pollen types, between about 10 and 30% in individual samples, could not be identified. Several taxa such as Poaceae,

Cyperaceae, Arecaceae, Leguminosae, Dipterocarpaceae, and Anacardiaceae were identified only to family level.

The degree of certainty in taxon identification has been indicated, using the notations of Benninghoff and Kapp (1962). When the identification is confirmed, no suffix is added. Either suffix 'comp' or ' sim' has been added when the status of identification is uncertain. The suffix 'comp' indicates that the represented pollen grain compares well with the reference taxon, but it is possible that the pollen grain in question is derived from another, closely related, taxon, whose pollen is not represented in the reference collection. The suffix 'sim' indicates that the represented pollen grain shows major similarity to the reference taxon, but could derive from other unrelated taxa. The suffix 'type' indicates that the represented pollen grains are derived from the reference taxon, but the pollen in question shows some degrees of variations within family or genus levels. The variations may be in size, and pollen features such as numbers of colpi, and pores, and outerwall appearances of the pollen grains in question. No suffix is added when identification is certain. The terms monolete and trilete are used to either indicate fern spores that have lost their exosporia preventing more refined identification or to fern spore taxa whose taxonomic status is unknown or uncertain. Descriptions and photomicrographs of selected pollen taxa recorded in this study are presented in Appendix A.

5.5. Charcoal counting

Microscope slides used for pollen analysis were also used for charcoal counting. All opaque angular particles of ≥10 µm maximum diameter, were counted as charcoal particles along three evenly spaced transects from each microscope slide. The result of the counts are presented in the form of charcoal/pollen ratios and charcoal concentrations, and used to indicate past forest fires.

5.6. Radiocarbon dating

All analysed cores were radiocarbon dated. In total, 23 radiocarbon dates were obtained, consisting of 19 AMS dates and 4 conventional dates. Samples for conventional radiocarbon dates were carefully collected. All visible root remains were removed. For these conventional radiocarbon dates (Wk 5775, Wk 5776, Wk 5777, and Wk 5779), the amount of sample sent to Radiocarbon Dating Laboratory, University of Waikato, New Zealand, was approximately 20 grams of oven dried material (105° C for 24 hours). In this laboratory, possible additional contaminants were physically removed, and the samples were chemically washed in hot 10% HCl, rinsed and dried.

Accelerator Mass Spectrometry (AMS) ^{14}C dates were undertaken by Waikato University and ANSTO. Waikato University measured three samples (Wk 6277, Wk 6277, and Wk 6278) and ANSTO dated the other samples (OZE 137 to OZE 148). Before material was sent for AMS analysis, possible contaminants such as rootlets and woody detritus were removed, using a 180

mμ mesh sieve. Samples were also sieved in 7 mμ mesh under running distilled water in order to remove fine particles and humid acids. The samples were then centrifuged at 3500 rpm for 3 minutes, and were washed with distilled water until the supernatant was extremely clear, indicating the removal of all humic acids from the samples. Organic residues from the samples were separated from inorganic matter, using Na-polytungstate. The samples were washed again 3 times with distilled water. Pollen concentrates for AMS dates were carefully collected and transferred to small glass vials.

The samples (Wk 6275, Wk 6277, and Wk 6278) sent to Waikato University for AMS dates were also pretreated with hot 10% KOH before sieving. According to Dr. Alan Hogg (Pers. Comm., 1999), Director of Radiocarbon Dating Laboratory in Waikato University, this alkali wash should have been undertaken in a nitrogen atmosphere and immediately followed with acid wash because samples, when alkaline, may absorb modern CO_2 and cause old samples to be younger. In order to avoid this problem and to provide a cross check for the AMS results produced by Waikato University, all subsequent samples sent to ANSTO were chemically pretreated in the ANSTO laboratory. The radiocarbon dates from both laboratories are presented in chapter seven.

5.7. Presentation of pollen and charcoal diagrams

Pollen and charcoal diagrams are shown, along with features of the core stratigraphy and radiocarbon dates. Pollen taxa have been grouped into three

major habitat groups and four taxon groups. They are riparian/peatland/dryland, peatland/dryland, submontane/montane, secondary taxa, herbs, aquatics, and pteridophytes. Riparian group includes vegetation communities occurring on inundated sites such as stunted and dwarf swamp forest, and riparian forest, while peatland/dryland forest comprises peat swamp forest, lowland dipterocarp forest, and kerangas/kerapah forest. The major purpose of the groupings is to indicate the possible sources of the taxa and for convenience in discussion. However, these groupings are very tentative since the represented taxa may not be confined to determined habitat type, but also may be present in other ecological groups or habitats. The pollen diagrams are shown in percentage form. The pollen sum consists of trees and shrubs. Herbs, aquatics, and ferns are excluded from the pollen sum but percentaged in relation to this sum.

TILIA version 2.0.B.4 (Grimm 1991) was used to generate pollen diagrams and lithology symbols. The diagrams were printed, using TGView 1.0.5.2 for Windows (see ftp://demeter.museum.state.il.us/pub/grimm). A stratigraphically constrained classification subroutine (CONISS) contained within the TILIA program was used to aid zonation of the diagrams (Grimm 1987). All determinable and identified taxa were used as input into CONISS.

5.8. Numerical analyses

Both classification and ordination methods were employed to uncover latent structure in floristic data, and modern pollen and fossil pollen spectra.

These descriptive statistical techniques are appropriate in this study because both methods provide sufficient explanation of variation in multivariate floristic and pollen data, which contain many zero values. The methods are complementary (Bridge 1993).

The aims of these analyses were to identify patterns of modern and fossil pollen spectra, based on their similarity. By comparing the (dis)similarity levels between modern pollen spectra and fossil pollen assemblages, it was expected that refined inferences of past environmental and climatic conditions could be made.

5.8.1. Classification

The floristic data and modern pollen spectra were classified, following Ward's agglomerative method (1963) and the unconstrained cluster analysis subroutine in the TILIA 2.0.B.4 program (Grimm 1991). In these methods, a sample or a group of similar samples is agglomerated into larger clusters by measuring their resemblance (Van Tongeren 1987). Resemblance values can be estimated by different techniques, but Euclidean (dis)similarity distance is extensively used in ecological studies (Bridge 1993) and was adopted here. The Ward's method is based on error sum of squares clustering (Van Tongeren 1987), while the CONISS program is based on incremental sum of squares (Grimm 1991). Systat 8.0 was used to produce the Ward's cluster tree (SPSS Inc. 1998). Because results of Ward's method and CONISS are comparable, only unconstrained cluster analysis by CONISS has been applied to fossil pollen spectra.

5.8.2. Ordination

There are two methods of ordination: direct and indirect (Ter Braak and Prentice 1988). In direct ordination, relationships between the relative abundance of taxa and environmental data are used to determine site scores, while in indirect analysis, ordination of sites is undertaken without reference to environmental data, plotting sites with similar taxon composition close on the ordination diagram (Ter Braak 1994). In direct analysis, ordination axes are constrained to be linear combinations of environmental variables (Ter Braak 1987; Ter Braak 1994).

Correspondence Analysis (CA) is a popular indirect ordination in ecological studies, which uses a unimodal response model (Jongman *et al.* 1987). This method was adopted for this study.

Based on χ^2 (chi-square) distance, CA measures the relative positions of objects such as species abundance, presence or absence of species, and other types of ecological data in reduced space. The results of the analysis are arranged in a scatter diagram that allows similarity and dissimilarity of the objects to be visually determined (Greenacre 1984; Ter Braak 1994; Legendre and Legendre 1998).

The importance of ordination axes is estimated by eigenvalues, which range from 0 to 1. An eigenvalue over 0.3 of the ordination axis is considered to be sufficient to explain major variations in the data: if less than 0.3, results of ordination may adequately explain some remaining variation within the data (Ter Braak 1987). In CA, the ordination of sample scores is derived from the

calculation of species data only. Data on environmental variables do not influence the ordination, and need not be included in CA, but may be used in environmental interpretation of the ordination results. This technique is considered appropriate to reveal major variations in species composition in response to environment variables (Gauch *et al.* 1977).

In this study, pollen spectra are assumed to indirectly reflect past vegetation communities. Similarly, the variables of charcoal/pollen ratio and charcoal concentration should have some relationship with past forest fires. Moisture content and inorganic residue, to some extent, indicate the physical and chemical properties of peat, which might indirectly indicate patterns of palaeoenvironmental and vegetational change. The influence of these variables on pollen data can be assessed using Monte Carlo permutation tests (See section 5.8.3.).

Vectors representing environmental variables were plotted on CA ordination diagrams to illustrate the influence of environmental variables on pollen data. The direction of these environmental variables is indicated by vector angle, and relative explanatory power is shown by vector length. Samples and pollen taxa located towards the projected arrow of the environmental variables are interpreted to have strong relation with the variables (Ter Braak 1987; Ter Braak and Wiertz 1994).

Although many other variables could directly and indirectly affect the vegetation composition, it is useful to include these selected environmental variables in the CA ordination diagram in order to help environmental

interpretation. The inclusion of environmental variable vectors in the CA ordination diagram has been used previously by Ter Braak (1994), for example, in order to indicate the relationship between selected environmental factors and algal communities. It is important to note that the inclusion of these environmental variables in CA does not affect the ordination of fossil pollen data.

A supplementary technique in CA was used to compare the distribution of fossil pollen and modern pollen spectra in an ordination diagram. In this case, samples of modern pollen spectra were made passive, and thus do not affect the ordination of fossil pollen spectra. The location of these supplementary samples is then plotted after the algorithm protocols in CA for fossil pollen spectra as active samples are complete (Ter Braak and Šmilauer 1998). Using this supplementary technique, the (dis)similarity levels between fossil pollen spectra and modern pollen can be compared.

A computer program CANOCO 4 for Windows was used to carry out the ordinations and the Monte Carlo tests, while CANODRAW, a drawing package within CANOCO 4, was used to generate ordination diagrams (Ter Braak and Šmilauer 1998).

5.8.3. Monte Carlo permutation test

In this study, the contributions of charcoal/pollen ratios, charcoal concentrations, moisture contents, and inorganic residues to variations in the pollen data are tested by unrestricted Monte Carlo permutation tests (ie

completely randomised permutation). This procedure generates a number of new data sets of species data by permutating randomly the samples in the pollen data, while data for the environmental variables are fixed. A significant level of tested environmental variables indicates the acceptance or rejection of the null hypothesis, that the influence of each environmental variable on pollen assemblages is not significant.

This multivariate method is based on random events. Thus, the Monte Carlo method is a protocol of the manipulation of random numbers (Hammerley and Handscomb 1965; Kalos and Whitlock 1986). A test statistic of a set of data is evaluated by comparing it with alternative sets of data, which are randomly generated (Manly 1997). The test statistic by Monte Carlo test is comparable with the conventional test statistics such as t-test and F-test if the assumptions such as normality of data required by the conventional statistical test are fulfilled (Manly 1997). The significance level determined by Monte Carlo depends on the number of permutations. To obtain the 5% significance level, at least 19 permutations are required (Manly 1997; Ter Braak and Šmilauer 1998). The power of the test increases with more permutations (Ter Braak and Wiertz 1994). The maximum number of permutations offered in CANOCO 4 for Windows is 9999, and was adopted in this study. In the past, computers were slow in performing the Monte Carlo simulation. Using a Pentium-class machine, the relatively small data sets of this study were permutated, by CANOCO, 9999 times within a few minutes.

The confidence level (P-value) in this test is given to four decimal places in order to determine the importance of the variables. The 5% confidence level is achieved if the P-value is ≤ .05, and the 1% confidence level is achieved if the P-value is ≤ .01. The Monte Carlo significance level is obtained by randomly permutating the data sets, without the assumption of normality and mathematical derivations. The F-ratio that accompanies the results of the Monte Carlo test within CANOCO is a multivariate test statistic, which is calculated in each permutation.

Interpretation of the statistical test results from Monte Carlo permutations is aided by examining pollen diagrams, and the results of CA ordination, in relation to the environmental variables. It is important to realise that the distribution of pollen scores in the ordination diagram along the two axes is a simple model in a reduced space, and low values of pollen taxa usually have strong influence (Ter Braak 1987).

Chapter 6: Modern Pollen Rain in the Lake Sentarum Region

6.1. Introduction

A study of modern pollen rain is undertaken in order to assist interpretation of fossil pollen studies (Flenley, 1973). The main principle behind the use of modern pollen spectra as indicators of past environment is that "the present is the key to the past", a uniformitarian approach proposed by Lyell (1850). The application of the principle is based upon assumptions that the present distribution of vegetation is controlled by environmental variables that controlled past vegetation distribution, and that ecological affinities of vegetation have remained relatively unchanged over time (Lowe and Walker 1997). This statement must be qualified by the acceptance of the fact that human impact on vegetation has increased through time. Despite uncertainties resulting from human impact, modern pollen studies are important in identifying indicators of particular conditions. In addition, full comparison of modern and fossil pollen may allow accurate reconstruction of past environments in areas where human impact has not been substantial. Such comparisons are particularly important in tropical rainforest environments where the pollen flora is diverse and many taxa can not be identified, or are identifiable only to a coarse taxonomic level. In the tropics, local vegetation acts a major contributor to pollen rain (Flenley 1973; Morley 1981a, 1981b, 1982a, 1982b) because the majority of vegetation in tropical dipterocarp forests produces a small number of pollen grains. Most insects in tropical forests are

not gregarious. This condition tends to cause pollen grains are not widely dispersed within tropical forests. Lack of strong wind in closed tropical forest environment and heavy rains also have strong influence on local deposition of pollen grains in this humid region.

This chapter consists of several sections, relevant to the documentation of modern pollen description in relation to extant vegetation that will be applied to reconstruction of the fossil records. The first sections examine previous modern pollen rain studies from tropical lowland forests and selected highlands in Indonesia and Malaysia. The next section describes the sampling strategy adopted in this study for both vegetation and derived pollen spectra. The results of both vegetation and surface pollen data are then presented, analysed, and discussed.

6.2. Previous modern pollen studies from tropical equatorial forests in Southeast Asia

In an early study, Flenley (1973) identified over 60 pollen types in surface ground and canopy trap samples from Ulu Gombak Virgin Jungle Reserve (3°19'N, 101°44'E), with altitudes between 440 and 790 m ASL, located in the state of Selangor in Peninsular Malaysia. The lowland area is covered by riverine forest dominated by *Saracca taipingensis*, and lowland dipterocarp forest. Fagaceae and Lauraceae taxa are common in the lower montane forest, at altitudes between 1,200 and 2,000 m ASL. Above 2,000 m ASL, *Dacrydium* spp, Ericaceae, and Myrtaceae are commonly found on the upper montane forest (Putz 1978). In this study, Flenley (1973) found that the modern pollen rain from the reserve was dominated by local tree taxa such as

Fagaceae, Dipterocarpaceae, Urticaceae/Moraceae, Elaeocarpaceae, *Trema,* *Macaranga,* and *Antidesma.* Values of Dipterocarpaceae were relatively low compared to many other tree pollen taxa. Percentages of terrestrial herbs and shrubs such as Liliaceae, Geraniaceae, and *Croton* were low, while fern spores were relatively abundant. Flenley (1973) found that the total number of tree pollen taxa caught in canopy traps was higher than in ground traps on the forest floor. In contrast, values of fern spores were higher on the ground than in canopy traps. This might indicate that rain out and canopy components consist largely of tree pollen taxa, while the trunk space component is dominated by fern spores.

Local trees (Asha Thamotherampillai, pers.comm. 1999) also dominated surface samples from the Setia Alam peatland forest of Central Kalimantan. Major pollen taxa found in this study were *Planchonella,* *Palaquium, Combretocarpus rotundatus, Blumeodendron, Calophyllum,* and *Eugenia.*

Beuning (1996) undertook a modern pollen study in lowland East Java. Surface samples were collected from ten lakes and man-made reservoirs along an east-west transect at varying altitudes between 150 and 1,290 m ASL. Lowland pollen taxa such as *Ficus* and Elaeocarpaceae were well represented in these samples, while other lowland pollen taxa such as *Artocarpus elastica,* *Myrica, Macaranga, Mallotus, Trema, Casuarina,* and Myrtaceae were found in low values in almost all samples. Pollen derived from *Celtis* and *Acalypha* dominated the drier eastern sampling sites from Ranu Betok and Ranu Lading. *Amaranthus* pollen was recorded in several sampling sites from eastern lakes

and was absent from the wetter western sampling sites. *Pinus* pollen was not prevalent, but had low values in the sampling sites close to pine plantations. From this study, Beuning (1996) asserts that locally forested sites are dominated by local pollen taxa, while samples from open sites receive both local pollen and regional pollen taxa. The samples from disturbed and non-forested sites were predominantly characterised by Poaceae and Cyperaceae.

6.3. Modern pollen rain from highland regions in equatorial Southeast Asia

Based on a modern pollen spectra from Mt. Kinabalu, Sabah, Flenley (1973) found that pollen derived from *Quercus* and *Lithocarpus* dominated at altitudes of 1,400- 2,400 m ASL, and that pollen derived from *Phyllocladus* became dominant at higher altitudes. Other major pollen taxa recorded were Cyatheaceae comp., Ericaceae and *Myrica/Casuarina*. *Leptospermum* was common around 3,000 m ASL. Fern spores occurred throughout the diagram, but Poaceae values were very low because alpine tropical grassland is not found on the summit of Mt. Kinabalu. Flenley (1973) thought that tree pollen taxa were transported upslope, above the forest limit, because he found lower altitude pollen taxa in samples from higher altitudes.

Another surface sample study from Bukit Baka-Bukit Raya (2,278 m ASL), located at *c.* 0° 40' S, 112° 40' E in the Schwaner Range, West Kalimantan was undertaken by Maloney (1987). From 1,600 to 2,000 m ASL, this study showed that pollen derived from *Quercus* and *Castanopsis/Lithcarpus* dominated the lower montane forest zone. Pollen values for *Myrica/Casuarina* were persistently recorded in all samples between

1,675 and 2,278 m ASL. Fern spores were also abundant throughout the spectra, but their values, especially those of Cyatheaceae, increased above 2,000 m ASL. Several pollen types such as Myrtaceae, Cyperaceae, Urticaceae/Moraceae, *Nepenthes, Rhododendron* type, *Vaccinium* type, and *Elaeocarpus* were dominantly found in the upper montane zone, between 2,000 and 2,300 m ASL. Pollen of *Phyllocladus hypophyllus* was persistent from 1,600 to 2,300 m ASL, but values for this taxon became high above 2,000 m ASL. Low and variable values for *Dacrycarpus imbricatus,* and *Dacrydium falciforme* were irregularly distributed with altitude.

It is interesting to note that some lowland elements such as Dipterocarpaceae were present in these pollen samples (Maloney 1987). This supports the proposal of Flenley (1973) that some pollen grains are transported upslope in the tropical Malayan region. This is especially true if open vegetation types are dominant in upper montane zones. By contrast, Myrica/*Casuarina* pollen may be transported down-slope. This taxon is commonly restricted to the upper montane zone, but occurs throughout the diagram. Maloney (1987) also suggests that most pollen taxa recorded in this study originated from local taxa. These taxa included *Phyllocladus hypophyllus, Vaccinium* type, *Nepenthes* type, *Schefflera,* and *Pinanga* type.

Stuitjs (1993) studied modern pollen rain from Gede Parango National Park, Kawah Putih, and Ranca Upas in highland West J a. From the Gede Parango National Park, ten surface samples were collected at different altitudes, between *c.* 1,300 and 3,000 m ASL. From Kawah Putih and Ranca Upas, five and four surface samples were collected, respectively.

Between *c.* 1,300 and *c.* 2,400 m ASL, major pollen taxa recorded from Gede Parango National Park were *Dacrycarpus imbricatus, Castanopsis* comp., *Altingia, Schima,* and *Daphniphyllum.* Values for Poaceae were very low at lower altitudes, but suddenly increased at high altitudes (above 2,500 m ASL). Cyperaceae was also more abundant at high altitudes. Pollen of *Rapanea* was extremely abundant between 2,400 and 2,600 m ASL, very low below 2,400 m ASL, and very common between 2,600 and 3,000 m ASL. Pollen of *Quercus, Rhododendron* comp., *Eugenia* comp., and Urticaceae/Moraceae occurred in low values throughout the samples. Pollen of *Myrica* comp. was largely confined to altitudes between 2,600 and 2,900 m ASL, but was present throughout the diagram.

Pollen values for *Symplocos,* Lauraceae, and *Polyosma* were restricted to lower altitudes, up to 2,500 m ASL, while percentages for Rosaceae and *Vaccinium* were variably present above 2,600 m ASL. Substantial values for *Engelhardia* pollen type were recorded in seven samples. Values for monolete and trilete spores were constantly present in all samples. Pollen of *Asplenium* was restricted to lower altitudes (between 1,300 and 2,400 m ASL), while *Lycopodium clavatum* was more common above 2,700 m ASL. Pollen of Polypodiaceae was variably recorded. Stuijts (1993) also noted that pollen of local trees was predominantly recorded in the samples from forested sites, while pollen of Poaceae, Cyperaceae, Piperaceae, Urticaceae/Moraceae, and Compositae dominated the samples from non-forested sites.

Local tree pollen taxa such as *Altingia, Castanopsis* comp., *Quercus, Engelhardia,* and *Myrica* dominated surface samples from Kawah Putih in

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West Java, a crater lake (2,200 m ASL). Pollen values for *Engelhardia* were unexpectedly high since this taxon was rarely found at the sample sites. This might indicate that *Engelhardia* is a high pollen producer, and pollen of *Engelhardia* is widely dispersed. Pollen of *Altingia, Castanopsis* comp. and *Quercus* was probably transported upslope (Stuijts 1993). Pollen derived from *Vaccinium, Rapanea,* and Rosaceae was encountered in low values. It is probable that these taxa are under-represented in pollen records (Flenley 1973; Stuitjs 1993).

Urticaceae/Moraceae, Compositae, and Piperaceae predominantly represent shrub pollen types. In the herb group, substantial percentages of Poaceae were constantly recorded in all samples, while values for Cyperaceae were relatively low. Ferns were predominantly represented by monolete and trilete spores. The source of pollen derived from *Polypodium vulgare*, Poaceae, Cyperaceae, and undifferentiated fern spores was very likely regional, while high values for the *Polypodium vulgare* pollen type was from local sources, and may have indicated disturbance (Stuijts 1993).

Surface samples from Ranca Upas (*c.* 1,750 m ASL), West Java incorporated four samples from the marsh and one from a transition zone between the marsh and forest. Major local tree pollen taxa recorded in these samples were *Altingia, Castanopsis* comp., *Quercus,* and *Engelhardia.* Values for other local tree pollen taxa such as Ericaceae, *Schima, Ilex, Eugenia, Pandanus,* and *Memecylon* were low. Urticaceae/Moraceae, Piperaceae, Compositae, Poaceae, and Cyperaceae were also well represented. Monolete pollen types were found commonly at high values, while trilete spore values

were low. High values for *Davallia* pollen were also recorded, while values for other fern spores such as *Popypodum glaucum* type, *P. vulgare* type, and *Lycopodium cernuum* were variably low (Stuijts 1993).

Modern pollen rain results from Danau Padang, located in the Mount Kerinci area of Central Sumatra, were reported by Morley (1980). *Eugenia*, Euphorbiaceae, *Engelhardia*, *Lithocarpus*, Meliaceae, *Prunus wallichii*, *Quercus*, Rubiaceae, Sapotaceae, and Urticaceae are commonly found in the lower montane forest. In the upper montane forest, *Quercus* are less common, and are replaced by *Eugenia*, and *Schima wallichii*. Two other common taxa in the upper montane zone are *Podocarpus imbricatus*, and *Symingtonia populnea*.

Morley (1980, 1982a) reported that modern pollen spectra recorded from these lower and upper montane forest types strongly reflect the character of the forest types, and are closely associated with altitude. Substantial values for pollen of *Madhuca* comp. (Sapotaceae), *Aglaia* comp. (Meliaceae), *Nauclea* comp. (Rubiaceae), and *Celtis* (Ulmaceae) were recorded in moderate frequencies in the samples from lower montane forest sites. Values for pollen of *Trema* and *Macaranga* comp. were higher in the samples from lower montane than upper montane forests, and this might relate to higher disturbance at the lower altitudes. However, substantial pollen values for these taxa were also recorded in the lower and upper montane forests.

The composition of pollen spectra from the lower montane forest was very diverse, incorporating pollen taxa from lower and upper montane forests. In the lower montane samples, pollen taxa of *Quercus* and *Lithocarpus* were

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very common. Other pollen types such as *Eugenia, Elaeocarpus, Engelhardia, Trema,* and *Macaranga* also had moderate representation. Some pollen types such as *Elaeocarpus, Quercus, Lithocarpus,* and *Eugenia* were also recorded in all samples, while pollen of *Engelhardia* was restricted to samples from the lower and upper montane sites.

In contrast, pollen values for *Podocarpus imbricatus, Schima* comp., *Weinmannia* and *Symingtonia populnea* usually dominated the upper montane forest. Values for pollen of *Engelhardia, Ilex,* and *Saurauia* comp. had moderate representation, while low values for pollen of *Polyosma* were recorded in the samples from both the lower and upper montane forest.

Newsome (1988) studied the modern pollen rain at Danau di Atas, located in the Province of West Sumatra. Samples were collected from the swamp, non-forested and forested sites at varying altitudes. Samples from the swamp and non-forested sites were located between 1,400 m and 2,000 m ASL (lower montane forest), while other samples were situated between 2,000 and 3,300 m ASL (upper montane forest).

In these modern pollen spectra from the upper montane forest zone, *Lithocarpus/Castanopsis,* and *Quercus* were dominant, and pollen of Urticaceae/Moraceae was found at moderate values. Pollen of *Cyathea* comp. was often abundant in the samples from non-forested sites, and the forested sites.

In the swamp and non-forest sites of the lower montane zone, values for Cyperaceae, Poaceae, Compositae, and undifferentiated ferns were very high,

while values for *Lycopodium cernuum* were moderate in the non-forested sites but very high in the swamp sites. Other pollen taxa were not well represented.

Low values for *Dacrycarpus, Podocarpus,* and *Dacrydium* were recorded in samples from the swamp and forested sites. Values for *Altingia, Engelhardia* were relatively low, while values for *Elaeocarpus* comp., *Myrsine* comp., and Myrtaceae type 1 were moderately low and these pollen taxa were probably under-represented. Pollen values for *Schima* and *Symingtonia* were not consistent, very high in the samples from 2,000 m to 2,400 m ASL, but low in both the samples above 2,400 m ASL and below 2,000 m ASL. *Dacrycarpus, Engelhardia, Myrsine* comp. *Podocarpus, Schima, Symingtonia,* and Cyatheaceae were probably the best indicators of montane forest zones (Newsome 1988; Flenley 1973).

6.4. Overview

Flenley (1973) considered that the application of pollen studies to the elucidation of vegetation and climate in tropical lowland forests had not yet been established. This situation seems still valid for the tropical lowlands of Borneo. Fossil pollen studies from this island are labour-intensive and the interpretation of study results is at a preliminary stage.

All modern pollen rain studies from both lowland and highland areas reviewed here show that local taxa are the major contributors to modern pollen rain. Modern pollen spectra from lowland areas are different from those in highland regions, with much variation depending upon locally present vegetation occurring in each region.

The source of pollen from tree taxa is mainly from canopy trees. Trunk space movement of pollen in the tropical closed forests is very limited because light winds predominate in the tropics (Flenley 1973; Kershaw and Hyland 1975). Beuning (1996) estimated that the source of pollen varied, between about 400 m and 20 km away from the sampling sites. Kershaw and Strickland (1990) found that modern pollen spectra from rainforest in northeastern Queensland were dominated by local vegetation communities occurring within 10-20 m of the site, due to the predominance of insect-pollinated taxa.

Herbaceous pollen taxa such as Cyperaceae, and Poaceae together with other taxa such as *Macaranga, Mallotus, Trema, Stenochlaena palustris* and *Lycopodium cernuum* are well represented in disturbed and open sites (Stuitjs 1993). Values for other fern spores, particularly undifferentiated monolete and trilete types, are also high in disturbed and open sites, and these sites are very likely to receive a more regional pollen component.

Pollen values in primary forest are not generally linearly associated with abundance values of taxa in the present vegetation. Of those taxa that are actually recorded, many such as Ericaceae, *Gonystylus, Shorea,* and *Neoscortechinia* tend to be under-represented, while over-represented taxa include *Palaquium, Stemonurus,* and *Campnosperma*. Values for other pollen types such as *Calophyllum, Blumeodendron,* and *Eugenia* are relatively high, while values for *Combretocarpus rotundatus* and *Dactylocladus stenostachys* are low (Morley 1981b). However, these interpretations are tentative, depending upon scales of observation, geological setting, and geographic location.

Pollen distribution and dispersal are always in a dynamic state. Morley (1980) reported that pollen values for *Podocarpus imbricatus* were abundant from Danau Padang, while Newsome (1988) showed that this pollen taxon was rarely recorded from Danau di Atas. These sampling sites are located in the same region, the highlands of Central Sumatra. This phenomenon occurs because Morley (1980) and Newsome (1988) used different scales and times of observation, and the geological setting of sites was also different.

With respect to taxa recorded in the present day vegetation but absent in modern pollen spectra, Newsome (1988) noted that *Alangium rotundifolium* (Alangiaceae), *Flacourtia rukam* (Flacourtiaceae), *Garcinia lateriflora* (Guttiferae), *Goniothalamus* (Annonaceae), *Gynotroches axillaris* (Rhizophoraceae), *Olea javanica* (Oleaceae), *Prunus arborea* (Rosaceae), *Rhodoleia championi* (Hamamelidaceae), and *Tupinia sphaerocarpa* (Staphyleaceae) fell into this category.

There are several reasons that may explain such absences. Many pollen grains from tropical forests have not been collected or easily recognised at species level. Most pollen taxa are only identified at genus or family level, possibly leading to the pollen in question being mis-grouped or mis-identified. Some pollen types are not well fossilised and preserved, and others could be damaged or destroyed by strong acids during laboratory processing. In addition, some taxa do not produce many pollen grains. Some tropical forest taxa flower infrequently, requiring some type of natural disturbance or prolonged dry season before producing flowers. Most lowland dipterocarp

forest trees are insect pollinated, and thus the majority of them would produce a small amount of pollen (Newsome 1988).

The relationship between pollen production, dispersal, and fossilisation is very complex. Several major factors, such as vegetation types, climatic conditions, means of dispersal, roles of insects and possibly other animals in pollination, and sedimentary conditions, explain why relationship between pollen taxa and present day vegetation tend to be non-linear (Lowe and Walker 1997).

Rivers are prevalent in Borneo and especially in the Lake Senatarum region. Therefore, water may play a major role in pollen transport. Floodwater may contain regional pollen and may be a significant contributor to pollen spectra from tropical lowland swamp forests. Water transported taxa may include undifferentiated monolete and trilete spores, Poaceae, Cyperaceae, and probably some riparian arboreal taxa.

6.5. Results of ecological study

6.5.1. The present vegetation

A total of 1,064 trees and shrubs derived from 63 genera within 27 families were identified within the plots at PS1, PS2, PS3, and RP. Vegetation at LL was not measured, but it was observed that *Barringtonia, Memecylon,* and *Pandanus* trees were common around this lake.

The number of individual trees per plot varied, ranging from 20 to 70. The composition of plant taxa within the plots is very similar, indicating broad distribution of taxa within the environments sampled.

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Table 6.1. Basal area (%) for selected plant taxa found in sample plots 1-7 within currently undisturbed peatland forest (PS1)

Family	Genus	Basal area (%)	Family	Genus	Basal area (%)
Dipterocarpaceae	Dryobalanops	10.81	Dipterocarpaceae	Vatica	1.81
Dipterocarpaceae	Hopea	9.19	Burseraceae	Dacryodes	1.72
Sapotaceae	Palaquium	9.17	Meliaceae	Aglaia	1.56
Myrtaceae	Eugenia	8.80	Guttiferae	Calophyllum	1.53
Euphorbiaceae	Sapium	6.34	Leguminosae	Crudia	1.50
Leguminosae	Kingiodendron	6.12	Moraceae	Artocarpus	1.18
Rhizophoraceae	Pellacalyx	5.95	Elaeocarpaceae	Elaeocarpus	1.00
Lauraceae	Litsea	3.55	Anacardiaceae	Buchanania	0.97
Fagaceae	Lithocarpus	2.97	Melastomataceae	Pternandra	0.93
Leguminosae	Dialium	2.91	Burseraceae	Santiria	0.79
Leguminosae	Koompasia	2.58	Myrtaceae	Tristaniopsis	0.73
Dipterocarpaceae	Shorea	2.49	Euphorbiaceae	Aporusa	0.64
Anacardiaceae	Campnosperma	2.38	Leguminosae	Desmodium	0.64
Sapindaceae	Nephelium	2.08	Leguminosae	Sindora	0.60
Guttiferae	Garcinia	1.89	Rubiaceae	Ixora	0.53
Ebenaceae	Diospyros	1.86	Polygalaceae	Xanthophyllum	0.50

There were generally fewer species in the riparian forest (RP) than in the peatland forest (PS1, PS2, and PS3). This happens because the riparian habitat is more open due to rice paddy cultivation, while the peatland forest has a much more continuous canopy.

Dipterocarpaceae, Sapotaceae, and Leguminosae dominated sampled vegetation at PS1. Other major taxa recorded were *Eugenia, Sapium, Kingiodendron,* and *Pellacalyx.* The representation of Cyperaceae, Poaceae, Pandanaceae, *Calamus,* and ferns such as *Lycopodium cernuum, Lygodium macrophyllum,* and *Stenochlaena palustris* is low in these sampling sites. Table 6.1 presents basal area for selected plant taxa recorded in PS1.

Table 6.2. Basal area (%) for selected plant taxa found in sample plots 1-8 at previously logged peatland forest (PS2)

Family	Genus	Basal Area (%)	Family	Genus	Basal area (%)
Sapotaceae	Palaquium	12.73	Rubiaceae	Nauclea	1.83
Myrtaceae	Eugenia	11.04	Leguminosae	Dialium	1.59
Dipterocarpaceae	Dryobalanops	9.41	Euphorbiaceae	Excoecaria	1.58
Guttiferae	Calophyllum	6.80	Leguminosae	Desmodium	1.40
Dipterocarpaceae	Hopea	6.10	Ebenaceae	Diospyros	1.10
Leguminosae	Kingiodendron	5.78	Rubiaceae	Ixora	0.99
Anisophylleaceae	Combretocarpus	5.41	Guttiferae	Garcinia	0.93
Dipterocarpaceae	Shorea	5.34	Euphorbiaceae	Glochidion	0.90
Euphorbiaceae	Sapium	3.84	Sapindaceae	Nephelium	0.68
Rubiaceae	Morinda	3.83	Meliaceae	Aglaia	0.61
Rhizophoraceae	Pellacalyx	3.53	Anacardiaceae	Campnosperma	0.60
Lauraceae	Litsea	2.64	Myrtaceae	Tristaniopsis	0.55
Apocynaceae	Dyera	2.31	Fagaceae	Lithocarpus	0.48
Rubiaceae	Dichilanthe borneensis	2.23	Anacardiaceae	Gluta	0.46
Melastomataceae	Memecylon	2.09	Leguminosae	Koompasia	0.45

Taxa recorded in sampled vegetation at PS2 included *Palaquium, Eugenia, Dryobalanops, Calophyllum, Hopea, Kingiodendron, Combretocarpus rotundatus,* and *Shorea.* Many of these taxa are similar to those recorded at PS1. *Calamus* spp, *Nepenthes* spp, Lycopodiaceae, and Cyperaceae were commonly seen in the forest gaps. Basal area for selected plant taxa recorded in these sampling sites is given in Table 6.2.

Major plant taxa, which recorded a large basal area (>10%) at PS3, were *Shorea, Calophyllum, Eugenia,* and *Palaquium.* Seedlings of several trees such as *Shorea, Calophyllum, Dryobalanops,* and *Litsea* were commonly seen in this previously logged area, while Cyperaceae, *Calamus, Pandanus,* and *Macaranga* were found in the open area. Table 6.3 presents basal area for selected plant taxa in PS3 sites.

Table 6.3. Basal area (%) for selected plant taxa found in sample plots 1-4 at presently logged peatland forest (PS3)

Family	Genus	Basal Area (%)	Family	Genus	Basal area (%)
Dipterocarpaceae	*Shorea*	27.38	Leguminosae	*Dialium*	1.82
Guttiferae	*Calophyllum*	16.71	Euphorbiaceae	*Glochidion*	1.77
Myrtaceae	*Eugenia*	11.12	Leguminosae	*Kingiodendron*	1.62
Sapotaceae	*Palaquium*	10.79	Dipterocarpaceae	*Dryobalanops*	1.45
Lauraceae	*Litsea*	4.17	Rubiaceae	*Nauclea*	1.40
Euphorbiaceae	*Sapium*	3.90	Moraceae	*Artocarpus*	1.20
Rhizophoraceae	*Pellacalyx*	3.25	Euphorbiaceae	*Macaranga*	0.72
Dipterocarpaceae	*Hopea*	2.85	Ebenaceae	*Diospyros*	0.60
Melastomataceae	*Memecylon*	2.42	Guttiferae	*Mesua*	0.60
Leguminosae	*Koompasia*	2.30	Euphorbiaceae	*Neoschortechinia*	0.50
Anacardiaceae	*Campnosperma*	2.12			

Common trees recorded in RP sites were *Macaranga, Eugenia, Fagraea fragrans, Trema,* and *Pternandra.* Poaceae, Cyperaceae, and *Lygodium macrophyllum* dominated the understorey in this forest type. Table 6.4 presents basal area for selected plant taxa in RP sites.

The vegetation in both the previously logged peatland forests and the abandoned shifting cultivation sites are currently regenerating, as indicated by generally small tree diameter. Regeneration is occurring because continuing human impact on the peatland forests in the Lake Sentarum region is relatively low. The peatland forests are difficult to penetrate. Water is the only means of transportation of timber out of the lake region. Large scale logging in the peatland forest requires big investment for

Table 6.4. Basal area (%) for selected plant taxa in sample plots 1-8 at shifting cultivation (RP) sites

Family	Genus	Basal Area (%)	Family	Genus	Basal area (%)
Euphorbiaceae	Macaranga	23.59	Flacourtiaceae	Homalium	2.44
Myrtaceae	Eugenia	15.23	Leguminosae	Crudia	2.37
Loganiaceae	Fagraea fragrans	8.54	Rubiaceae	Ixora	2.15
Ulmaceae	Trema	7.22	Euphorbiaceae	Glochidion	1.72
Melastomataceae	Pternandra	5.46	Euphorbiaceae	Neoschortechinia	1.61
Ebenaceae	Diospyros	5.44	Rhizophoraceae	Pellacalyx	1.58
Euphorbiaceae	Antidesma	4.81	Sapotaceae	Palaquium	1.10
Moraceae	Artocarpus	4.17	Meliaceae	Aglaia	0.73
Dipterocarpaceae	Hopea	2.99	Dipterocarpaceae	Dryobalanops	0.55
Euphorbiaceae	Baccaurea	2.71	Flacourtiaceae	Flacourtia	0.51
Dilleniaceae	Dillenia	2.57	Guttiferae	Calophyllum	0.47

building a network of rails for dragging timber from the interior sites of the forests. Since the peat is mechanically very unstable, roads cannot be built over the peatland forests. Remote location and natural conditions of the peatland forests in the Lake Sentarum region protect these forest reserves from heavy human disturbance. Previous small-scale logging was manually done during high tide only.

The basal area data were analysed using hierarchical cluster analysis (Ward's method) within a Systat 8 program, and Correspondence Analysis (CA). Results of the classification are given in Figure 6.1, and summary results of the CA analysis are tabulated in Table 6.5. In the case of CA, axis 1, which explains 22 % of variation, twice that of axis 2.
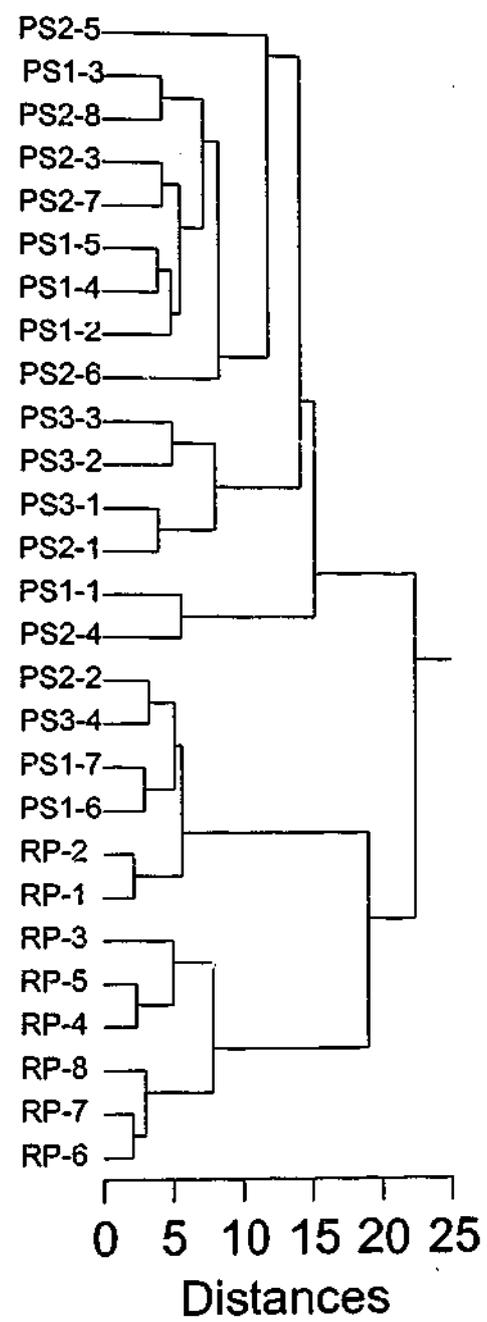
Figure 6.1. Dendrogram for present floristic data, based on Ward's method

Table 6.5. Summary results of the CA analysis for present vegetation data from 27 sampling sites

Axes	1	2	3	4	Total inertia
Eigenvalues	.55	.28	.22	.20	
Cumulative variance of species data (%)	22.2	33.4	42.2	50.2	
Sum of all unconstrained eigenvalues					2.49

Results of CA show a clear distinction between the riparian sites (RP) and the peatland forest sites (PS1, PS2, and PS3) along the first axis, with RP-1 and RP-2 separating from the other RP sites along the second axis (Figure 6.2). The dendrogram shows a somewhat similar pattern (Figure 6.1), with the major division separating a group totally composed of peatland sites from one predominantly of riparian sites. However, this latter group also contains four peatland sites (PS2-2, PS3-4, PS1-7, and PS1-6), all of which split from the main riparian group at the second hierarchical division. Interestingly, this group of peatland sites includes the two riparian sites (RP-1 and RP-2) that were separated in the ordination diagram. There is little systematic differentiation of peatland forest sites although the sites are spread along axis 2. Sites PS1-3, PS2-7, and PS2-8 are most divorced from the others although this separation is not evident in the dendrogram where sites PS1-1 and PS2-4 are most distinct.

The taxon ordination shows, predictably, that most taxa identified as predominantly peatland also occur on the left hand side of the first axis, and are spread out along the second axis (Figure 6.2). Similarly, most proposed riparian taxa fall on the right hand side of the first axis. Exceptions to this

pattern are the riparian taxa *Gluta, Elaeocarpus* and *Campnosperma* that fall within the peatland taxon group and the peatland taxa *Glochidion, Diospyros, Pternandra, Flacourtia, Homalium, Antidesma* and *Neoschortechinia* that fall within the riverine group. This illustrates the problem of allocating taxa with broad ecological ranges to specific habitat types and also problems with undertaking analysis mainly at genus rather than species level. It is interesting to note that three peatland taxa. Apocynaceae, *Excoecaria*, and *Dichilanthe borneensis* form a distinct group on the second axis. Similarly, *Ixora* in particular is separated from riparian taxa that mostly occur around the extreme right hand side of the first axis, together with secondary taxa, demonstrating the very disturbed nature of riparian sites.

6.5.2. Modern pollen spectra

Results of pollen analysis are presented in three pollen diagrams (Figures 6.3a, b, c, and d). In order to assess relationship between some vegetation and pollen spectra, percentage basal areas for tree taxa are also included on the diagrams. Each solid histogram represents the percentage of a pollen taxon, while each hollow histogram represents the percentage basal area of likely pollen source. The taxa are classified into six groups: riparian/peatland/dryland taxa, peatland/dryland taxa, secondary taxa, herbs, pteridophytes, and aquatics. Sample sites are arranged according to habitat types (i.e. PS1; PS2; PS3; RP; and LL).

(a)

(b)
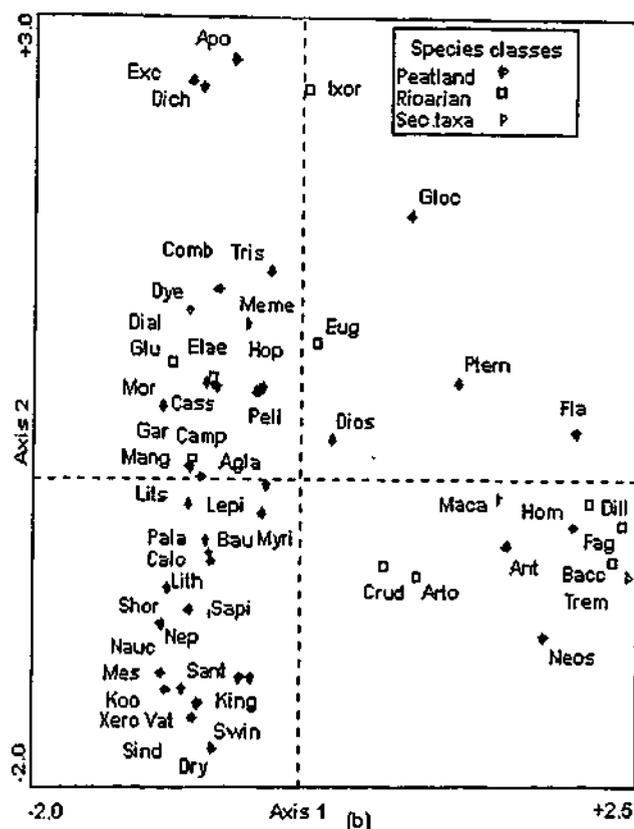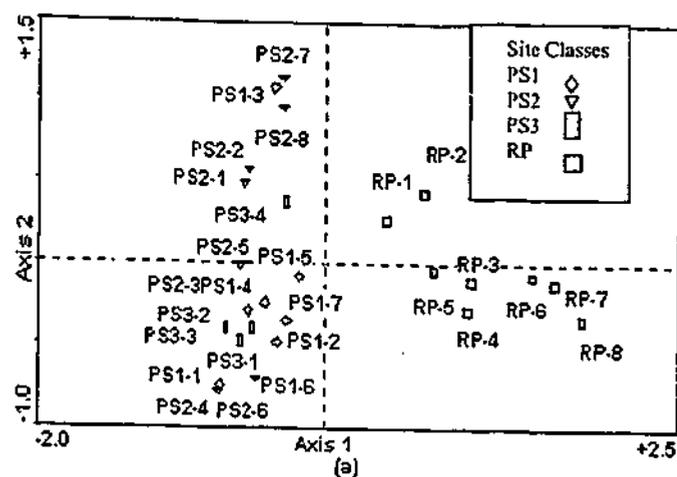
(Agla ;*Aglaia*, Ant;*Antidesma*, Apo;*Aporusa*, Arto;*Artocarpus*, Bacc;*Baccaurea*, Bau;*Bauhinia*, Buc;*Buchanannia*, Calo;*Calophyllum*, Camp;*Campnosperma*, Cass;*Cassia*, Comb;*Combretocarpus*, Crud;*Crudia*, Desm;*Desmodium*, Dial;*Dialium*, Dich;*Dichilanthe borneensis*, Dill;*Dillenia*, Dios;*Diospyros*, Dry;*Dryobalanops*, Dye;*Dyera*, Elae;*Elaeocarpus*, Eug;*Eugenia*, Exc;*Excoecaria*, Fag;*Fagrae fragrans*, Fla;*Flacourtia*, Gar;*Garcinia*, Gloc;*Glochidion*, Glu;*Gluta*, Hom;*Homalium*, Hop;*Hopea*, Ixo;*Ixora*, King;*Kingiodendron*, Koo;*Koompasia*, Lepi;*Lepisanthes*, Lith;*Lithocarpus*, Lits;*Litsea*, Maca;*Macaranga*, Mang;*Mangifera*, Meme;*Memecylon*, Mes;*Mesua*, Mor;*Morinda*, Myri;*Myristica*, Nauc;*Nauclea*, Neos;*Neoschortechinia*, Nep;*Nephelium*, Pala;*Palaquium*, Pell;*Pellacalyx*, Ptern;*Pternandra*, Sant;*Santiria*, Sapi;*Sapium discolor*, Seme;*Semecarpus*, Shor;*Shorea*, Sind;*Sindora*, Swin;*Swintonia*, Trem;*Trema*, Tris;*Tristaniopsis*, Vat;*Vatica*, Xero;*Xerospermum*)

Figure 6.2. CA ordination diagram for basal area data, showing site scores (a) and species scores (b)

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Most pollen taxa recorded in all samples are most likely derived from local peatland tree taxa such as *Macaranga/Mallotus* comp., *Terminalia* sim., Dipterocarpaceae comp., *Calophyllum*, Anacardiaceae, Arecaceae, *Eugenia/Syzygium*, *Garcinia*, and *Pandanus*. In accordance with Giesen's (1987, 1996) reports, aquatic plants are rarely recorded. *Ludwigia* sim. is the only aquatic pollen taxon recorded, in one sample from Lake Lukuk. This aquatic pollen is probably derived from *Ludwigia hyssopifolia* because this aquatic species is found in the lake region (Giesen 1987). Significant values for Cyperaceae, Poaceae, and *Lygodium macrophyllum*, monolete and trilete spores are recorded in the samples from the abandoned shifting cultivation (RP sites), while the former two taxa are also prevalent in samples from Lake Lukuk (LL sites).

6.5.2.1. Sample groups

Lake Lukuk (LL)

The composition of pollen spectra in this group reflects predominantly local vegetation around the lake and in riparian forest, while pollen taxa commonly associated with peatland and dryland forest are poorly represented. Pollen values of Dipterocarpaceae comp., Arecaceae comp., *Macaranga/Mallotus* comp., *Barringtonia*, *Calophyllum*, and *Mentangis* sim. are high throughout the whole group. Pollen of *Dillenia* is also consistently represented. Herb pollen (Poaceae and Cyperaceae) and pteridophyte spores are relatively well represented. *Pandanus* percentages are high in two samples but extremely low in LL-2 sample. However,

Pandanus pollen is relatively well represented in all samples from LL site. Pollen from *Trema,* Asteraceae, and Ulmaceae is absent, while pollen of *Terminalia* occurs only in one sample. Pollen percentages of *Palaquium* are low but persistent. Single values for *Ludwigia* and *Baccaurea* provide the only representation of these taxa in this analysis.

Riparian sites (RP)

The composition of pollen taxa changes markedly in this group. Disturbance taxa such as *Trema,* and *Macaranga/Mallotus* comp. are substantial. Values for *Pandanus,* Cyperaceae and Poaceae are consistently high, and values for monolete and trilete spores are the highest in this RP site. Values of Dipterocarpaceae comp. and Anacardiaceae are moderate but variable, while pollen values for *Eugenia* are extremely high in samples RP-1 and RP-6. Pollen of *Calophyllum* is persistent and particularly high in samples RP-3 and RP-8. *Mentangis* is recorded only in samples RP-1 and RP-2, and pollen of *Elaeocarpus* is high in sample RP-4.

Presently logged peatland forest (PS3)

PS3 site consists of samples PS3-1 to PS3-4. Pollen, values for Anacardiaceae (PS3-3 and PS3-4), and *Terminalia* (PS3-1 and PS3-2) are consistently high, while other pollen taxa are poorly represented. *Eugenia* pollen is consistently present in low values. Pollen of *Microcos* is found only in sample PS3-3. Values for *Palaquium,* and Dipterocarpaceae comp. are low, and values for *Calophyllum* are consistently high. Total herbs and ferns are the lowest for the diagram.
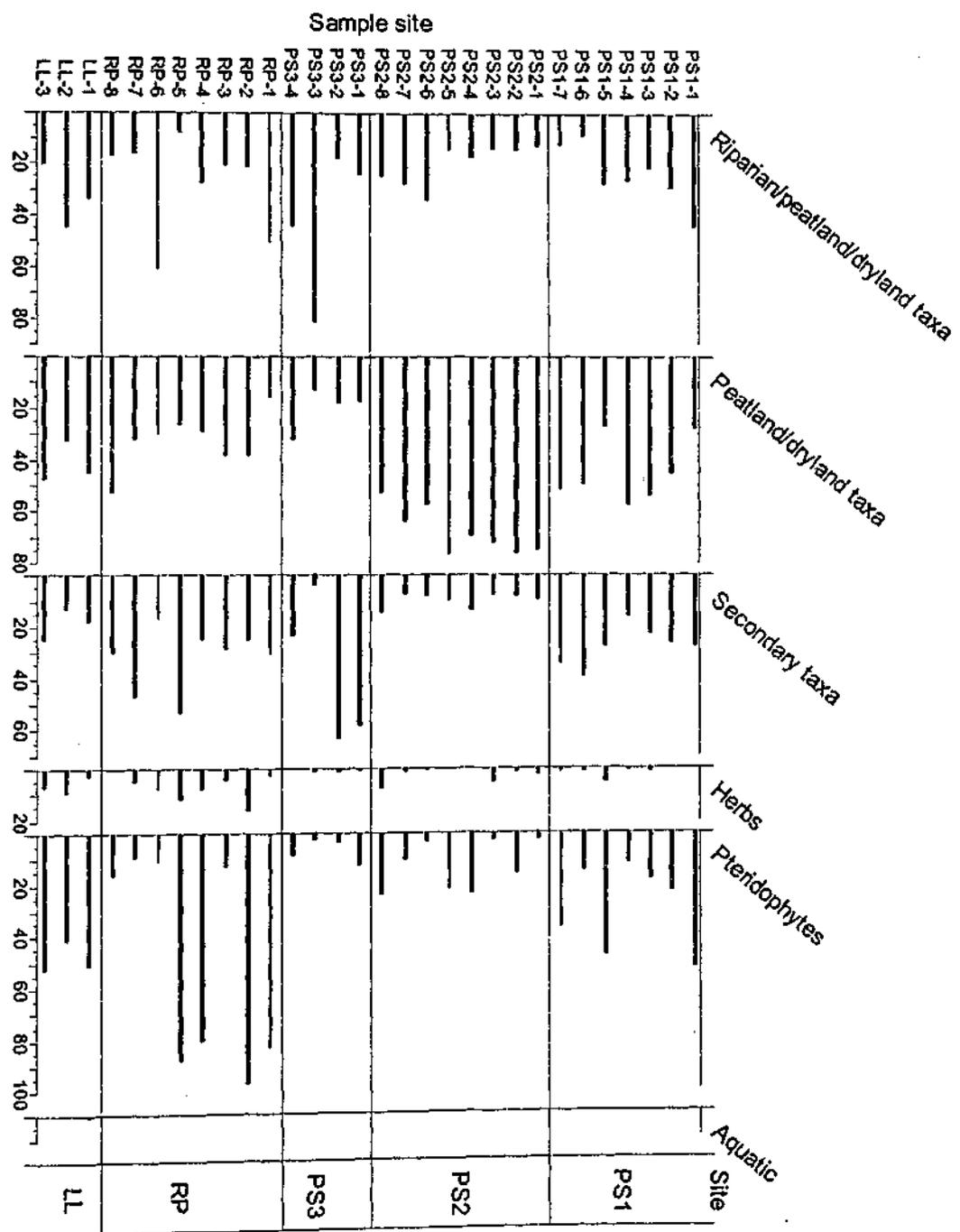
Figure 6.3.a. A summary pollen diagram for modern pollen spectra

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Figure 6.3.b. Percentage of basal area (hollow histogram bars) for present floristic data, and modern pollen rain (solid histogram bars) of riparian/peatland/dryland taxa, and peatland/dryland taxa
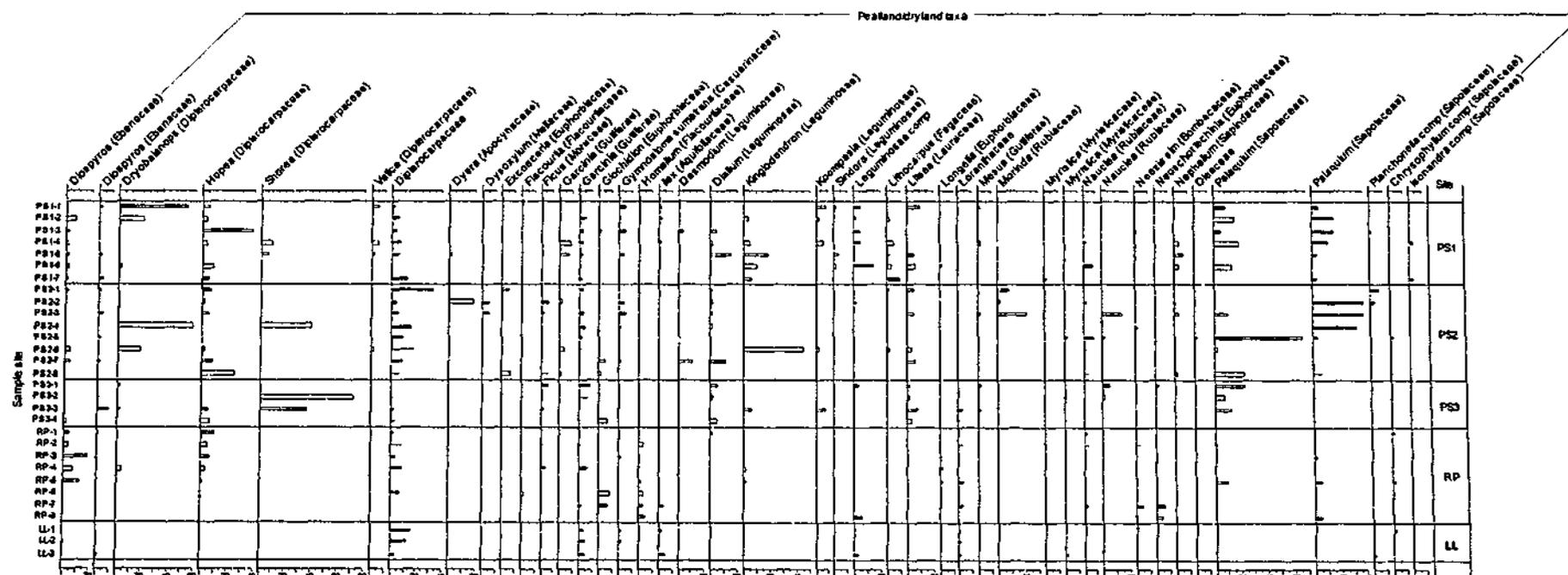
Figure 6.3.c. Percentage of basal area (hollow histogram bars) for present floristic data,
and modern pollen rain (solid histogram bars) of peatland/dryland taxa (continued)
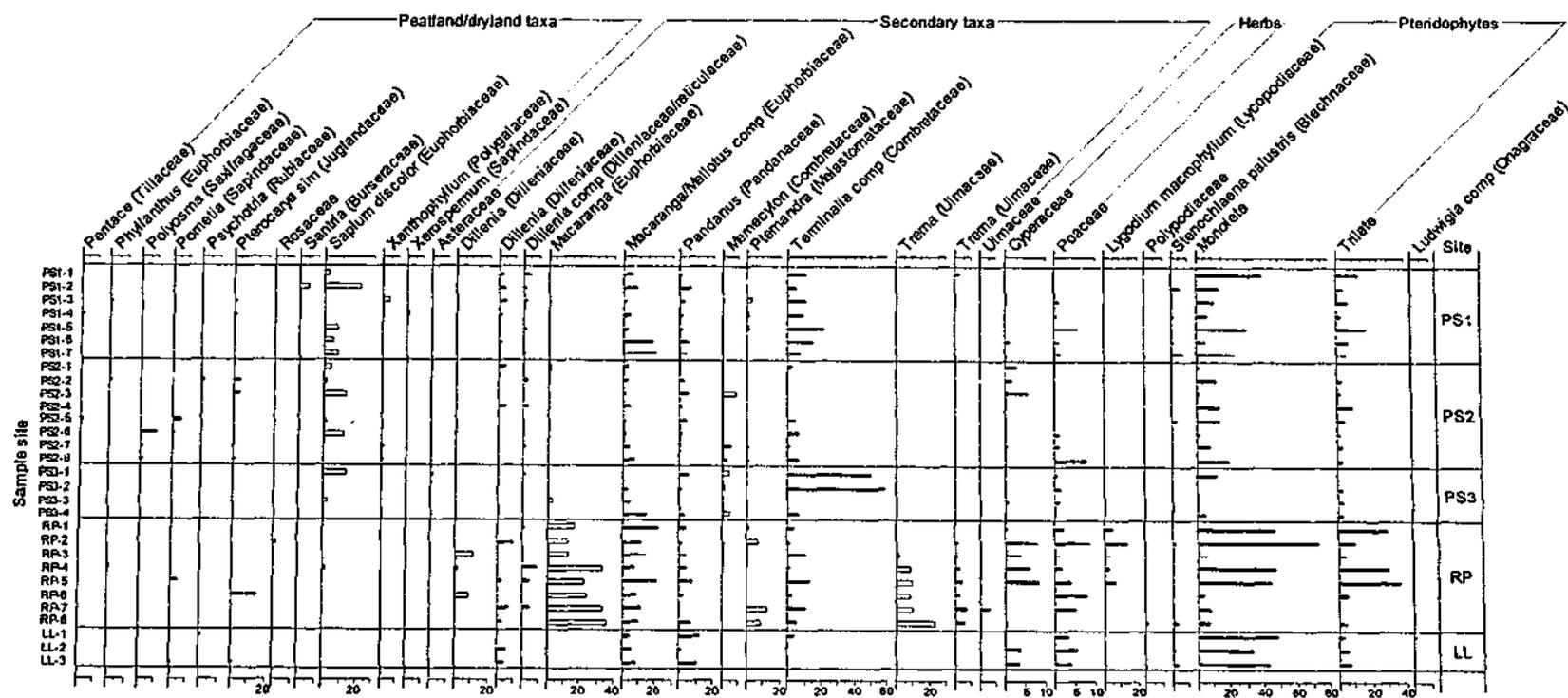
Figure 6.3.d. The continued percentage of basal area (hollow histogram bars) for present floristic data, and modern pollen rain (solid histogram bars) for peatland/dryland taxa (continued), secondary taxa, herbs and pteridophytes

Previously logged peatland forest (PS2)

In this group, pollen of Dipterocarpaceae comp. is consistently recorded and the highest for the modern pollen spectra. Pollen values for *Calophyllum* are high in the first two samples of the group, while pollen values for *Palaquium* are very high in three samples (PS2-2, PS2-3, and PS2-4). From the riparian/peatland/dryland taxa, Anacardiaceae comp. pollen and *Eugenia* are recorded consistently, while pollen values for undifferentiated monolete and trilete spores are consistently represented. Overall, values for other pollen taxa from trees and shrubs are low, although *Gymnostoma sumatrana, Combretocarpus rotundatus,* and *Dysoxylum* values are notable. Pollen of Poaceae is present in sample PS2-8, PS2-7 and PS2-6, but is absent in the other samples within this group. By contrast, pollen of Cyperaceae is present in samples PS2-1, PS2-2, and PS2-3, but is completely absent in the other samples (PS2-4 to PS2-8).

Preserved peatland forest (PS1)

Pollen taxa recorded in PS1 samples are relatively similar to those taxa found in PS2. Arecaceae comp., *Eugenia, Terminalia, Macaranga/Mallotus,* and *Pandanus* pollen and undifferentiated monolete and trilete spores are consistently represented. Pollen values of *Palaquium* are high in samples PS1-1 to PS1-4. *Calophyllum* is consistently present and high in samples PS1-6, and PS1-7. Dipterocarpaceae comp. Is consistently present in samples PS1-2, PS1-3, PS1-4, PS1-5, and PS1-7, while *Mentangis* sim. is well represented in samples PS1-1 and PS1-2. *Stenochlaena palustris* is variably present.

6.6. Numerical analysis

Results of Ward's classification and the stratigraphically unconstrained classification of modern pollen spectra from CONISS are presented in Figures 6.4. and 6.5. Results of these cluster analyses show comparable dendrogram trees. Both identify two major groups, but provide little systematic distinction between habitat types. Riparian sampling sites (RP) are classified similar to LL, PS1 and PS2 sites, while PS3 sites share some similarities to PS2 sites. The inundated nature of sample site PS1-1 may explain why this site is more similar to LL and RP sites, while several RP sites are relatively well forested and show greatest resemblance to PS1 sites.

Table 6.6 presents summary results of the first four CA axes, while Figure 6.6 presents the CA ordination diagram for site and pollen scores on the first two axes.

Axis 1 explains about 12% variance of pollen taxa, while axes 2 and 3 explain slightly less variance (about 11% and 9%) respectively. Figure 6.6a shows that PS2-2 and PS2-3 are separated from the others along the first axis. Pollen of *Dysoxylum, Pterocarya, Phyllanthus, Psychotria,* and *Ixora* has a strong influence on the isolation of three samples. PS2-1, PS2-4, and PS2-8 form a slightly separate cluster in the upper right quadrant, influenced by *Planchonella, Diospyros, Combretocarpus rotundatus* and *Ficus.*
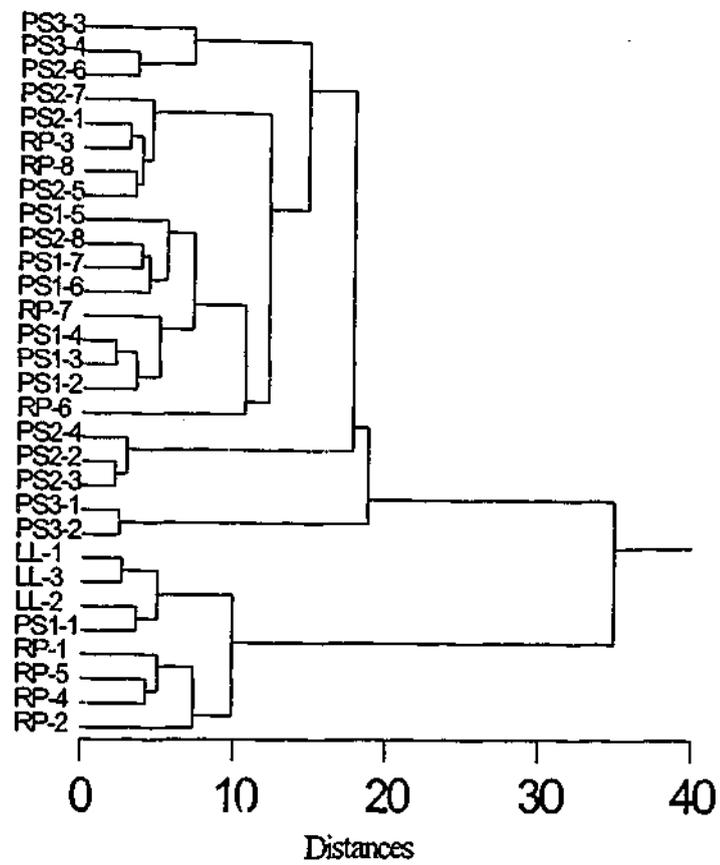
Figure 6.4. Dendrogram for modern pollen spectra, based on Ward's method
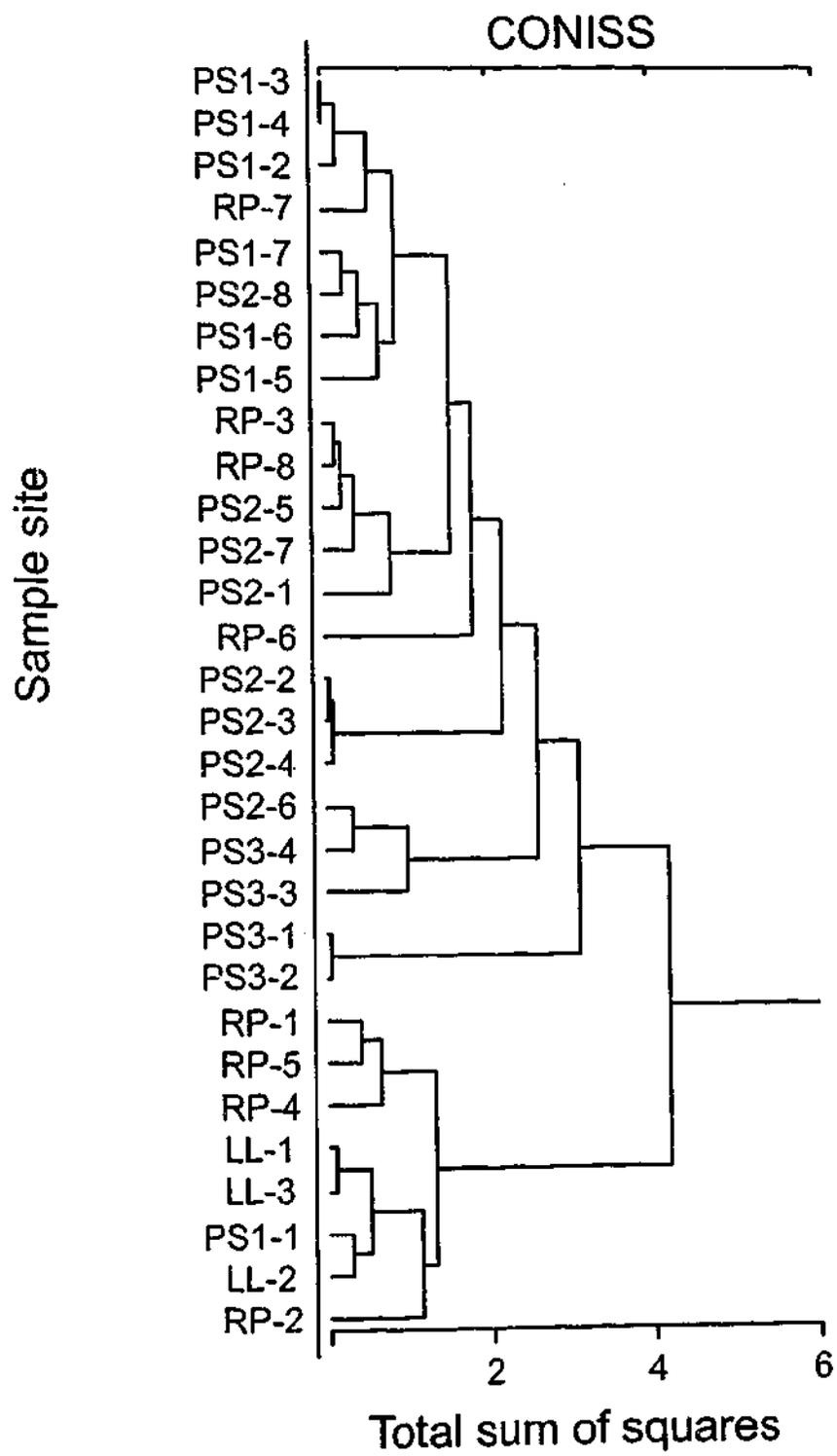
Figure 6.5. Dendrogram of unconstrained analysis (CONISS) for modern spectra
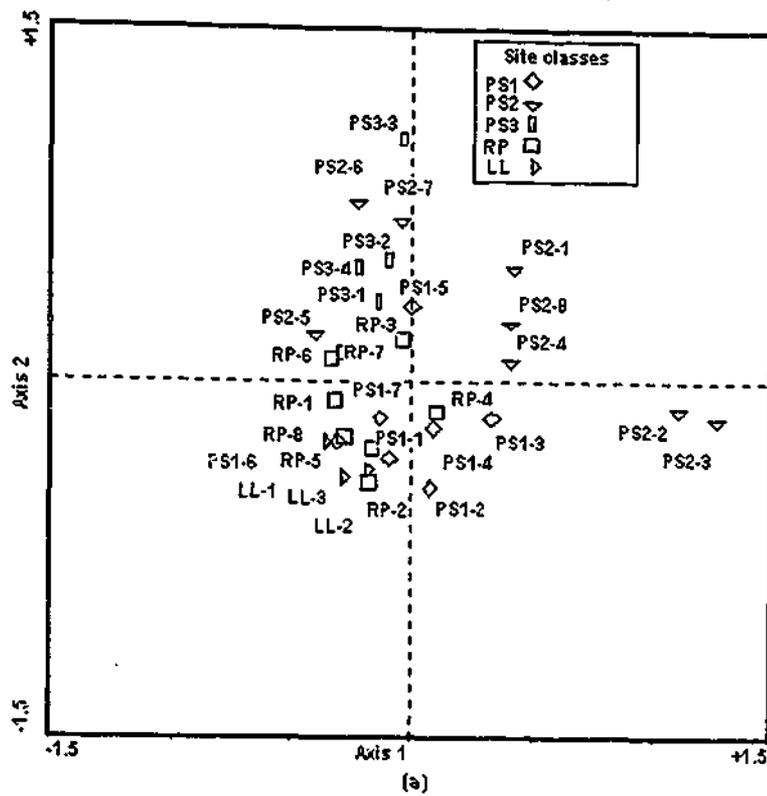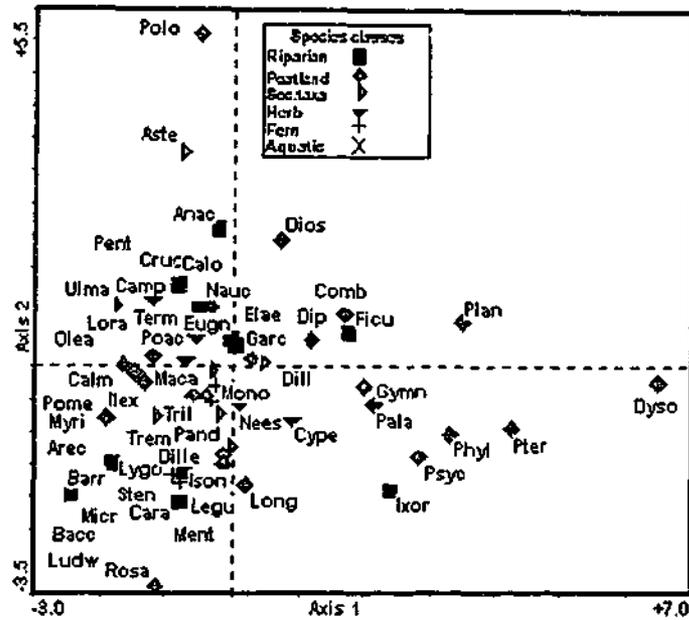
(Anacardiaceae, Anac; Arecaceae comp., Arec; Asteraceae, Aste; *Baccaurea*, Bacc; *Barringtonia*, Barr; *Calamus*, Calm; *Calophyllum*, Calo; *Campnosperma*, Camp; *Carallia*, Cara; *Chrysophyllum*, Chry; *Combretocarpus rotundatus*, Comb; *Crudia*, Crud; Cyperaceae, Cype; *Dillenia*, Dill; *Dillenia Reticulate* sim., Dille; *Diospyros*, Dios; Dipterocarpaceae comp., Dip; *Dysoxylum*, Dyso; *Elaeocarpus*, Elae; *Eugenia*, Euge; *Ficus*, Ficu; *Garcinia*, Garc; *Gymnostoma sumatrana*, Gymn; *Ilex*, Ilex; *Ixora*, Ixor; *Isonandra*, Ison; Leguminosae comp., Legu; *Longetia*, Long; Loranthaceae, Lora; *Ludwigia*, Ludw; *Lygodium macrophyllum*, Lygo; *Macaranga*, Maca; *Mentangis* sim., Ment; monolete, Mono; *Microcos*, Micr; *Myristica*, Myri; *Nauclea*, Nauc; *Neesia*, Nees; Oleaceae, Olea; *Palaquium*, Pala; *Pandanus*, Pano; *Pentace*, Pent; *Phyllathus*, Phyl; *Psychotria*, Psyc; *Planchonella*, Plan; Poaceae, Poac; *Polyosma*, Polo; *Pomelia*, Pome; *Pterocarya*, Pter; Rosaceae, Rosa; *Stenochlaena palustris*; Sten; *Terminalia*, Term; *Trema*, Trem; trilete, Tril; Ulmaceae, Ulma)

Figure 6.6. CA ordination diagram of modern pollen data, showing site scores (a), and pollen scores (b)

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This diagram also indicates that most RP sites are mixed with PS1, PS2, PS3, and LL sites. RP-4 forms a loose cluster with PS1-2, PS1-3, and PS1-4 (in the lower right quadrant), and RP-1, RP-2, RP-5, and RP-8 sites are mixed with PS1-1, PS1-6, PS1-7, LL-1, LL-2, and LL-3 (in the lower left quadrant). This intermixed pattern shown on axis 1 indicates that pollen taxa derived from each site (PS1, PS2, PS3, RP, and LL) are not clearly separated. On axis 2, PS3-3 is separated from the others, probably due to the influence of Asteraceae, Anacardiaceae comp., and *Polyosma*.

Table 6.6. Summary results of CA for modern pollen spectra

Axes	1	2	3	4	Total inertia
Eigenvalues	.152	.129	.114	.105	
Cumulative variance of species data (%)	12.6	23.3	32.7	41.5	
Sum of all unconstrained eigenvalues					1.207

6.7. Discussion

6.7.1. Pollen-vegetation relationships

The representation of identifiable plant taxa in the modern pollen spectra is relatively poor. Only 19 present plant taxa recorded in the floristic survey are found in pollen spectra. These pollen grains include *Calophyllum, Campnosperma, Crudia, Dillenia,* Anacardiaceae, Leguminosae comp., Dipterocarpaceae comp., *Carallia, Ixora, Combretocarpus rotundatus, Elaeocarpus, Diospyros, Eugenia, Garcinia, Palaquium, Macaranga/Mallotus* type, *Nauclea, Terminalia* sim., and *Trema.*

The absence of many other plant taxa in the modern pollen spectra from the Lake Sentarum could be the result of a number of factors. Many recorded plant taxa such as Dipterocarp, *Barringtonia,* and *Palaquium,* are pollinated by insects, such as bees, thrips, and flies. Secondly, storms are not common within the tropical forests. The predominant mode of insect pollination and non-windy conditions in the humid climate restrict pollen dispersal within the tropical forests. Further, many of tropical trees such as the dipterocarps have irregular flowering periodicity, and are low pollen producers, compared to wind-pollinated taxa.

Furthermore, there is a non-linear relationship between percentage representation of pollen and possible source plants. This is probably due to the collection of pollen from only one spot within each vegetation plot as well as the pollen production and dispersal characteristics of plants already

mentioned. More detailed examination of specific pollen-plant relationships is discussed in the following section.

6.7.2. Pollen representation

Results of CA suggest that variations in pollen spectra between sample sites are relatively small, and there is no clear separation between sample sites. Despite this generalisation, it seems that several densely forested sites have much more restricted pollen representation than more open sites. Peatland taxa such as *Palaquium*, Dipterocarpaceae comp., *Gymnostoma sumatrana*, *Garcinia*, *Nauclea*, *Diospyros*, and *Combretocarpus rotundatus* are relatively well associated with PS1, PS2, and PS3 sites (see the right side of the ordination diagrams), while secondary taxa such as *Trema*, *Macaranga/Mallotus* type, *Dillenia* (both smooth and reticulate types) characterise more open vegetation (RP samples). However, secondary taxa are also present in the forest, and may indicate local forest disturbance, while the occurrence of pollen from peatland taxa in the open sites indicates that pollen of peatland taxa can be transported to open forest (RP and LL sites).

The major sources of Dipterocarpaceae pollen are likely to be *Dryobalanops*, *Hopea*, *Shorea*, and *Vatica*. The wide distribution of Dipterocarpaceae within this forested region is indicated by the occurrence of its pollen in PS1, PS2, and PS3 sites. The presence of Dipterocarp pollen in RP and LL sites indicates that the pollen is transported to these sites. Dipterocarpaceae comp. pollen in this study was found in relatively low values, compared to representation of the family in this region. This family

is pollinated by insects (Ashton 1982), and is a low pollen producer. Bera (1990) estimated that *Shorea* produces 61,000-94,000 pollen grains per flower, while a flower of wind pollinated plants may produce an order of magnitude more pollen. Furthermore, infrequent flowering may have distorted the relationship between plant abundance and pollen representation in the surface samples.

Pollen of *Calophyllum* is very common in PS2 and LL sites. *Calophyllum* trees were recorded in several sites, particularly PS3, although this pollen was poorly recorded in sample plots at PS3. The presence of *Calophyllum* pollen in LL samples may indicate that *Calophyllum* pollen is transported to Lake Lukuk, probably via water. This interpretation suggests that the source of *Calophyllum* pollen may be from surrounding forests.

Similarly, pollen of Anacardiaceae was consistently recorded in sample plots at PS1, PS2, and PS3, and was also commonly encountered at RP and LL. Anacardiaceae comp. pollen is possibly derived from *Swintonia* and *Semecarpus*. Pollen of Anacardiaceae is abundant in samples at PS3, although the identifiable Anacardiaceae trees were not recorded in these sites. It is possible that other, unidentified trees are contributing to this component. Flowering season of Anacardiaceae is very likely annual, and many of the component species produce abundant flowers (Hou 1998).

Pollen of *Palaquium* is abundant in several samples from PS1 and PS2 sites, while the trees are common in all PS forest sites. The overall pattern suggests that high pollen values are a good indication of the local

presence of trees but low values cannot be taken as an indication of local absence.

Combretocarpus rotundatus is most likely a species with restricted distribution in the region today as it has only minor representation in tree and pollen form. However, occurrences are limited to PS1 samples suggesting this is the preferred environment of the species.

Pollen of *Diospyros* was consistently found in PS1, PS2, and PS3 sites, but poorly recorded in RP and LL sites. Conversely, *Diospyros* trees were relatively more common in RP sites than other sites (PS1, PS2, and PS3). This may suggest that different species are involved.

Trees of *Garcinia* were found in PS1 and PS2 sites. Pollen of *Garcinia* was consistently recorded through the whole record. The presence of *Garcinia* pollen in samples at PS3, RP, and LL suggests that this pollen was transported from forests to open sites, and therefore is widely dispersed.

Leguminosae comp. pollen could be derived from a number of genera including *Koompasia, Desmodium, Cassia, Dialium, Sindora,* and *Kingiodendron*. Trees of Leguminosae are widely distributed in sample plots at PS1, PS2 and PS3, but derived pollen is mainly restricted to PS1 sites. I appears that this pollen type is under-represented.

Nauclea pollen was generally recorded in low values. *Nauclea* trees were recorded in main plots at PS2 and PS3. The signature of *Nauclea* pollen indicates that this taxon is widely distributed in this region.

Calamus pollen is rarely recorded. Although *Calamus* is advantaged by human disturbance, it declines when disturbance levels are high. *Calamus* is widely used by local peoples for various purposes, such as

sleeping mats, hats, fish traps, and furniture.

Arecaceae comp. pollen is consistently recorded. The sources of this pollen type are unknown, but it is probably derived from several palms. By contrast, no single *Gymnostoma sumatrana* tree was recorded in the sample sites, but its pollen is consistently present in PS1 and PS2 sites. It is probable that this pollen is transported by wind to samples at PS1 and PS2.

From riparian taxa, *Barringtonia* was noted as a common taxon in the inundated dwarf swamp forest at Lake Lukuk. Its pollen was consistently recorded in samples at LL. The source of this pollen could be from a number of *Barringtonia* species, especially *B. acutangula* and *B. reticulata*. *Barringtonia* trees predominantly occur in the inundated dwarf swamp forest (Giesen 1987). Lim (1998) noted that most species of *Barringtonia* flower regularly, almost throughout the year, but seldom reach full bloom. Bats and insects (probably moths and honey bees) are known as the pollination agents of *Barringtonia*. The signature of *Barringtonia* pollen suggests that this pollen is well preserved in lake sediment adjacent to stands of the species.

Eugenia/Syzygium pollen was commonly recorded in the modern pollen spectra. It may derive predominantly from *Eugenia*, whose trees were encountered in plots at PS1, PS2, and PS3. *Eugenia* frequently bears flowers, twice or three times a year (Morton 1987) and its pollen grains may be dispersed by insects, wind and water. Consistent values of *Eugenia* pollen in all samples indicate that *Eugenia* in this region is widely distributed.

Crudia pollen was occasionally recorded in PS1, PS2, PS3, and LL

samples. It is unknown why *Crudia* pollen was not encountered in samples at RP, as *Crudia* trees were consistently recorded at this site.

Ixora pollen was recorded in few samples at PS1 and PS2. This species has preferred flowering seasons, but few species are observed to bear flowers all year. Pollination is by insects, particularly moths and butterflies (Utomo 1998).

The source of *Mentangis* sim. pollen is probably from *Ixora mentangis* and other species of Rubiaceae. Giesen (1987) reported that *I. mentangis* commonly occurs with *Barringtonia* in the dwarf swamp forest around the lakes. It seems that high values of this pollen in LL sites reflect local parent trees, while high values in PS1 sites may indicate that the source of this pollen could be also from other species of Rubiaceae. This makes the use of *Mentangis* pollen type as an environmental indicator taxon uncertain.

Secondary pollen taxa include *Dillenia*, *Macaranga/Mallotus* comp., *Pandanus*, *Terminalia*, and *Trema*. *Dillenia* is a common secondary taxon that was recorded more commonly at RP than at other sites.

Macaranga/Mallotus pollen was consistently recorded in samples at all sites, although higher in samples at RP than other sites. This suggests a close relation between this pollen and its parent plants at RP. The occurrence of its pollen in samples at peatland sites suggests that *Macaranga/Mallotus* taxa also occur in peatland forest. The main source of *Macaranga/Mallotus* pollen type is likely to be *Macaranga* and *Mallotus* regrowth in disturbed and open forests (Lim 1998). *Macaranga* produces

abundant pollen grains, and flowers several times a year. Even a young tree of *Macaranga* may bear flowers (Lim 1998).

Pandanus pollen is also widely recorded. Consistent values of *Pandanus* pollen are thought to have strong correlation with forest disturbance because *Pandanus* leaves are intensively harvested by local people and used to make traditional mats, hats and other weaving crafts in the lake region. This tree has a positive response to forest disturbance and may become abundant in open and disturbed forest sites. Morley (1981a; 1982b) found that *Pandanus* pollen dominated the Tasekbera pollen record because this tree predominantly occurred around the core sites. When forest is cleared, *Pandanus* is simply left on the disturbed site (Stone 1992).

Trema pollen is restricted to RP sites. The signature of this pollen suggests that *Trema* pollen is a good indicator of disturbed sites. By contrast, the signature of *Terminalia* pollen is difficult to interpret because pollen of *Terminalia* sim. is probably derived from a number of taxa including *Memecylon*, *Melastoma*, and *Pternandra*. *Melastoma* and *Memecylon* are common taxa in disturbed sites, but *Pternandra* may occur on forested peatland as well as in old secondary forest. It is possible that the presence of *Terminalia* sim. pollen does not necessarily reflect forest disturbance. *Terminalia* taxa are seen to flower frequently and probably produce abundant pollen grains (Boer 1998). The distribution of *Memecylon* is relatively wide, but some species prefer open sites (Haron 1998).

Herbs are poorly represented in these modern pollen spectra. This is a reflection of the fact that the Lake Sentarum region is largely forested. However, good representation of herbs and fern spores in RP sites indicate open vegetation, and probably the inundated nature of this riparian forest.

These modern pollen spectra, overall, reflect local vegetation communities and the present environments of Lake Sentarum. Most pollen taxa are derived from local parent plants that occur in both plots (PS1, PS2, PS3, and RP) and surrounding forests in the lake region. Both the floristic data and pollen spectra reflect the fact that the Lake Sentarum region is largely forested, but with some degree of disturbance. Forest disturbance is even evident in PS1 sites, which were previously thought to be free from human impact. It is possible though that disturbance is not caused by humans, but it is simply a reflection of the natural dynamics of the system. Other sample sites (PS2, PS3, RP and LL) strongly indicate human influence. It seems that PS1 and PS2 sites are less disturbed than RP sites. Pteridophytes are relatively high in RP sites, probably also reflecting the effect of regular floods that carry fern spores. LL sites have good representation of the present vegetation communities. The presence of the aquatic taxon (*Ludwigia* sim.) in sample LL-1 clearly represents open water.

Only a few of the pollen spectra from forested sites (PS1, PS2, and PS3) reflect the composition of the present vegetation. A poor relation between modern pollen spectra and the present vegetation in tropical forest was also reported by Flenley (1973) and (Payawal 1981). This study shows that pollen of *Calophyllum, Palaquium,* and Dipterocarpaceae are strongly associated with forested sites, while high pollen values for *Macaranga, Dillenia, Trema,* Poaceae, Cyperaceae, monolete and trilete spores indicate more open habitat.

Chapter 7: The Fossil Pollen Records

7.1. Introduction

This chapter presents results of fossil pollen and charcoal analyses from the four cores (HN3, HN1, DP1, and DP4) and their interpretation individually. The results include sediment description, radiocarbon ^{14}C dates and pollen and charcoal diagrams. Patterns within the data are then examined by application of several numerical methods before interpretation. Individual interpretation of records is considered appropriate at this stage, due to the different environments from which the cores were collected, and their distinctive stratigraphies. Integration of sequences is attempted in chapter 8.

7.2. Core HN3

7.2.1. Sediment description

Core HN3 is composed entirely of peat and is short, only 124 cm in length. The core can be divided into three sections. From 0 to 66 cm depth is fibric peat with woody detritus. The middle section from 66 cm to 95 cm is humic peat, while the bottom section from 95 cm to 124 cm is fibric peat (Figure 7.2.a). The Munsell colours of these sections are difficult to separate. The colours overlap, from dull yellowish brown (10Y R4/3) to brown (10Y R4/4). The core is very moist, with an average moisture content of 78%, while the inorganic residue after ignition ranges from 1.1% to 7.4%.

The core is dated by seven radiocarbon (^{14}C) AMS dates and one conventional (^{14}C) date. These dates usefully conform to an age/depth sequence, and suggest that the core covers probably at least the last 30,000 years. Results of these radiocarbon dates are shown in Table 7.1.

Table 7.1. Results of radiocarbon age (^{14}C years BP) for core HN3

Sample ID	Depth (cm)	Radiocarbon Age (Years BP)	$\sigma^{13}C$ ($^o/_{oo}$)	Material dated	Remarks
OZE 133	14-15	265 ± 35	-30.0*	Pollen	AMS date
Wk 6278	41-42	1,366 ± 72	-29.9**	Pollen	AMS date
OZE 134	60-61	2,920 ± 50	-30.0*	Pollen	AMS date
Wk 6275	67-68	3,117 ± 57	-29.4**	Pollen	AMS date
OZE 135	71-72	13,070 ± 70	-30.0*	Pollen	AMS date
Wk 6277	91.5-92.5	16,840 ± 120	-29.5**	Pollen	AMS date
OZE 136	94-95	28,600 ± 250	-30.0*	Pollen	AMS date
Wk 5779	104-124	28,780 ± 100	-30.1±0.2**	Bulk sediment	Conv.date

Note: * estimated value; ** measured value; Wk (Waikato Radiocarbon Laboratory); OZE (ANSTO)

Figure 7.1 presents an age-depth curve for core HN3. From the topmost sample until about 70 cm depth, the ages of core HN3 range from 300 to 3,000 years BP. There is a likely hiatus between depths 70 cm and 93 cm as there is a 10,000 year difference in the ages. This may have occurred due to conditions being unfavourable for sediment accumulation or due to erosion of accumulated sediments with rapid global change after the height of the last glacial maximum (around 17,000 years BP). A similar situation most likely existed between samples at 92 and 94 cm where there is an age gap of at least

11,000 years, 16,840 to 28,600 years BP. Possible reasons for peat initiation, accumulation and erosion are discussed in section 7.2.6.
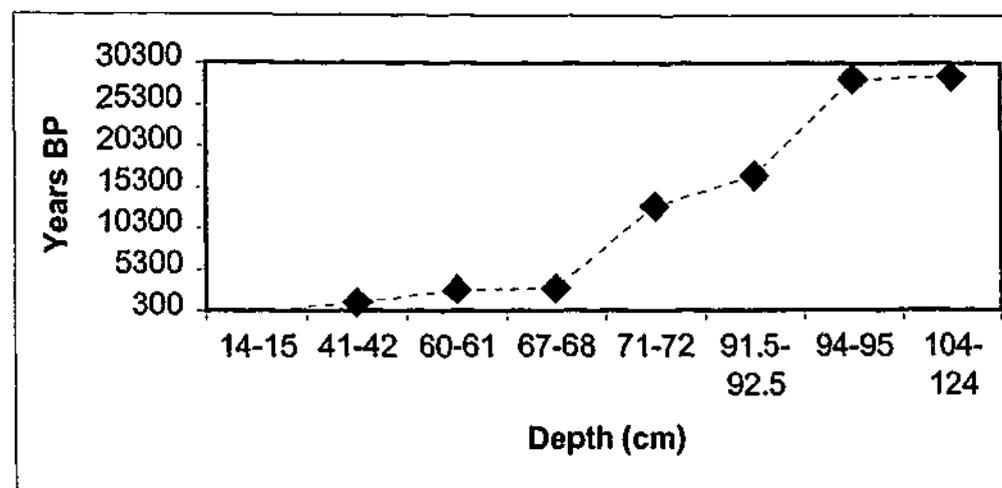
Figure 7.1. An age-depth curve for core HN3

7.2.2. Pollen diagram

Results of fossil pollen and microscopic charcoal analyses are presented in five pollen diagrams. Figure 7.1.a presents a pollen summary diagram with core stratigraphy, moisture content, inorganic residue, charcoal values, pollen concentration, and the dendrogram of stratigraphically constrained cluster analysis. Figures 7.2.b and 7.2.c present peatland/dryland taxa. Riparian/peatland/dryland and submontane and montane taxa groups are presented in Figure 7.1.d, while the remaining groups are given in Figure 7.1.e.
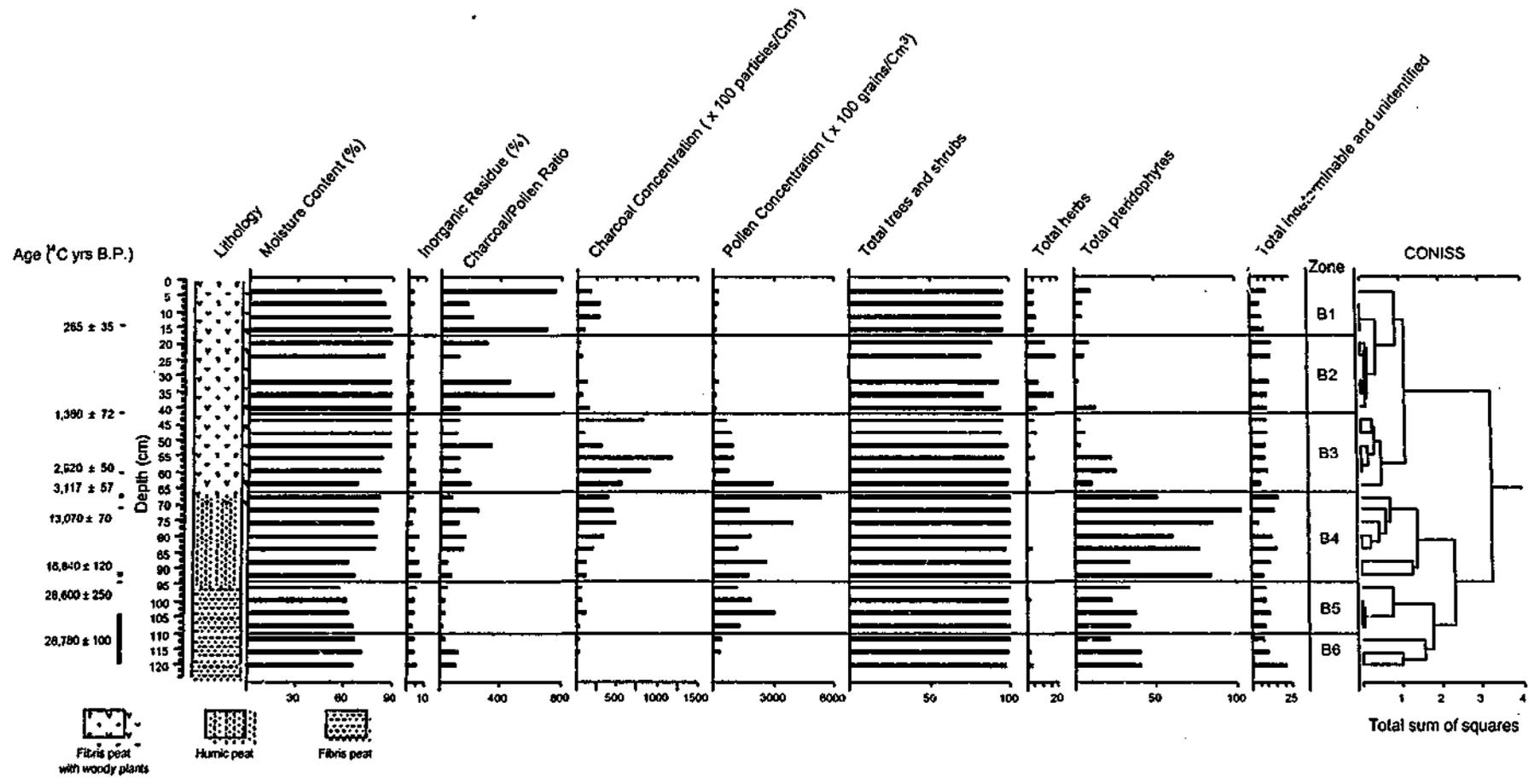
Figure 7.2.a. A summary pollen diagram of core HN3
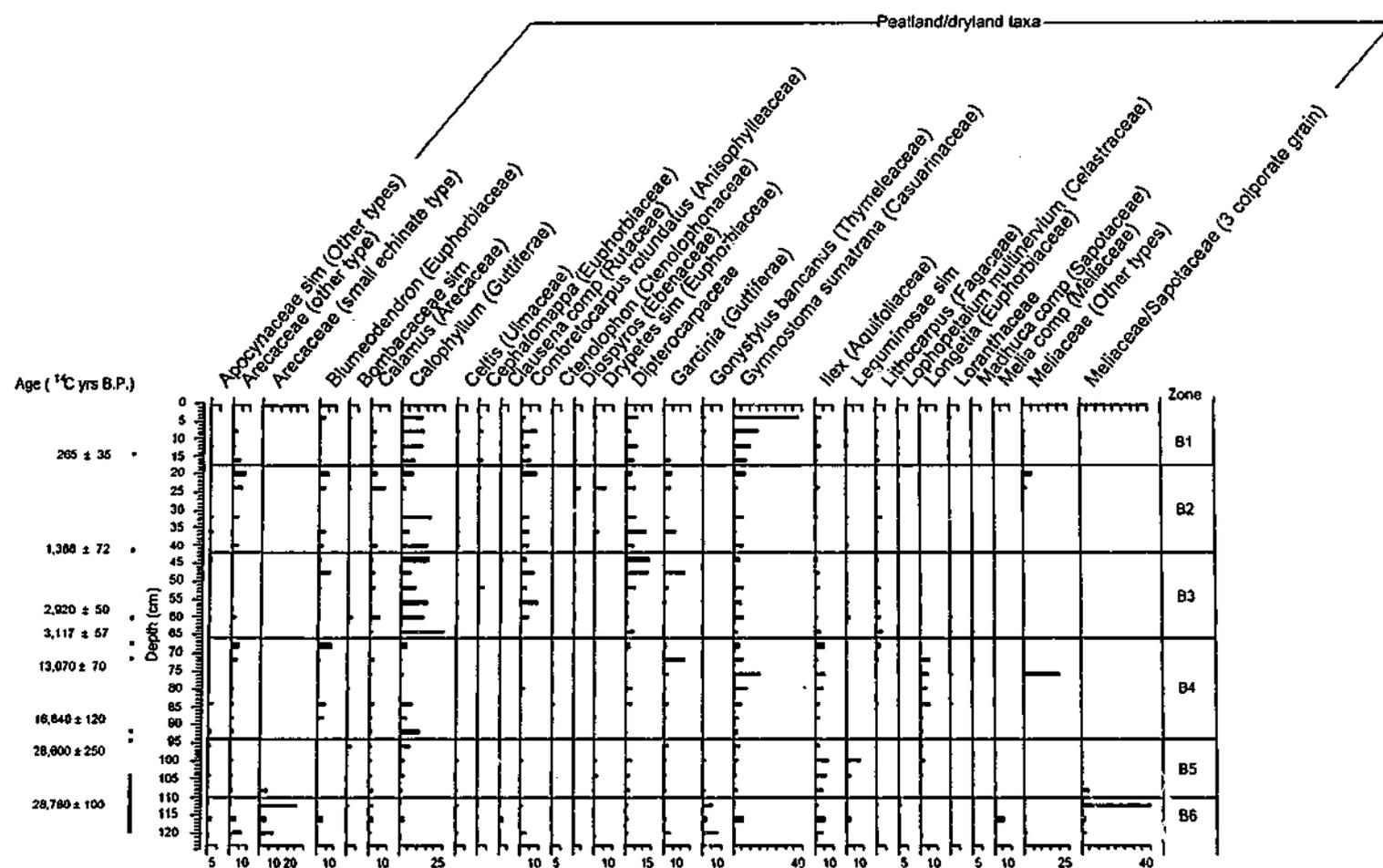
Figure 7.2.b. Pollen diagram of core HN3, showing peatland/dryland group
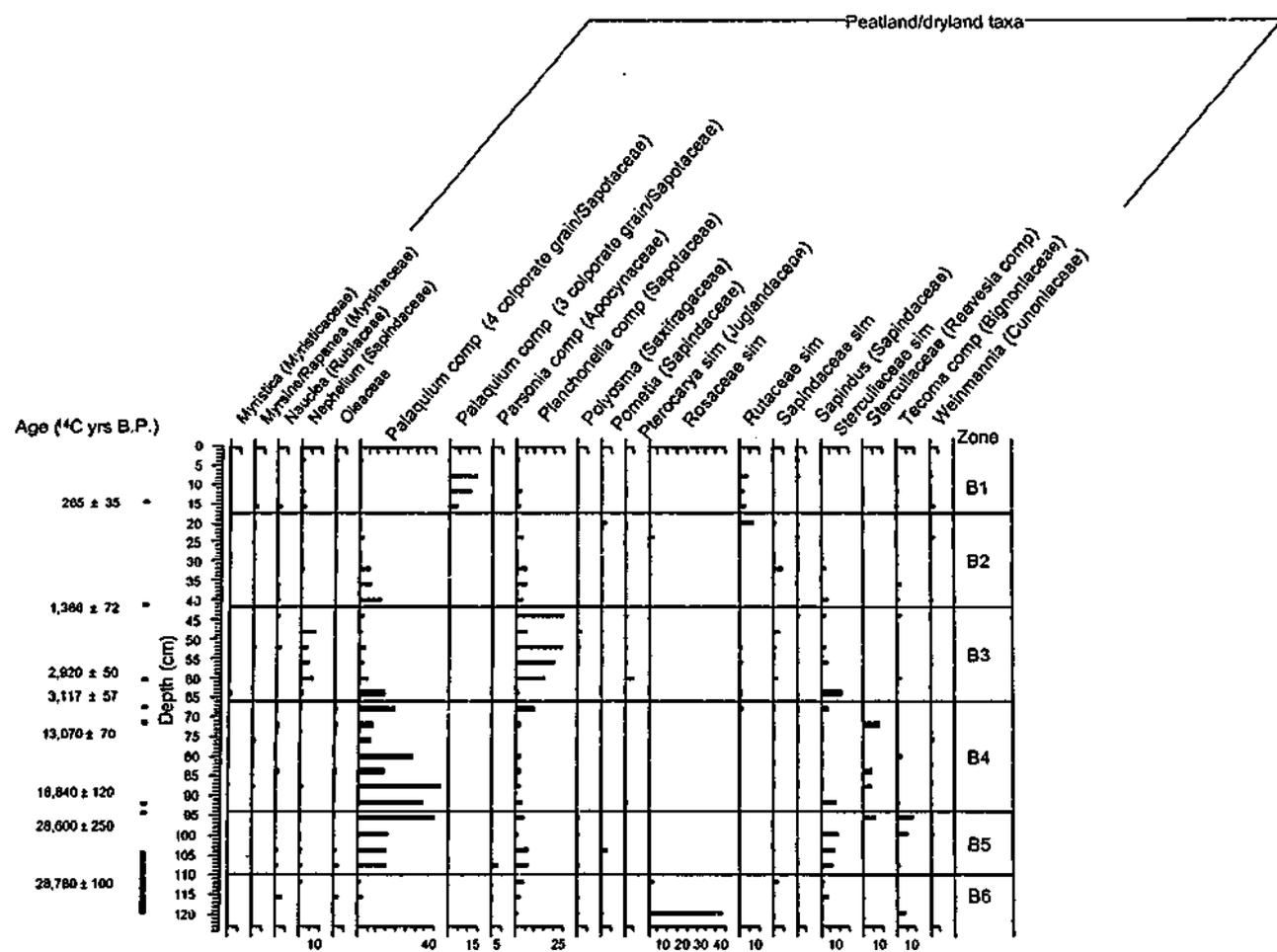
Figure 7.2.c. Pollen diagram of core HN3, showing peatland/dryland group (continued)
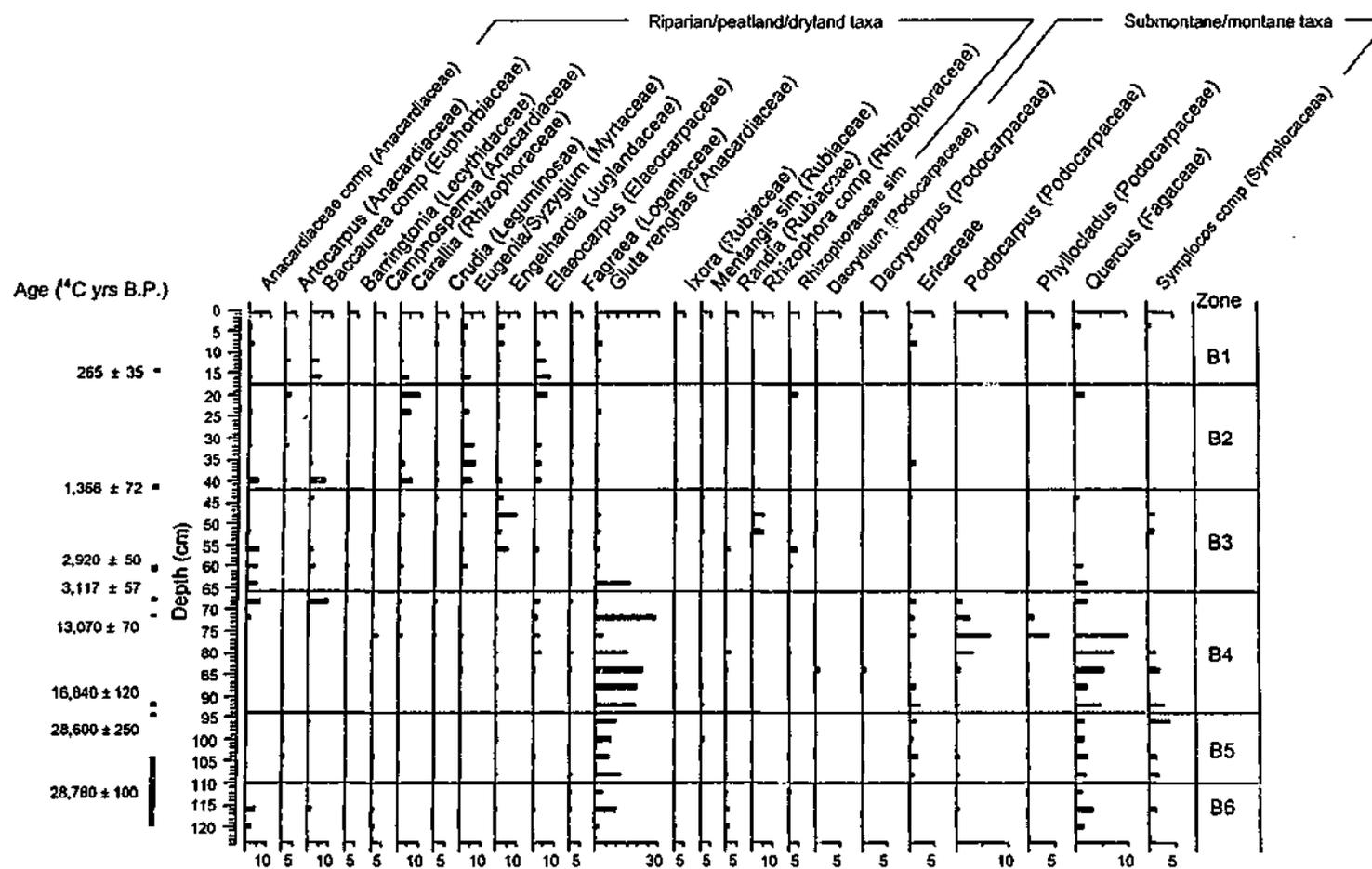
Figure 7.2.d. Pollen diagram of core HN3, showing riparian/peatland/dryland group and submontane/montane taxa
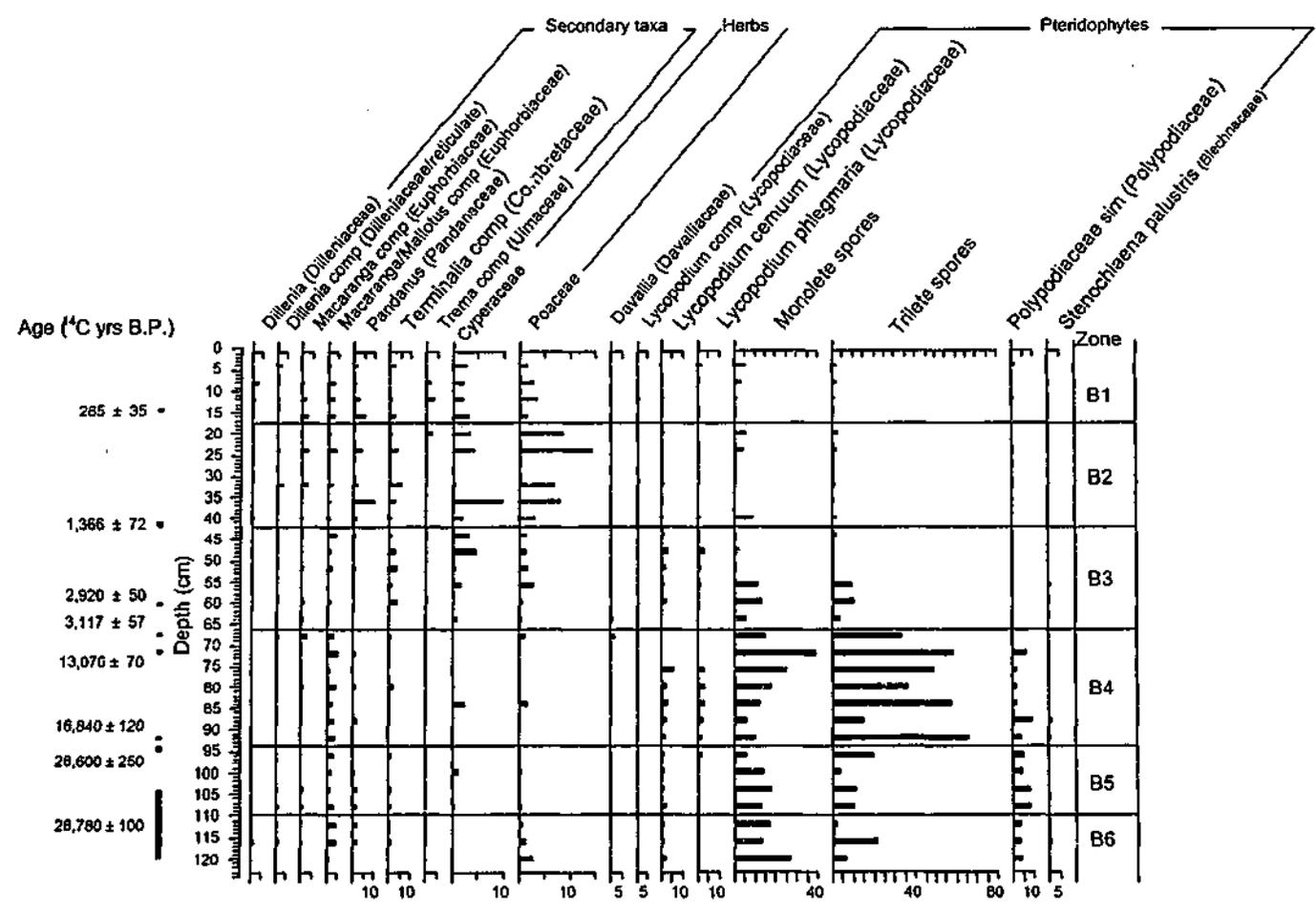
Figure 7.2.e. Pollen diagram of core HN3, showing secondary taxa, herbs and pteridophytes

In this record, 81 taxa of trees and shrubs were identified. Other taxa included herbs (Poaceae and Cyperaceae), and pteridophytes. No aquatic pollen taxa were found in this record. The proportion of indeterminable and unknown pollen grains varies between approximately 10 and 22%. Almost all of these unknown grains are probably derived from trees and shrubs because the herb flora is better known and herbs are rarely found in this record. Sapotaceae (*Palaquium* and *Planchonella*), *Calophyllum, Gymnostoma sumatrana*, Dipterocarpaceae, and Meliaceae dominate the peatland/dryland taxa group. *Gluta renghas, Carallia, Elaeocarpus,* and *Eugenia* characterise the riparian/peatland/dryland taxa. Values of secondary taxa, herbs, and submontane/montane taxa are consistently low (below 5%). Monolete and trilete spores are common. Other fern spores are Polypodiaceae, *Lycopodium cernuum,* and *L. phlegmaria.*

7.2.3. Pollen diagram zonation

Constrained cluster analysis was employed to assist in the zonation of the pollen diagrams (Figure 7.2.a). This classification, undertaken on all pollen and spore taxa, provides two major groups at the 3.3 dissimilarity level (samples 4 cm to 64 cm and samples 68 cm to 120 cm). Each group has been divided into three zones. Zones B1-B3 show high levels of internal spectrum similarity except for the topmost sample of zone B1. As the difference between this sample and others in B1 is the result largely of a single high value of *Gymnostoma sumatrana,* it is considered that this is insufficient to warrant a separate zone allocation. Internal variation between samples is greater in the

lower zones of B6-B4 but, again, much of this variation is caused by occasional high taxon values, which do not alter the general composition of zones.

Zone B6 (120-110 cm, three samples) > c. 30,000 years BP

A major component of this basal zone is the riparian tree *Gluta renghas,* while other riparian taxa such as *Campnosperma, Randia, Fagraea* and Anacardiaceae have consistent but low representation. From the peatland/dryland group, pollen values for Rosaceae and Meliaceae/Sapotaceae are erratic with single high values, while *Gonystylus bacanus* sim. and the small echinate palm have relatively high values throughout the zone. Dipterocarpaceae, *Ilex,* Leguminosae, Arecaceae, and *Calamus* are consistently recorded. Other taxa represented in this group are *Blumeodendron, Combretocarpus rotundatus, Calophyllum, Gymnostoma sumatrana, Lophopetalum, Melia,* Meliaceae, *Palaquium, Aglaia,* Bombacaceae, *Celtis, Clausena, Nauclea, Nephelium, Pterocarya* sim., Sapindaceae comp., and *Weinmannia.* Of the montane taxa, only *Quercus* is consistently present, while *Macaranga/Mallotus* comp. dominates the poorly represented secondary taxa. Of the non-woody taxa, Poaceae, *Lycopodium cernuum,* and Polypodiaceae sim. are consistently present, while values for monolete and trilete spores are relatively high. Both pollen and charcoal concentrations are low while charcoal/pollen ratios are notable.

Zone B5 (110 cm-94 cm, four samples) c. 30,000 – 28,000 years BP

Gluta renghas sim. has increased and is the only consistently recorded taxon in the riparian/peatland/dryland group. Pollen values for *Palaquium*

comp. are substantially higher, dominating the peatland/dryland group with *Planchonella* comp., *Gymnostoma sumatrana, Ilex, Calophyllum,* Dipterocarpaceae, Sterculiaceae, *Calamus, Garcinia, Longetia,* and *Tecoma* sim. are regularly present. In the submontane/montane taxa group, *Quercus, Podocarpus, Symplocos,* and Ericaceae have low values. In secondary taxa, *Macaranga/Mallotus* remains the only important taxon, although *Pandanus* and *Terminalia* have some representation. Only occasional values of Poaceae and Cyperaceae are recorded, while pteridophyte values are relatively unchanged from the previous zone, apart from an increase in Polypodiaceae percentages. Pollen concentrations are much higher than in the previous zone, while charcoal values are the lowest for the whole record.

Zone B4 (93 cm- 66 cm, seven samples) c. 17,000 – 13,000 years BP

Values for *Gluta renghas* pollen are the highest for the record, with notable values for other riparian/peatland/dryland taxa including *Elaeocarpus,* Anacardiaceae, *Carallia, Eugenia, Engelhardia, Fagraea,* and *Baccaurea,* especially in the upper part of the zone. Within peatland/dryland taxa, values for *Palaquium* comp. peak in this zone, but pollen values for many other taxa of this group tend to fluctuate a great deal. The most prominent of these taxa are *Blumeodendron, Calophyllum, Gymnostoma sumatrana, Garcinia,* and *Longetia.* Percentages of pollen of *Planchonella, Calamus,* Dipterocarpaceae and Arecaceae have remained constant. Pollen values for Meliaceae are very high in one sample only. It is important to note that pollen values for submontane/montane taxa, particularly *Quercus,* and *Podocarpus,* are

significantly higher in this zone, and clearly the highest for the diagram. *Dacrydium, Dacrycarpus,* and *Phyllocladus* are confined to this zone. As in zones B6 and B5, pollen values for *Macaranga/Mallotus* are constant but low, while pollen of other secondary taxa, Cyperaceae and Poaceae are only occasionally present. Percentages for monolete and trilete spores are the highest in this zone, while Polypodiaceae and *Lycopodium cernuum* have generally maintained representation, and are joined by *L. phlegmaria.* Pollen concentrations have sharply increased, while charcoal concentrations and pollen/charcoal ratios are significantly higher than in the previous zones.

Zone B3 (66 cm - 42 cm, six samples) c. 3,000 – 1,350 years BP

There are major changes in all pollen groups around the base of this zone. Pollen values for *Gluta renghas* sharply decrease, while values for many other riparian taxa, including *Baccaurea,* Anacardiaceae type, *Engelhardia,* and *Eugenia* become generally higher. *Barringtonia* appears for the first time. In the peatland/dryland forest group, pollen values for *Calophyllum, Planchonella, Combretocarpus rotundatus, Nephelium,* and Dipterocarpaceae are significantly higher, while pollen values for *Palaquium* comp. have substantially declined. There are few occurrences of submontane/montane taxa, while values of herbs and secondary taxa are generally higher, apart from those of *Macaranga/Mallotus* comp. Values for monolete and trilete spores have sharply declined, especially in the upper part of the zone, while Polypodiaceae sim. has disappeared and the lycopods have less frequent occurrence. Charcoal

concentrations are the highest for the record, while pollen concentrations and charcoal/pollen ratios are substantially higher.

Zone B2 (42 cm - 18 cm, five samples) c. 1,350 - 400 years BP

In this zone, pollen values for *Gluta renghas* are only sporadic, while other members of the riparian/peatland/dryland forest group, including *Carallia, Eugenia,* and *Elaeocarpus* have relatively high representation. Anacardiaceae, *Artocarpus, Barringtonia, Crudia, Dillenia, Engelhardia, Fagraea, Ixora,* and Rhizoporaceae are present infrequently. Pollen values for *Calophyllum, Palaquium* comp., *Planchonella,* and Dipterocarpaceae are high in the bottom part of the zone, but are significantly lower in the upper part of the zone. Meliaceae and Rutaceae are confined to the upper part of the zone. *Blumeodendron, Combretocarpus rotundatus, Gymnostoma sumatrana, Garcinia, Lithocarpus,* and *Calamus* are variably present, while Arecaceae is consistently low except in the upper part of the zone. A number of taxa, including *Polyosma* and *Pterocarya,* have disappeared from the record. Montane taxa are hardly represented. Secondary taxa and herbs, notably *Pandanus,* Cyperaceae and Poaceae, have increased their representation substantially, and peak in the zone. The representation of pteridophytes is very low. Charcoal/pollen ratios are high, although both charcoal and pollen concentrations are low.

Zone B1 (18 cm-0 cm, four samples) c. 400 - 0 years BP

Pollen values for riparian/peatland/dryland taxa are similar to those in zone B2. The main changes occur in the peatland/dryland group. Pollen values

for *Gymnostoma sumatrana* increase to an extremely high value in the topmost sample, while there is a substantial peak in *Palaquium* comp. Pollen values for *Calophyllum, Combretocarpus rotundatus,* and Dipterocarpaceae are consistently high, while *Blumeodendron, Planchonella* comp., *Lithocarpus, Calamus,* Arecaceae, *Weinmannia, Tecoma, Sapindus,* and Rutaceae have low values. It is interesting to note that a low pollen value for *Gonystylus bacanus* reappears in this zone after an absence since the basal two zones. Poaceae values are significantly lower. Charcoal/pollen ratios, on average, reach their highest values. Charcoal concentrations are substantially higher than values in zone B2, but pollen concentrations remain low.

7.2.4. Unconstrained incremental sum of squares cluster analysis

The unconstrained classification provides three major groups (Figure 7.3). The lowest group is composed of only four samples of zone B4, two of which are stratigraphically adjacent. The middle group is mostly derived from zones B4 and B5, for except samples 64 cm (zone B5) and 116 cm (zone B6). The topmost group contains all samples above 60 cm, from mainly zones B1, B2, and B3, in a mixed form, supporting the small degree of variation identified in the stratigraphically constrained analysis. This group also contains samples 112 cm and 120 cm from the lower most zone (B6), and these two form a distinct cluster. Overall, the classification suggests a degree of inter-zone variability, at least within the upper and lower parts of the diagram.

CONISS

Sample axis labels (top to bottom):
8cm(B1)
12cm(B1)
16cm(B1)
32cm(B2)
40cm(B2)
24cm(B2)
36cm(B2)
20cm(B2)
48cm(B3)
4cm(B1)
56cm(B3)
60cm(B3)
44cm(B3)
52cm(B3)
112cm(B6)
120cm(B6)
100cm(B5)
104cm(B5)
108cm(B5)
116cm(B6)
64cm(B3)
88cm(B4)
96cm(B5)
68cm(B4)
80cm(B4)
84cm(B4)
92cm(B4)
72cm(B4)
76cm(B4)

Total sum of squares: 1 2 3 4
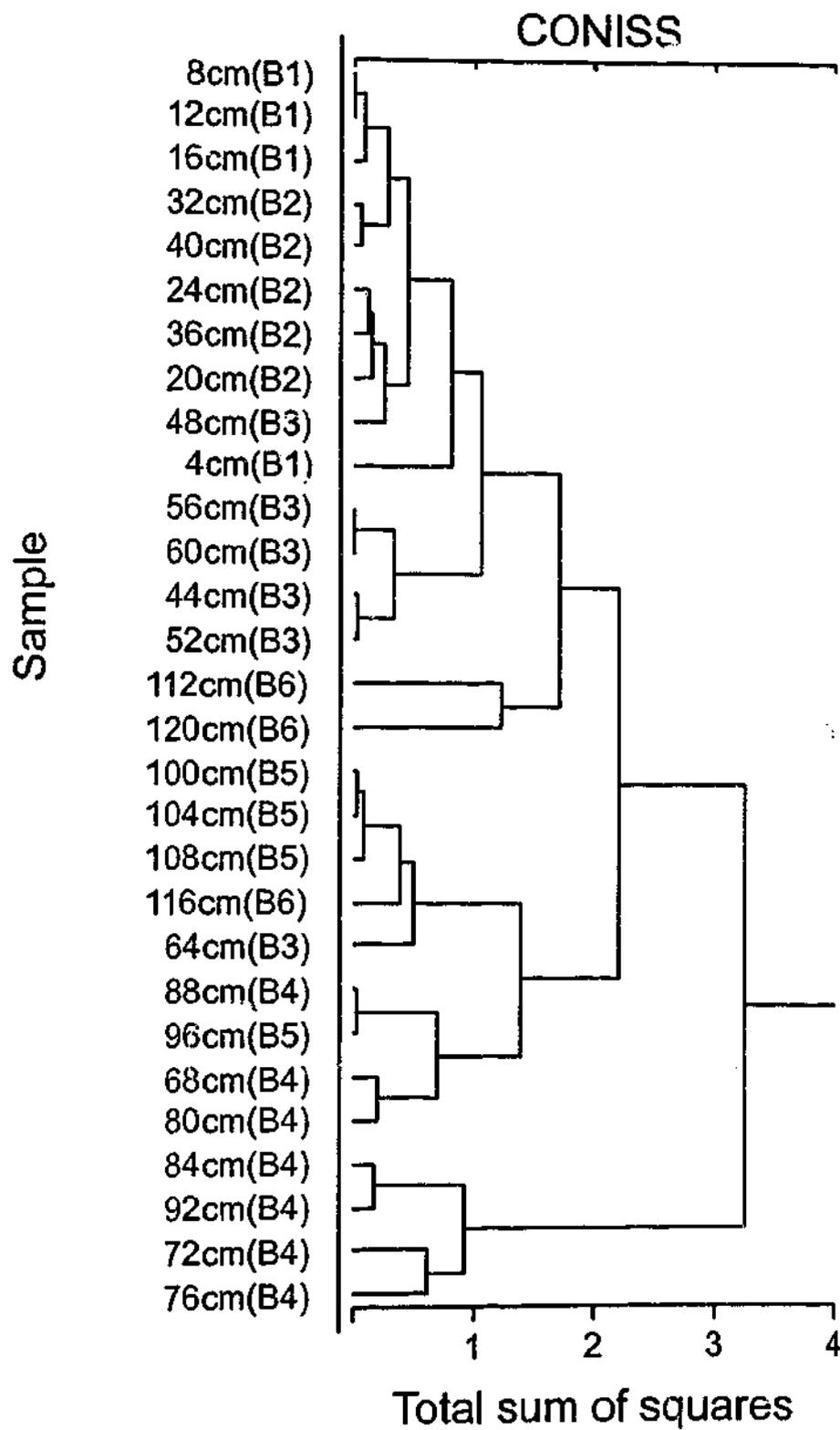
Figure 7.3. Results of the stratigraphically unconstrained classification (CONISS) for core HN3

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7.2.5. Results of correspondence analysis (CA) and the assessment of

environmental variables

Summary results of CA are tabulated in Table 7.2. Both axes 1 and 2 have strong eigenvalues (> .3), and explain 19.0 % and about 13.2 % variance, respectively.

Table 7.2. Summary results of CA on total pollen spectra from core HN3

Axes	1	2	3	4	Total inertia
Eigenvalues	.429	.300	.138	.150	2.261
Cumulative percentage variance of pollen data	19.0	32.2	40.5	47.2	
Sum of unconstrained eigenvalues = total variance of pollen data					2.261

Results of CA show a similar pattern of clustering to those of unconstrained cluster analysis (Figure 7.3). On axis 2, samples 112 cm and 120 cm are separated from others, probably because of pollen values for *Lophopetalum*, Arecaceae, Rosaceae, Meliaceae/Sapotaceae, *Pometia* and *Gonystylus bacanus* (Figure 7.4). Along axis 1, samples from 72 cm to 116 cm occur to the left of the origin, while samples from 4 cm to 68 cm are located on the right side of the diagram.

The pattern of clustering in this diagram shows that recent fossil samples (4 cm to 68 cm) dated between 300 and 3,000 yr BP are linked with modern pollen sample sites (Figure 7.4). These fossil samples are strongly associated with the mix of present types of peatland forest taxa, and open riparian and swamp forests. There is little clear grouping of taxa on Figure 7.4.

Figure 7.4. CA ordination diagram for core HN3, showing site scores (a) and environmental variables (b). Lines indicate samples with radiocarbon dates, which are given in the two error range. An asterisk symbol (*) indicates samples with conventional radiocarbon dates.

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(Agla; Aglaia; Anac1;Anacardiaceae sim. (small type); Apo1;Apocynaceae; Are1;Small echinate palm (Arecaceae); Arec;Arecaceae; Arto;*Artocarpus*; Aste;Asteraceae; Bacc;*Baccaurea*; Barr; *Barringtonia*; Blum;*Blumeodendron*; Bomb;Bombacaceae; Calm;*Calamus*; Calo;*Calophyllum*; Camp;*Campnosperma*; Cara;*Carallia*; Celt;*Celtis*; Ceph;*Cephalomappa*; Clau;*Clausena*; Comb;*Combretocarpus rotundatus*; Crud;*Crudia*; Clen;*Ctenolophon*; Cype;Cyperaceae; Dacr;*Dacrydium*; Dava;*Davalia*; Dile;*Dillenia*; Dille;*Dillenia* (reticulate type); Dios;*Diospyros*; Dip;Dipterocarpaceae; Dryp;*Drypetes*; Dyso;*Dysoxylum*; Elae;*Elaeocarpus*; Enge;*Engelhardia*; Eric;Ericaceae; Eugn;*Eugenia*; Fagr;*Fagraea*; Garc;*Garcinia*; Glut;*Gluta renghas*; Gony;*Gonystylus bancanus*; Gymn;*Gymnosperma sumatrana*; Ilex;*Ilex*; Ison;*Isonandra*; Ixor;*Ixora*; Legum;Leguminosae; Lith;*Lithocarpus*; Long;*Longetia*; Loph;*Lophopetalum*; Lora;Loranthaceae; Lyce;*Lycopodium cernuum*; Lycop;*Lycopodium* comp.; Lyph;*Lycopodium phlegmaria*; M.Sa;Meliaceae/Sapotaceae; Mac1;*Macaranga* comp. (small type); Maca;Macaranga/*Mallotus* comp.; Madh;*Madhuca* comp.; Mel1; *Melia*; Meli; Meliaceae; Ment;*Mentangis* sim.; Mono;monolete; Myri;*Myristica*; Myrs;*Myrsine/Rapanea*; Nauc;*Nauclea*; Neph;*Nephelium*; Olea;Oleaceae; Pal1;*Palaquium* comp.. (4colporate grain); Pal2;*Palaquium* comp.. (3colporate grain); Pand;*Pandanus*; Pars;*Parsonia* comp..; Phyl;*Phyllocladus*; Plan;*Planchonella*; Poac;Poaceae; Podo;*Podocarpus*; Poly; Polypodiaceae; Polyos;*Polyosma*; Pome;*Pomelia*; Pter;*Pterocarya*; Quer;*Quercus*; Rand;*Randia*; Reev;*Reevesia* comp..; Rhi1;*Rhizopora*; Rhiz;Rhizoporaceae; Rosa;Rosaceae; Ruta;Rutaceae; Sten;*Stenochaelena palustris*; Ster;Sterculiaceae; Symp;*Symplocos*; Teco;*Tecoma*; Term;*Terminalia*; Trem;*Trema*; Trit; trilete; Wein;*Weinmannia*)

Figure 7.5. CA ordination diagram for core HN3, showing pollen scores

The environmental variables show greatest relationship with pollen variation along axis 1, with moisture content, and charcoal/pollen ratios increasing or higher towards present. There is an inverse relationship between

moisture content and inorganic residue. Charcoal content, by contrast, shows a

weak relationship with axis 2.

Table 7.3. Results of environmental assessment for core HN3 , based on 9999
completely randomised Monte Carlo permutation tests under reduced model
(**significant at the >1 % confident level, ns = not significant)

Environmental variables	P-value estimate	F-ratio	Variance explained
Moisture content	<.0001**	4.09	.30 (13.3%)
Charcoal concentration	<.0701 ns	1.54	.11 (4.8%)
Inorganic residue	<.0910 ns	1.45	.10 (4.4%)
Charcoal/pollen ratio	<.6175 ns	.87	.06 (2.7%)
Residual			1.691 (74.8%)
Total inertia			2.261 (100%)

Results of Monte Carlo tests are tabulated in Table 7.3. This test shows

that the variable of moisture content is statistically significant, while the other

variables are not statistically significant.

7.2.6. Interpretation of the core HN3 record

The topmost samples of the core (zone B1), in conjunction with the

surface sample data set, provide some basis for interpretation of the record in

that they can be compared directly with the present day landscape. The

extremely high proportion of rainforest taxa, most of which can be found in

peatland forests, reflects well the local vegetation and suggests that most pollen

may be derived from trees growing in close proximity to the core site. Most of

the taxa are represented in the surface samples. The vegetation of nearby Lake

Pemarak is probably reflected in the values for Poaceae, Cyperaceae and

Barringtonia, in particular, while the charcoal level indicates the degree of

burning that has taken place both within the forest and on the dry lake surface

where there was sufficient fuel to burn, during dry periods like that at the time of sample collection. Disturbance of the forest itself is best indicated by the significant values for indicator taxa such as *Trema, Terminalia* and *Pandanus*.

In reconstructing the history of the site, it must be stressed that it is likely that only short periods of time within the last 30,000 years or so are represented. Estimates of average rates of tropical peat accumulation from elsewhere in Indonesia suggest values of between 0.3 and 13.3 mm/yr (Neuzil, 1997) and even using the lowest figure, an accumulation of some 10 m rather than 1.24 m would be expected if accumulation had been continuous and regular. The conventional estimate of peat accumulation in coastal areas of Northwest Borneo is between 2-3 mm/yr (Anderson 1983). Furthermore, even in peats, which have achieved a thickness of over 10 m in the last few thousand years, recent dating has indicated major phases of non-deposition (Page *et al.* 1999). The radiocarbon dates provide some basis for assessment of the timing and length of non-depositional periods although contamination is always a possibility in discontinuous sequences. The basal date, taken from bulk sediment, is likely to be the most suspect as a large component of tropical peatlands are composed of penetrated roots (Anderson 1983; Brady, 1997), which will date younger than the sediment matrix. The AMS dates should be less influenced by rootlet contamination although the prepared samples contained resistant plant material other than pollen that may have derived from decomposed root material.

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The earliest period, indicated by zone B6, was dated to around or beyond 30,000 yrs BP. The subfibrous nature of the peat, together with substantial variation in composition of pollen spectra and the low pollen concentration values, suggest that accumulation was fairly rapid and that it covers a short period of time. The composition of the swamp forest was clearly different to that of today within the area and, from the location of the samples in relation to the modern spectra on the ordination diagram (Figure 7.4), probably very different also from the range of vegetation types in the region. A number of peatland taxa, including Meliaceae/Sapotaceae (tricolporate), Sterculiaceae and small echinate palm, present or conspicuous in this zone, are not recorded in recent samples, while the common species *Gonystylus bancanus* has only minor representation in surface samples. Riparian taxa are infrequent except for *Gluta renghas* that has only occasional presence in surface samples. By contrast, fern spores are relatively well represented, as they are in riverine and frequently flooded vegetation types today.

Clearly environmental conditions in zone B6 were very different to those at present, but the precise nature of these is difficult to determine. The relatively high values for fern spores could suggest higher effective precipitation than today and more frequent flooding on the basis that fern spores, being well dispersed by water, could have derived from dry land rainforest in the upper catchment. As there is no evidence of vegetation types like those of Lake Pemerak within the region today, it is possible that the lake did not exist, at least in its present form, and that the area was more generally

flooded rather than the water being concentrated within the lake area. However, the presence of *Gluta renghas* does indicate that some form of river system did exist. In addition, the postulation of more general inundation appears to be contradicted by the consistent presence in the pollen samples of *Gonystylus bancanus* which is a peatland forest tree that is not tolerant of water logging (Soerianegara and Lemmens, 1994). Under these circumstances, the possibility that the ferns were local, either growing within the immediate peat forest or within the 'lake' system, has to be considered. Although ferns are not extensive today, they may well have been during the last glacial period when temperatures were possibly lower. The occurrence of *Podocarpus*, and *Quercus*, are the only possible indicators of reduced temperatures and perhaps suggest some regional expansion of montane and submontane forest taxa.

Gonystylus bancanus virtually disappears during the period represented by zone B5. Despite the decline of *G. bancanus* and other marked changes in the composition of the peatland forest at the zone B6-5 boundary, there is little change in riparian vegetation or differences in hydrology between the two periods. The ordination diagram illustrates the maintenance of vegetation composition very different to that of today. The consistent presence of Ericaceae, in addition to *Quercus* and *Podocarpus*, and the maintenance of relatively high pteridophyte percentages, provides greater confidence in the postulation of temperatures lower than today. As the two basal dates are so similar, it cannot be determined whether or not there is a time gap between the periods represented by zones B6 and B5.

The dates derived from the zone B5/B4 boundary of around 29,000 and 17,000 yrs BP indicate a long period of non deposition, or erosion of accumulated sediment, that included the earlier part of the Last Glacial Maximum. The date of the end of the period represented by zone B4 is less certain. Judging by the date of 3,117 yrs BP, the zone could extend well into the Holocene. However, the date of 13,110, only 4 cm below the 3,117 yrs BP date, makes it likely that zones below zone B3 fall into the Last Glacial Maximum and Late Glacial. Support for a Last Glacial Maximum date (zone B4) is provided by highest representation of the montane taxa *Podocarpus*, *Phyllocladus* and *Quercus*, together with some representation of Ericaceae, the only representation in the diagram of *Dacrycarpus* and *Dacrydium* and, possibly, the very high values for pteridophyte spores. It is surprising, however, that the montane conifers are best represented towards the end of the period, which dates less certainly to the Last Glacial Maximum than the early part of the period. Either the dates are not totally reliable or it took montane taxa some time to arrive within the pollen catchment area of the site from the mountains, some 100-200 km away. The source of these taxa is also possibly from heath forests within the lake region as these submontane/montane taxa may predominantly occur in heath (kerangas/kerapah) forests (Bruenig 1974; Kartawinata 1978; Whitmore 1998).

It appears that at least part of the Last Glacial Maximum experienced sufficiently wet conditions to allow peat development although precipitation levels lower than those of the other peat-forming periods might be inferred

from the decomposed nature of the peat during the period represented by zone B4, as well as the fact that temperatures are likely to have been lower than today. Drier conditions might also be suggested from the relatively high representation of species of *Lycopodium* that are indicative of open canopied vegetation and increased charcoal levels that indicate greater fire frequency or effectiveness than previously.

The zone B4/B3 boundary marks the largest changes in the pollen and sedimentary record and supports the evidence for a major time gap, possibly extending from about 13,000 to 3,000 yrs BP. It may be surprising that the late Holocene period, rather than the early-mid Holocene, is represented considering that the bulk of peat in other parts of Kalimantan was formed during the earlier period (Page *et al.*, 1999; Neuzil 1997). However, a second phase of peat growth is evident within the last 2,000 years in coastal areas of Borneo (Anderson 1983; Neuzil 1997) and the early growth phase was probably more related to sea level rise and the subsequent attainment of hydrological equilibrium than any climate change. Consequently it could be that, regionally, effective precipitation has been higher in the late Holocene than it was in the early Holocene. Alternatively some change in the hydrology of the system may have prompted renewed peat growth in the Late Holocene.

In comparison with the late Pleistocene, the pollen spectra show marked similarities to the suite of surface samples as indicated by the ordination diagram (Figures 7.4 and 7.5). Riparian components of the vegetation had changed substantially with a mix of taxa including *Barringtonia* replacing

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Gluta renghas. In the peatland components, the increases in percentages of *Calophyllum* and Dipterocarpaceae are particularly notable. A more open environment is indicated by increasing representation of Poaceae and Cyperaceae as well as some maintenance of *Lycopodium* values. One explanation for these features is increased environmental variability that initiated or caused further development of the discrete lake system which dries periodically. The destruction of *Gluta* communities may have been a cause or effect of this variability, the latter possibly also related to human activity. This tree species would have been vulnerable to anthropogenic fire due to its high timber quality and location in relation to more open environments and fishing grounds. As this riparian environment was opened up, sustained disturbance and perhaps increased climatic variability would have resulted in the replacement of *Gluta* by a variety of other colonists which formed a more open and stunted vegetation. The sharp reduction in fern spores is consistent with greater channelling of water within the lake basin and consequently less flooding of the peatlands, although fern reduction is likely to have been predominantly a response to increased temperatures from the Pleistocene to Holocene, indicated by the disappearance of montane elements and increased representation of the lowland dipterocarps. Charcoal levels were as high if not higher than during the Last Glacial Maximum and a further increase in burning is indicated, most likely the result of environmental variability induced by climate, people, or a combination of the two influences.

There is little change in the riparian environment through zones B2 and

B1 where peat accumulation is likely to have been more continuous. Higher values for grasses may indicate more frequent lake drying although the lack of any similar response in Cyperaceae suggests that the grasses may be reflecting an opening up of terrestrial and peatland forests. Increased representation of other opportunistic taxa such as *Terminalia, Trema* and *Pandanus,* as well as highest charcoal/pollen ratios for the whole recorded period, provide supporting evidence for increased forest disturbance. It is likely that these changes reflect increased human impact on the landscape although ENSO variability,suggested to have increased during the late Holocene (Mglore et al. 1992), would most likely have facilitated high disturbance levels.

7.3. Core HN1

7.3.1. Sediment description

HN1 is a short, 150 cm-long peat core. The sediment consists of fibric and humic peat. From the surface to 12 cm, the peat is fibric and changes to humic from 12 cm. Between 35 cm and 45 cm, this humic peat contains some clay, and from 45 cm to 138 cm, the peat remains humic but with some woody detritus. The lower most sediment, from 138 cm to 150 cm, is purely humic peat (Figure 7.6.a). The base of the peat deposit was not reached.

According to the Munsell Chart, the colour of the top 12 cm is dull yellowish brown (10YR 4/3). This turns to yellowish brown (10YR 5/6) at 12 cm, and returns to dull yellowish brown from 33 cm depth until the base of the core.

The core was very moist and contains very little inorganic matter (Figure 7.6.a) The average moisture content is 75.3%, while mean inorganic residue is 3.1% of oven dry weight. Two samples at 35 cm and 45 cm have relatively high inorganic matter content (17%). The core is dated with five AMS radiocarbon dates and one conventional radiocarbon date (Table 7.4). These radiocarbon dates are not in sequence, and none are of Holocene age.

7.3.2. Pollen diagram

Results of fossil pollen and microscopic charcoal analyses are presented in five diagrams. Figure 7.6.a is a summary diagram, which includes lithology, moisture contents, inorganic residues, charcoal/pollen ratios, charcoal concentrations, pollen concentrations, total trees and shrubs, total herbs, aquatics, and total pteridophytes. Figures 7.6.b and 7.6c present peatland/dryland taxa, while riparian/peatland/dryland taxa, and submontane/montane taxa are presented in Figure 7.6.d, and secondary taxa, herbs, aquatics, and pteridophytes are given in Figure 7.6.e.

Seventy-seven pollen taxa were recorded from core HN1. In the peatland/dryland taxa group, values of *Calophyllum, Gymnostoma sumatrana, Ilex, Lithocarpus, Madhuca* comp., *Palaquium, Planchonella* comp., Dipterocarpaceae, and Sterculiaceae sim. are high, while values for *Calamus, Dacrydium, Celtis, Lophopetalum, Ctenolophon,* and *Gonystylus bacanus* are low. In the riparian/peatland/dryland group, values for pollen of *Gluta renghas* are extremely high (up to 25%), while pollen values of Anacardiaceae comp., *Baccaurea,* and *Elaeocarpus* reach up to 10%, and pollen values of

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Campnosperma, Carallia, Dillenia, Engelhardia, Eugenia/Syzygium, Fagraea, Ixora, Microcos, and *Mentangis* sim. are consistently below 5%. In the submontane/montane group, *Quercus* pollen is consistently present, *Symplocos* pollen is consistently present in the upper part of the record, while values for Ericaceae and *Podocarpus* are variable. In the secondary taxa group, pollen values of *Macaranga/Mallotus* comp.

Table 7.4. Radiocarbon ages (^{14}C years BP) for core HN1

Sample ID	Depth (cm)	Radiocarbon Age (Years B.P.)	σ ^{13}C (‰)	Material dated	Remarks
OZE 137	10-11	12,440 ± 60	-30.0*	Pollen	AMS date
OZE 138	27-28	28,900 ± 250	-30.0*	Pollen	AMS date
OZE 139	49-50	28,250 ± 150	-30.0*	Pollen	AMS date
OZE 140	102-103	24,250 ± 120	-30.0*	Pollen	AMS date
Wk 5777	120-148	23,570 ± 170	-29.7±0.2**	Bulk sediment	Conv.date
OZE 141	149-150	32,800 ± 300	-30.0*	Pollen	AMS date

Note: * estimated value; ** measured value;
Wk (Waikato Radiocarbon Laboratory); OZE (ANSTO)

and Pandanaceae are higher than other secondary pollen taxa. Pollen from aquatics and herbs are very low and sporadic. Monolete spore values are relatively high in most samples, while values for trilete spores are high but variable. Spore values for other fern taxa such as Polypodiaceae comp. (type 2), and *Lycopodium cernuum* are inconsistent. Other fern taxa presented in this diagram are Cyatheaceae, Polypodiaceae comp. (type 1), *Lycopodium phlegmaria,* and *Stenochlaena palustris.*

7.3.3. Pollen diagram zonation

The results of this stratigraphically constrained classification provide a clear distinction between samples above and below 70 cm at a 3.8 dissimilarity level. The basal four samples then separate clearly from the lower group while the top two samples separate from the upper group. Ten groups form at the 0.9 dissimilarity level, which is used as the basis of zone determination. The single sample at 60 cm is distinct, and identified as forming a subzone of zone A5.

Zone A 10 (134 - 150 cm, four samples)

The spectra are dominated by the peatland/dryland taxon, *Calophyllum,* with few other pollen taxa having consistent representation. Of other peatland/dryland taxa, *Gymnostoma, Ilex, Madhuca, Neoscortechinia, Clausena,* and Sterculiaceae are present. Outside of this group, only the riparian/peatland/dryland Anacardiaceae taxa are conspicuous. There are sporadic occurrences of submontane/montane, secondary, herb and aquatic taxa, while, apart from monolete spores, pteridophyte representation is negligible. Pollen concentrations and charcoal values are very low.
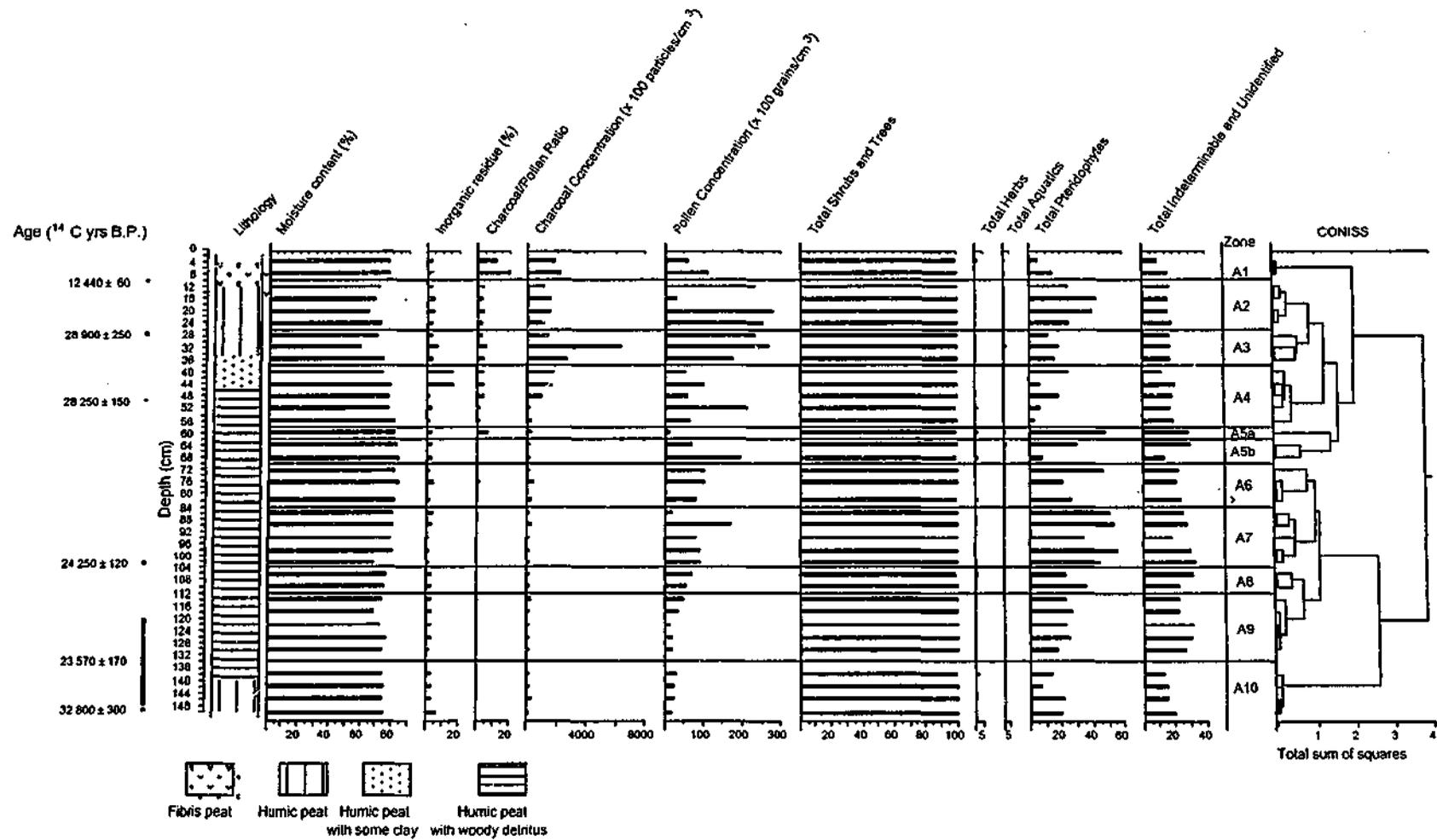
Figure 7.6.a.A pollen diagram for core HN1
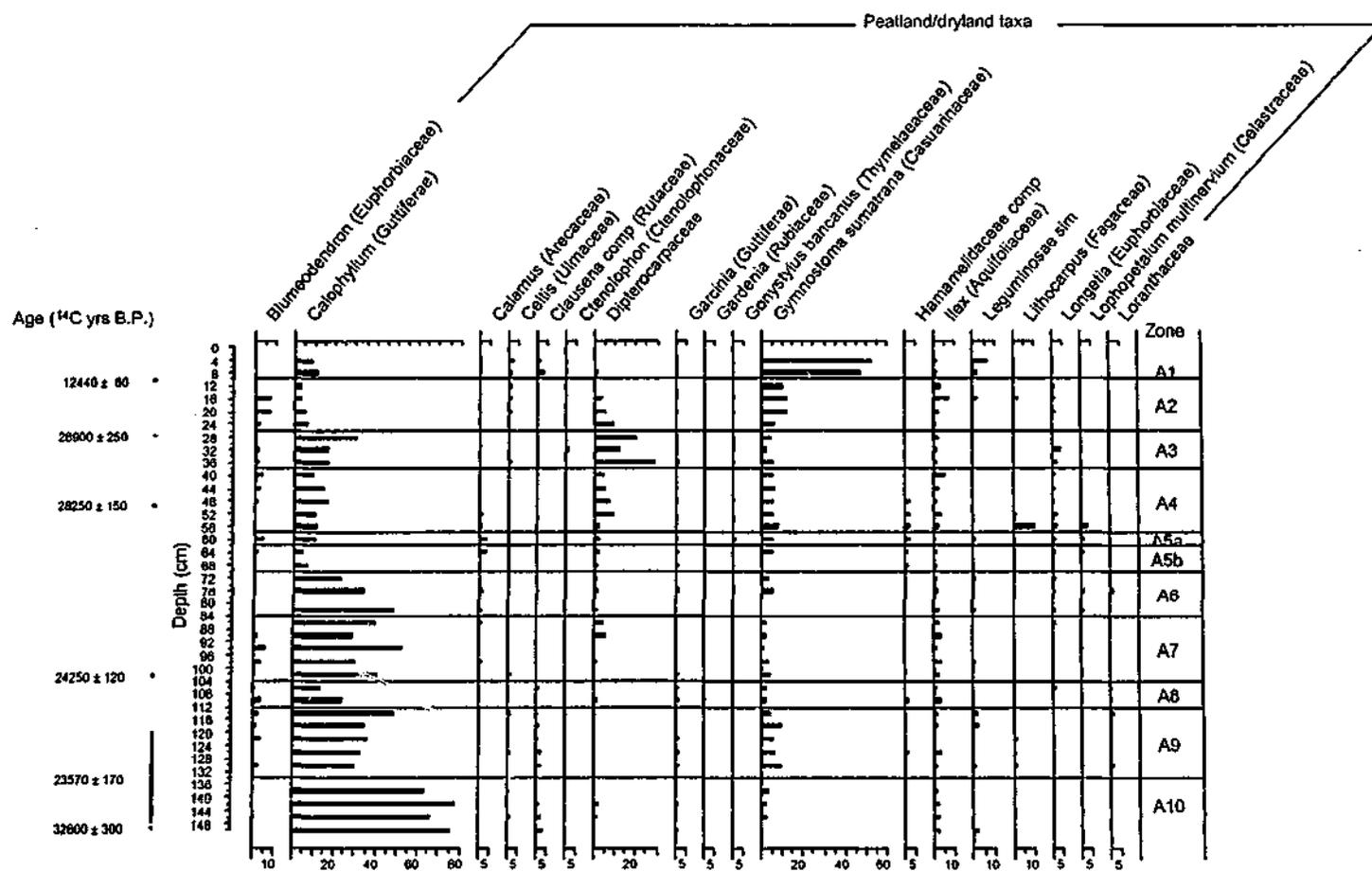
Figure 7.6.b. Pollen diagram core HN1, showing peatland/dryland taxa

Figure 7.6.c. Pollen diagram core HN1, showing peatland/dryland taxa (continued)

Figure 7.6.d. Pollen diagram core HN1, showing riparian/peatland/dryland
and submontane/motane taxa
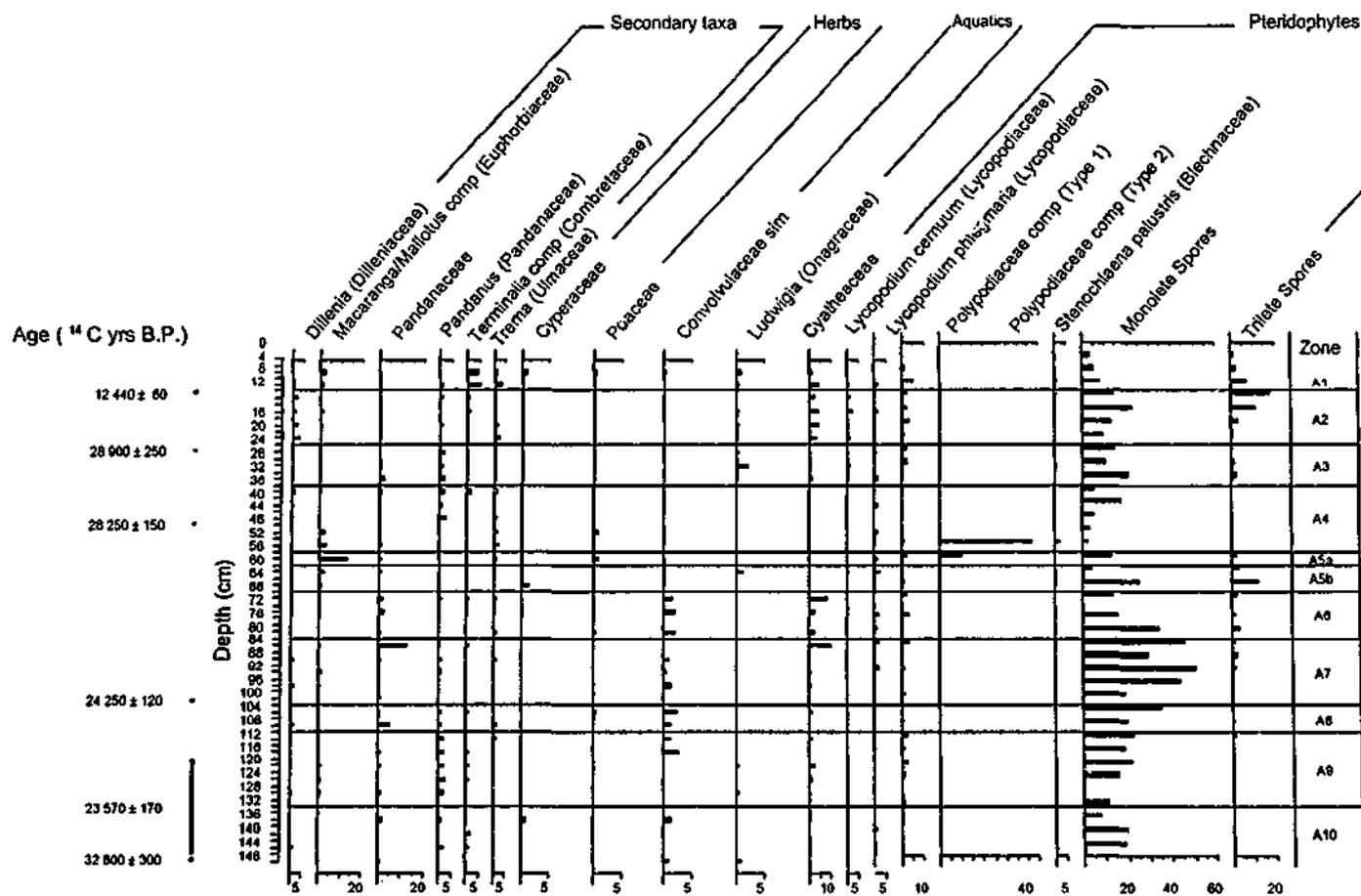
Figure 7.6.e. Pollen diagram core HN1, showing secondary taxa, herbs, aquatics, and pteridophytes

Zone A 9 (134 - 112 cm, five samples)

This zone is characterised largely by differences in representation of peatland/dryland taxa. *Calophyllum* has substantially reduced values, while *Gymnostoma sumatrana, Madhuca* comp., and Sterculiaceae sim. (three pored type) are conspicuous. Values of riparian/peatland/dryland taxa are relatively unchanged. In the submontane/montane group, values for *Quercus* and *Podocarpus* pollen are marginally higher in than the previous zone, while Ericaceae pollen is present. Secondary taxa such as *Macaranga/Mallotus* comp., *Pandanus, Terminalia* comp., Pandanaceae and *Trema* are consistently present. Aquatic pollen and fern spore values remain unchanged, but herb pollen is totally absent. Overall, the number of pollen taxa recorded in this zone is higher than in the previous zone. Both pollen and charcoal values remain low.

Zone A 8 (112 cm - 108 cm, two samples)

This zone consists of two samples. Pollen values for *Calophyllum* have further sharply declined, while there are notable increases in *Madhuca* comp., *Palaquium, Planchonella* comp., Meliaceae sim., and Meliaceae/Sapotaceae sim. Within the riparian group, values for *Gluta renghas* are higher, while those for other taxa are barely changed. Values for submontane/montane taxa, secondary taxa, herbs, and most fern spores remain low, while monolete spores maintain their representation, on average. Charcoal values also remain low, while pollen concentrations are higher than in the previous zones.

Zone A 7 (108 cm - 84 cm, five samples)

In this zone, the main changes to arboreal taxa are a recovery in *Calophyllum*, the first notable presence of Dipterocarpaceae in the lowermost two samples, and a high value for the secondary taxon Pandanaceae in the topmost sample. Fern spores achieve their highest percentages for the diagram, largely due to monolete spores and a high value for Cyatheaceae in the topmost sample. Pollen concentrations are relatively high, overall, while charcoal concentrations remain low.

Zone A 6 (84 cm - 70 cm, three samples)

Calophyllum continues to dominate, while *Blumeodendron* is almost absent. Dipterocarpaceae values are reduced, while values for *Madhuca* comp. are generally much higher. There is a single high value for *Nauclea*. *Ctenolophon* and *Lophopetalum* are present, but *Gonystylus bacanus* is absent. Within the riparian/peatland/dryland group, values for *Gluta renghas* steadily increase, while Anacardiaceae comp. (small type) has disappeared from the diagram. Values for submontane/montane, secondary, aquatic, and herb taxa maintain relatively low but constant values. Within the ferns, monolete spores are much reduced. Trilete spores peak in the top sample, while Cyatheaceae and Polypodiaceae have consistent representation. Pollen concentrations remain relatively high, while charcoal values remain low.

Zone A 5 (70 cm -58 cm, three samples)

This zone represents a major transition within the diagram and has been divided into two subzones. The overall characteristics of this zone are a substantial reduction in *Calophyllum*, generally increased representation of

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Zone A 5 (70 cm -58 cm, three samples)

This zone represents a major transition within the diagram and has been divided into two subzones. The overall characteristics of this zone are a substantial reduction in *Calophyllum,* generally increased representation of

Gluta renghas comp., and the first appearance of *Symplocos*, and highest values of *Quercus* for the diagram. There are peaks in *Macaranga/Mallotus* comp., and Polypodiaceae comp. within subzone A5a. Values for Sterculiaceae sim. (three-pored type) are high in subzone A5b, but are reduced again in subzone A5a. Similarly, pollen concentrations are moderately high in subzone A5b, but very low in subzone A5a. Charcoal values remain low through the whole zone

Zone A 4 (58 cm - 38 cm, five samples)

This zone is characterised by higher values for Dipterocarpaceae and highest percentages of *Gluta renghas*. Values for pollen derived from *Calophyllum, Gymnostoma sumatrana,* and Sterculiaceae sim. (three-pored type) maintain their representation while *Blumeodendron* appears consistently in the upper part of this zone and *Lithocarpus* has its only significant representation for the diagram in the lower part of the zone. Values of Meliaceae sim., Meliaceae/Sapotaceae sim., *Palaquium,* and *Planchonella* comp. are highly variable. Within submontane/montane taxa, pollen of *Quercus* and *Symplocos* are consistently represented, while pollen of *Podocarpus, Engelhardia* and Ericaceae is variably represented. Apart from *Gluta renghas,* values for the riparian/peatland/dryland taxa are generally low. Secondary taxa, herbs, and ferns are present in low percentages, while aquatics are totally absent. Half way through the zone, there is the beginning of sustained increases in both charcoal concentrations and charcoal/pollen ratios, the point at which

there is a peak in inorganic sediment. Pollen concentrations are very similar to those in the previous three zones.

Zone A 3 (38 cm - 27 cm, three samples)

In this zone, pollen values for *Calophyllum* are slightly higher, while pollen values for Dipterocarpaceae are clearly the highest for the record. Riparian, peatland, submontane/montane, and secondary taxa are poorly represented. Similarly, fern spore values are low. Charcoal/pollen ratios remain unchanged, but charcoal concentrations are higher, and pollen concentrations reach their highest values for the diagram.

Zone A 2 (27 cm - 10 cm, four samples)

Calophyllum pollen reaches its lowest values for the record, and there is a substantial reduction in Dipterocarpaceae pollen values. In contrast, *Blumeodendron* and *Gymnostoma sumatrana* have moderately increased, while *Madhuca* comp. is the best represented taxon in this zone. Values for *Palaquium* and Sterculiaceae sim. (three pored type) remain constant. This zone also has a good representation of riparian taxa, particularly *Gluta renghas, Quercus,* Ericaceae, *Dacrycarpus,* and *Podocarpus* are present, while secondary taxa and herbs are sparse. Pteridophytes have substantially higher values, with trilete spores sharing dominance with monolete spores and Cyatheaceae, *Lycopodium cernuum,* and Polypodiaceae comp. (type 1) are relatively well represented. Charcoal concentrations and charcoal/pollen ratios remain relatively high, while pollen concentrations are generally high.

Zone A 1 (10 cm - 4 cm, two samples)

The major features of this zone are notably higher values for *Calophyllum* and particularly *Gymnostoma sumatrana*, and significantly lower values for riparian taxa, especially *Gluta renghas* comp. Submontane/montane taxa are mainly absent, while values for secondary taxa, aquatics, herbs, and pteridophytes are very low. Charcoal/pollen ratios are clearly the highest for the diagram, while charcoal and pollen concentrations are generally high.
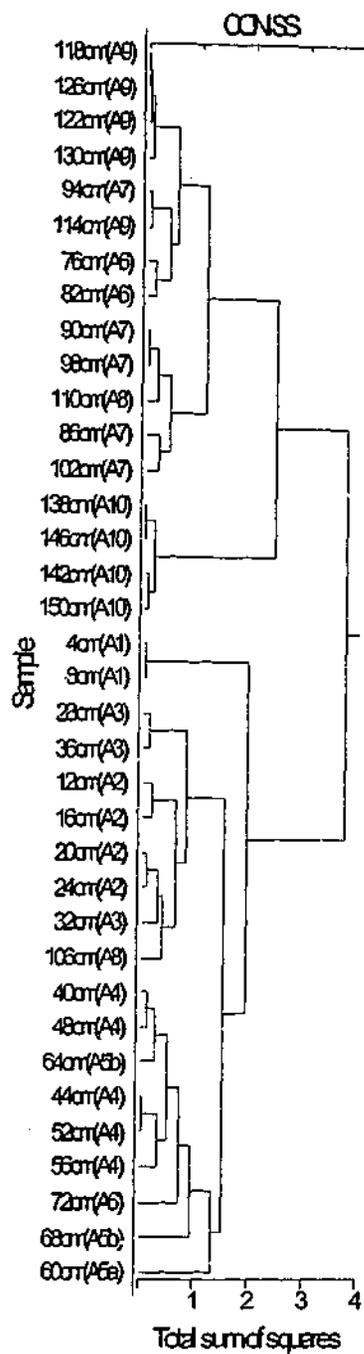
Figure 7.7. Results of the stratigraphically unconstrained classification
(CONISS) for core HN1
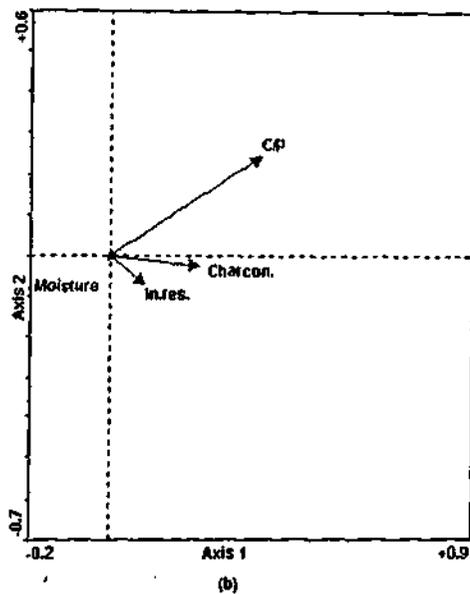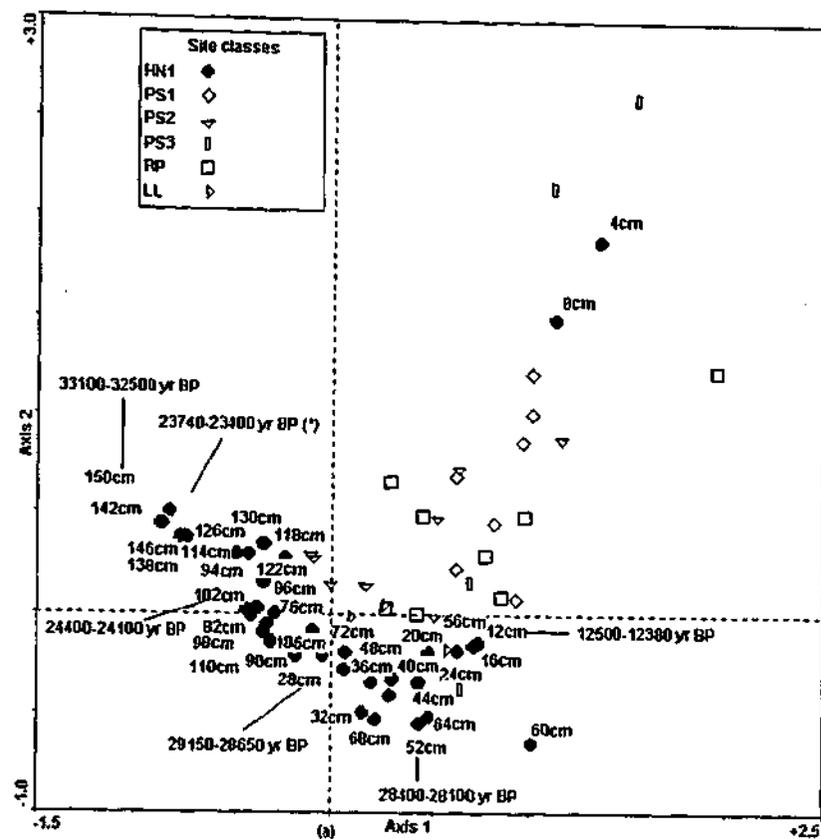
Figure 7.8. The CA ordination diagram for core HN1, showing site scores and supplementary samples of modern pollen spectra (a), and showing the selected environmental variables (b). Lines indicate samples with radiocarbon dates, which are given in the two error range. An asterisk symbol (*) indicates samples with conventional radiocarbon dates.

Species classes

Riparian	▪
Peatland	◆
Montane	▲
Sec.taxa	▶
Herb	▼
Fern	+
Aquatic	×

Axis 2

Axis 1

+5.0

-3.0

-2.5

+4.0

Term
Legum
Ruta
Gymn
Clau
Eugn
Cype
Micr
Ixor
Neos
Celt
Sapi
Trem
Neph
Calo
Enge
Ana1
Rosa
Ludw
Conv
Pand
Cyat
Lora
Camp
Cara Dile
Pol1
Pent Meli
Mono
Ilex
Myri
Lyph Tril
Sapo
Podo
Garc
Blum
Lith Poac
Ste1
Quer Dacy
Ment
Panda
Ste2
Myrs
Gard Plan
Lyce
Maca
Sten
Cten Madh
Anac
Eric
Dacr
Elae
Mora Glut Loph
Bacc
Nauc Calm
Pal1 Long Symp
MSa Phyl Hamm
Gony
Dip
Fagr
Pol2

(Ana1; Anacardiaceae comp. (small type); Anac; Anacardiaceae; Bacc;*Baccaurea*; Blum;*Blumeodendron*; Calm;*Calamus*; Calo;*Calophyllum*; Camp;*Campnosperma*; Cara;*Carallia*; Celt;*Celtis*; Clau;*Clausena*; Comb;*Combretocarpus rotundatus*; Conv: Convolvulaceae; Cten;*Ctenolophon*; Cype;Cyperaceae; Dacr;*Dacrydium*; Dile;*Dillenia*; Dios;*Diospyros*; Dip;Dipterocarpaceae; Elae;*Elaeocarpus*; Enge;*Engelhardia*; Eric: Ericaceae; Eugn;*Eugenia*; Fagr;*Fagraea*; Garc;*Garcinia*; Gard; *Gardenia*; Glut;*Gluta renghas*; Gony;*Gonystylus bancanus*; Gymn;*Gymnostoma sumatrana*; Hamm: Hammamelidaceae; Ilex;*Ilex*; Ixor;*Ixora*; Legum;Leguminosae; Lith: *Lithocarpus*; Long;*Longetia*; Loph;*Lophopetalum*; Lora;Loranthaceae;Ludw; *Ludwigia*;Lyce;*Lycopodium cernuum*; Lyph;*Lycopodium phlegmaria*; MSa;Meliaceae/Sapotaceae; Maca;*Macaranga/Mallotus* comp.; Madh;*Madhuca* comp.; Meli; Meliaceae; Ment;*Mentangis* sim.; Micr;*Microcos*; Mono;monolete; Mora: Moraceae; Myri;*Myristica*; Myrs;*Myrsine/Rapanea*; Nauc: *Nauclea*; Neph;*Nephelium*; Neos: *Neoscortechnia*; Pal1;*Palaquium* comp. (4 colporate grain); Pand;*Pandanus*; Panda;Pandanaceae; Pent;*Pentace*; Phyl;*Phyllocladus*; Plan;*Planchonella*; Poac;Poaceae; Podo;*Podocarpus*; Poly;Polypodiaceae; Polyos;*Polyosma*; Pome;*Pometia*; Pter;*Pterocarya*; Quer;*Quercus*; Rosa;Rosaceae; Ruta;Rutaceae; Sapi;Sapindaceae; Sapo: Sapotaceae; Sten;*Stenochlaena palustris*; Ste1;Sterculiaceae sim. (three pored type); Ste2: Sterculiaceae (four porate type); Symp;*Symplocos*; Term;*Terminalia* comp.; Trem;*Trema*; Tril; trilete)

Figure 7.9. CA ordination diagram of the HN1 record, showing pollen scores

7.3.4. Unconstrained incremental sum of squares cluster analysis

The results of this classification identify a major division at a 3.7 dissimilarity level (Figure 7.7). This division essentially reinforces the distinction between the upper zones (A1 to A5) and the lower zones of the diagram identified in the constrained classification. Each division breaks into smaller clusters that generally consist of adjacent samples. The major exception is sample 106 cm that joins with the upper parts of the core. The dendrogram also indicates that the topmost two samples (4 cm and 8 cm) and the lowermost samples (138-150 cm) form distinct clusters.

7.3.5. Results of correspondence analysis (CA) and assessment of environmental variables

Summary results of CA analysis are presented in Table 7.5. The first two CA ordination axes explain 18.7% and 15 % variance of species data, significantly higher than the next two axes.

Table 7.5. Summary results of CA for pollen spectra from core HN1

Axes	1	2	3	4	Total inertia
Eigenvalues	.294	.236	.189	.115	1.57
Cumulative percentage variance of fossil pollen data	18.7	33.7	45.7	53.1	
Sum of all unconstrained eigenvalues = total variance of pollen data					1.57

Figure 7.7 presents the CA ordination diagrams of axes 1 and 2, showing site scores (a) and the environmental variables (b), and Figure 6.8 presents the CA ordination diagram for pollen taxon scores of core HN1.

The two samples (4 and 8 cm) are clearly separated from the other samples, probably due to high values of *Terminalia*, Leguminosae, and *Gymnostoma sumatrana*. These two samples also may indicate a major discontinuity within the sediment. The similarity between these samples and modern pollen data is relatively strong.

The ordination shows that samples from 12 cm to 72 cm, except samples 60 cm and 28 cm, are grouped in the lower right corner of the diagram. Taxa with pollen values greater than 10%, which are associated with the samples in the lower right-hand quadrant, are Dipterocarpaceae, *Gluta renghas*, trilete spores, and Polypodiaceae. Consistent values (<5%) of *Quercus*, *Symplocos*, *Dacrydium*, *Podocarpus*, and Ericaceae may also have some influence on the positioning of these samples. The separation of sample 60cm is probably because of the influence of *Macaranga/Mallotus*, Polypodiaceae (type 2), and *Gonystylus bancanus*, while sample 28 cm may be disassociated due to possession of a high value of *Calophyllum*. The left side of the diagram generally represents samples from zones A6 to A10 and these remain clumped on the second axis.

Results of the assessment of environmental variables by Monte Carlo permutation tests are given in Table 7.6. The tests show that both charcoal values are statistically more influential than the other variables. The variance explained by the charcoal/pollen ratio is 12.7%, and variance explained by charcoal concentration is 7.6%. Total variance explained by all selected

variables is about 28% (Table 7.6). The residual variance accounts for about 72%.

From Figure 7.8.b, it can be seen that charcoal concentrations relates clearly to variation along axis 1, while charcoal/pollen ratios are related to variation along both axes 1 and 2. These data suggest that taxa such as Leguminosae, *Terminalia, Gymnostoma sumatrana, Eugenia,* Cyperaceae, *Trema,* and Cyatheaceae could be fire-tolerant.

Table 7.6. Results of environmental assessment for core HN1, based on 9999 completely randomised Monte Carlo permutation tests under reduced model (**significant at the >1 % confidence level, ns = not significant)

Environmental variables	P-value estimate	F-ratio	Variance explained
Charcoal/pollen ratio	<.0001**	5.10	.20 (12.7%)
Charcoal concentration	<.0006**	2.90	.12 (7.6%)
Moisture content	<.0696 ns	1.53	.08 (5.1%)
Inorganic residue	<.6222 ns	.77	.04 (2.5%)
Residual			1.131 (72.1%)
Total inertia			1.571 (100%)

7.3.6. Interpretation of the core HN1 record

The ordination indicates that most of the pollen spectra, with the exception of the topmost two samples, have little in common with the modern pollen spectra and quite possibly represent vegetation and environments not represented, or not common, within the area today. The most different spectra are those from the basal zone (A10) that are also unusual in being so clearly dominated by a single taxon, *Calophyllum.* This taxon, though, is well represented in some modern spectra and indicates that the vegetation was peatland forest. The consistent presence of *Quercus* suggests that submontane

forest was regionally more extensive or occurring closer to the site than today, and temperatures may have been slightly cooler than present.

The next zone, A9, shows a substantial decline in *Calophyllum*, but this decline is compensated for by increases in other peatland taxa, and the very low values for taxa that could have derived from riverine taxa indicate that flooding of the forest was limited. Although the peatland forest was more diverse, the forest was probably secondary in appearance, and dominated by *Calophyllum*. Temperatures may have further declined slightly with increased representation of submontane/montane taxa including Ericaceae and *Podocarpus* as well as *Quercus*, though their increased representation may also be a function of a fall in *Calophyllum* percentages. Increasing evidence for open water is indicated towards the top of zone A9 with increases in riverine taxa, most notably *Gluta renghas* and the aquatic Convolvulaceae.

The increase also in fern spores might suggest that flooding of the area was more frequent. These conditions persist from zone A8 until near to the top of zone A6 when there are notable increases in *Quercus* and *Gluta* to high levels that are largely sustained until the end of the period represented by zone A4. There is a compensatory decline in *Calophyllum*. Despite the strong representation of *Gluta*, the decline of Convolvulaceae and monolete ferns in the upper zones (A5 to A1) may suggest reduced flooding.

The period includes what appears to be a major disturbance recorded largely in subzone A5a. Although the major taxa are little affected, it would appear, from the peaks in *Macaranga* and Polypodiaceae, that the vegetation

became very much more open. The general lack of response in riverine and aquatic taxa suggests that flooding was not a factor. In fact *Gonystylus bancanus* and *Lophopetalum*, which are intolerant of flooding (Soerianegara, 1994; Kartasubrata, 1994), have their only significant values for the diagram within and just above this subzone, respectively. The small peak in charcoal suggests that fire may have been the cause of the disturbance and could possibly be indicative of a major drought and/or the first evidence of human activity in the area.

Both charcoal concentrations and charcoal-pollen ratios have higher sustained representation from the middle of zone A4 indicating that burning became a regular feature of the vegetation from this time. The lack of a vegetation response suggests that the introduction of regular burning or an increase in burning frequency did not have a marked or immediate influence on the vegetation. The lack of response also suggests that the increase in burning is unlikely to have been from natural events. In contrast to the vegetation, there is a major change in the sediments just after the increase in burning with two samples of relatively high inorganic matter. It is unlikely that the inorganic matter represents an increase in deposition as there is no evidence for a change in fluvial activity. It is most likely that the inorganic residues represent concentration as a result of peat oxidation. As the HN1 pollen record does not indicate that the climate in this region was drier in the last glacial times, it is possible that the peat had achieved maximum height under prevailing hydrological conditions.

There are major changes in the representation of peatland and riverine forest taxa in the periods represented by zones A3 and A2 including temporary reversals in the importance of *Gluta* and *Calophyllum*, but both zones show high diversity as well as abundance of montane-submontane taxa and probably indicate lowest temperatures for the record. Values for Ericaceae, *Symplocos* and *Dacrydium* as well as *Quercus* are probably sufficiently high to indicate a local forest source.

The top two samples of the core are very different to any others and suggest that there could have been a major hiatus close to the top of the core. The much younger date at the zone A2/A1 boundary suggests that zones A3 and A2 could relate to the Last Glacial Maximum. The samples of zone A1 also show close similarity to some surface samples and it is possible that they represent recent sediments. Although local villagers say that this site is regularly flooded, the percentages of taxa that could indicate riverine forest are very low. Either previous samples indicate extremely regular flooding or values for riverine taxa are artificially reduced by dominance of the high producing pollen species, *Gymnostoma sumatrana*. The latter interpretation is supported by sharp reductions in representation of almost all other taxa. Considering the likely influence of *Gymnostoma* pollen, on representation levels of other taxa, the values for secondary taxa, particularly *Trema*, are probably very significant and indicate substantial forest disturbance. The similarity of these two samples to PS3 sites are probably due to pollen of *Terminalia*. This taxon could be derived from *Melastoma* that is commonly associated with forest disturbance.

7.4. Core DP1

7.4.1. Sediment description

Core DP1 was retrieved from very moist sediments in the dried bed of the Lake Pemerak, using a modified Livingstone sampler. The place where this core was collected is locally known as a kerinan, a moist depression in the lake bed. When the water level recedes in the Lake Sentarum during seasonal droughts in this region, kerinan is a place with sufficient water for fish to survive.

The length of the core DP1 is 300 cm, and mostly dominated by clay and fine sand. From 0 to 8 cm, the core is slightly moister than below, and is composed of clay with small rootlets and fine sand. From 8 to 24 cm, the sediment is mostly clay with fine sand; from 24 to 82 cm, the sediments are mainly fine sand, with some clay; and from 82 to 300 cm, the sediment predominantly consists of fine sand.

The core sediments are moist, with average water content of 31%, while the average value for inorganic residue is extremely high, about 93% of oven dry weight. The Munsell colours of the core are varied. From 0 to 74 cm, the colour is olive brown (2.5 Y 4/4), dark olive (5 Y 4/4) from 74 to 100 cm, and generally olive (5 Y 5/6) from 100 to 300 cm. The results of three AMS radiocarbon (^{14}C) dates on this core are presented in Table 7.7. The dates are in stratigraphic order but the long period of time represented in such a short core makes it unlikely that sediment accumulation has been continuous.

Table 7.7. Results of AMS radiocarbon age (^{14}C) for core DP1

Sample ID	Depth (cm)	Radiocarbon Age (Years B.P.)	σ ^{13}C ($^0/_{00}$)	Material dated
OZE 146	5-7	3850±40	-30.0*	Pollen
OZE 147	21-22	14810±70	-30.0*	Pollen
OZE 148	81-82	42200±700	-30.0*	Pollen

Note: * estimated value by ANSTO

7.4.2. Pollen diagram

Because of very low pollen content, only samples from above 82 cm depth were analysed, a total of 20 samples. The results of pollen and charcoal analyses are presented in Figures 7.10.a-d. Ninety four pollen taxa were recorded. Pollen values for individual taxa recorded in this record are generally low, less than 10%, except for *Gymnostoma sumatrana, Macaranga/Mallotus,* Cyperaceae, Poaceae, Polypodiaceae, and monolete spores.

The CONISS dendrogram provides the basis for division of the diagram. Four zones emerged at the 0.3 dissimilarity level, with the lowest (C4) clearly distinct from the remainder. This is included in zone C1 as floristically it relates clearly to the surface samples. The dendrogram is presented in Figure 7.10.a, together with the summary pollen diagram. No age estimates are provided for zones, at this stage, due to the small number of radiocarbon dates and the expectation that there will be major time gaps within an 80 cm sequence with a basal age of 42,200 years.

7.4.3. Pollen diagram zonation

Zone C 4 (67 - 80 cm, six samples)

The main features of this zone are very high values for monolete spores and substantial values for Polypodiaceae, *Macaranga/Mallotus* comp., and *Quercus*. Aquatic pollen taxa including *Ludwigia* and *Sparganium* are consistently represented while there are low values for Cyperaceae and Poaceae. A variety of riparian taxa is consistently encountered. In peatland/dryland group, *Calophyllum, Ilex, Clausena, Gymnostoma sumatrana, Garcinia*, Dipterocarpaceae, *Palaquium, Madhuca*, Apocynaceae, Arecaceae, *Blumeodendron, Nephelium, Pentace, Pometia, Celtis*, Leguminosae and Sterculiaceae are found. Arecaceae and *Eugeissona* comp. are also present. Charcoal/pollen ratios and charcoal and pollen concentrations are slightly lower, on average, in this zone than in other zones.

Zone C 3 (58 - 38 cm, five samples)

An abrupt change occurs at the zone C4-C3 boundary. Pollen values for *Sparganium, Gymnostoma sumatrana*, Poaceae, and Anacardiaceae (small type) sharply increase, while pollen values for *Quercus, Macaranga/Mallotus*, Polypodiaceae, and monolete spores sharply decline. Pollen values for Dipterocarpaceae and *Madhuca* slightly increase, while pollen values for many other peatland/dryland taxa substantially decrease. Within the group of riparian/peatland/dryland taxa, percentages of *Barringtonia, Mentangis, Gluta renghas* sim., and *Microcos* are higher. The overall picture among the non-arboreal taxa is that pteridophytes are substantially reduced, while herbaceous

taxa have increased. The increase in *Sparganium* is compensated by a decrease in *Ludwigia* in the aquatics. Charcoal/pollen ratios and pollen concentrations are slightly higher but there is little change in average charcoal concentrations.

Zone C 2 (38 - 22 cm, four samples)

This zone is very similar to zone C3, except that values for Poaceae and Cyperaceae are higher, and *Ludwigia* has become scarce. Values for pteridophytes, secondary taxa, and submontane/montane taxa are generally unchanged, but *Podocarpus* is entirely absent. *Ilex* also becomes rare. Charcoal/pollen ratios, and charcoal and pollen concentrations remain unchanged, on average.

Zone C 1 (22 - 0 cm, five samples)

This zone corresponds with a general change in sediment from sandy clay to clay with fine sand. Total values for Poaceae and Cyperaceae have increased to be equivalent to those of total trees and shrubs. Pollen values for *Sparganium* and *Ludwigia* sharply decline, and only a few aquatics are recorded. Values for monolete spores remain constant but values for trilete spores are highest for the record in the top two samples. Only *Gymnostoma sumatrana* in the peatland forest group and *Mentangis* retain reasonably high values although Arecaceae percentages increase towards the surface. *Trema,* Anacardiaceae, and *Carallia* have notable presence in the topmost sample, and *Dillenia* (reticulate) has its only good representation for the diagram within the group of riparian/peatland/dryland taxa.
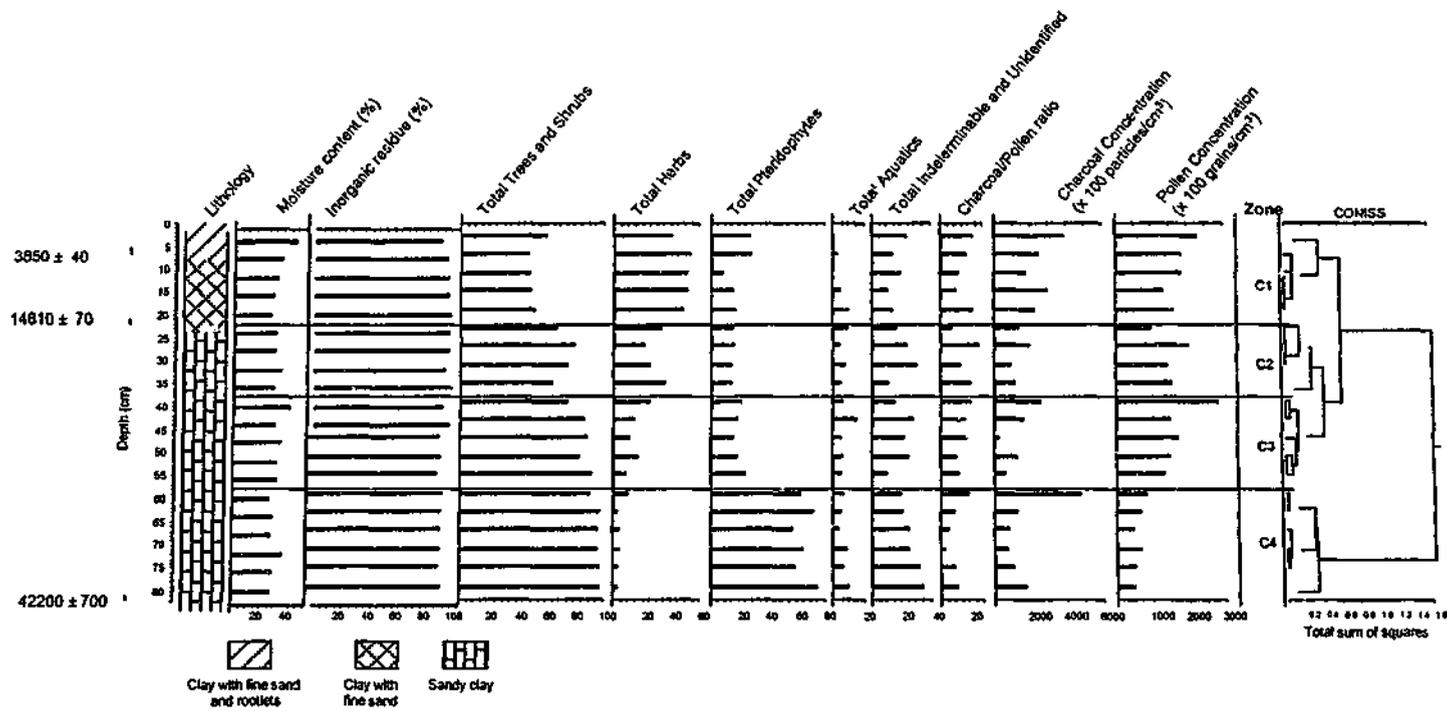
Figure 7.10.a. A summary pollen diagram for core DP1
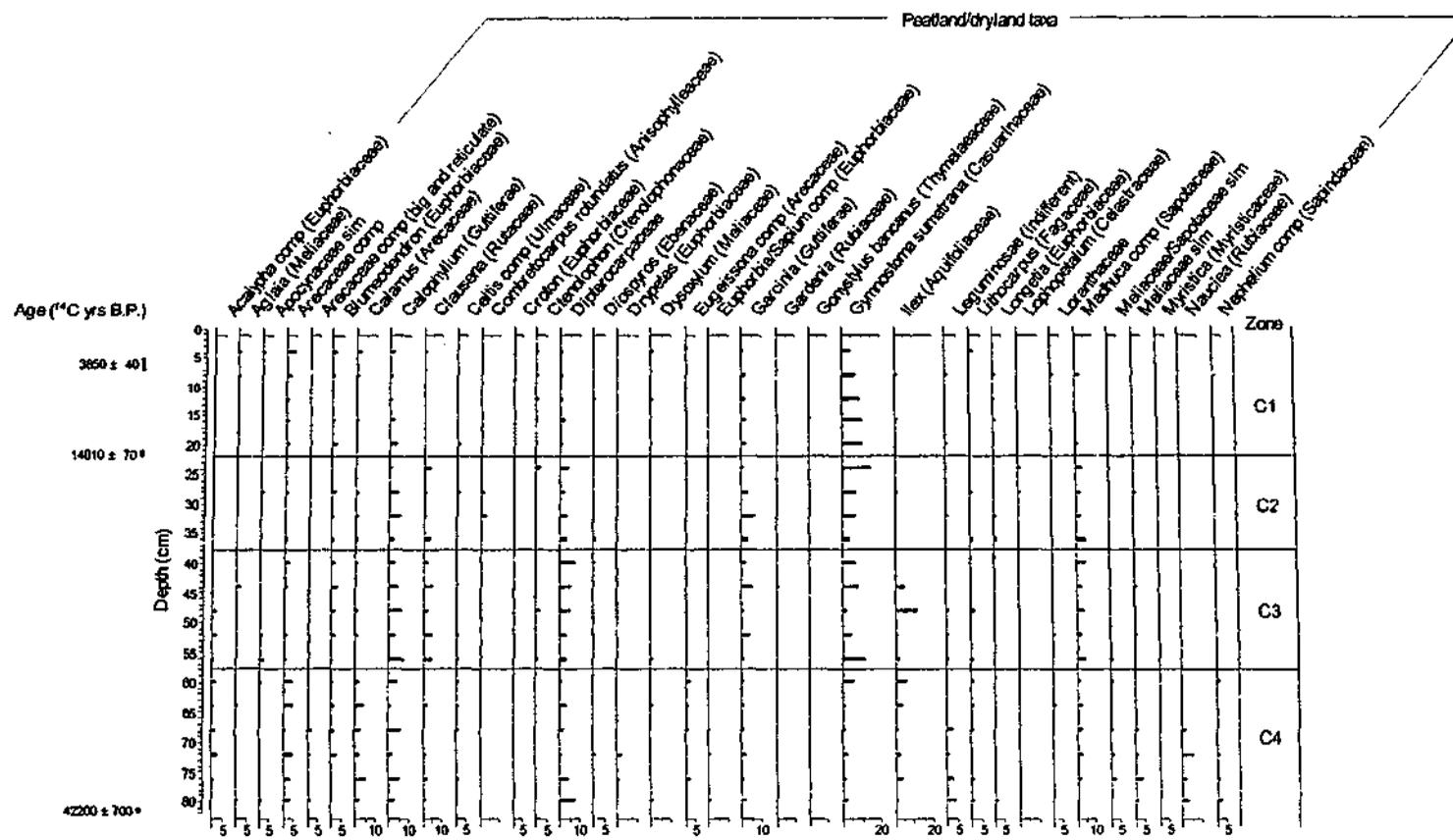
Figure 7.10.b. Pollen diagram for core DP1, showing peatland/dryland taxa
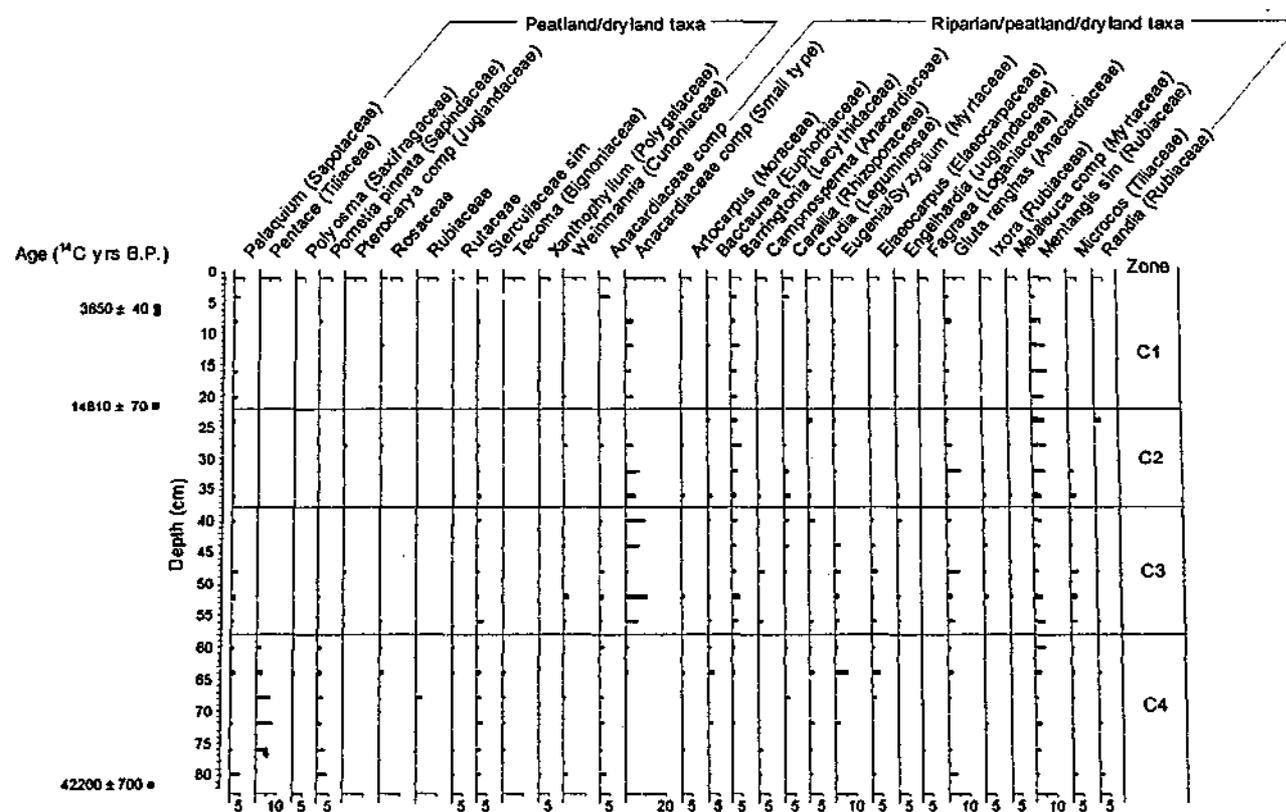
Figure 7.10.c. Pollen diagram for core DP1, showing the remainder peatland/dryland taxa, and riparian/peatland/dryland taxa

Figure 7.10.d. Pollen diagram for core DP1, showing submontane/montane and secondary taxa, herbs, aquatics, and pteridophytes

Barringtonia remains present but *Microcos,* and *Ixora* have disappeared from the diagram Charcoal/pollen ratios and charcoal and pollen concentrations remain constantly high.

7.4.4. Unconstrained incremental sum of squares cluster analysis

Results of unconstrained incremental sum of squares cluster analysis provide three clear clusters (Figure 7.11). The classification also shows that variation in pollen taxa between samples is relatively small as the first division occurs at only the 1.5 dissimilarity level, while the second division is at the 0.5 dissimilarity level. The first division separates samples from the lowest zone (C4), while the remaining samples divide in the middle of zone C2, effectively separating the topmost from the mid-diagram samples. The elimination of distinction between the top three zones indicates that changes in forest composition are not accompanying the strong stepwise reduction in forest representation relative to herb cover.

CONISS

16cm(C1)
20cm(C1)
8cm(C1)
12cm(C1)
24cm(C2)
36cm(C2)
4cm(C1)
28cm(C2)
32cm(C2)
40cm(C3)
52cm(C3)
44cm(C3)
48cm(C3)
56cm(C3)
68cm(C4)
76cm(C4)
72cm(C4)
60cm(C4)
64cm(C4)
80cm(C4)

Sample

0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6
Total sum of squares
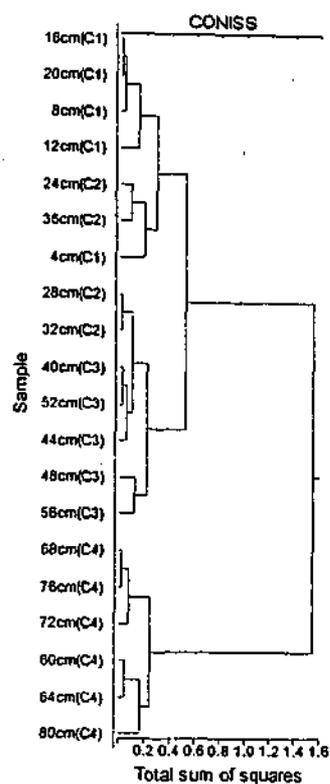
Figure 7.11. Results of the stratigraphically unconstrained classification (CONISS) for core DP1

7.4.5. Results of correspondence analysis (CA) and the assessment of environmental variables

Table 7.8 provides summary results of the CA ordination. The results show that the first CA ordination axis is substantially more important than the next three axes. Axis 1 explains about 37% variance, while axis 2 explains about 13% variance. The CA ordination diagram for sample scores on axes 1 and 2 is given in Figure 7.12.

(Ana1; Anacardiaceae comp. (small type); Anac; Anacardiaceae; Bacc;*Baccaurea*; Blum;*Blumeodendron*; Calm;*Calamus*; Calo;*Calophyllum*; Camp;*Campnosperma*; Cara;*Carallia*; Celt;*Celtis*; Clau;*Clausena*; Comb;*Combretocarpus rotundatus*; Conv: Convolvulaceae; Cten;*Ctenolophon*; Cype;*Cyperaceae*; Dacr;*Dacrydium*; Dile;*Dillenia*; Dios;*Diospyros*; Dip;Dipterocarpaceae; Elae;*Elaeocarpus*; Enge;*Engelhardia*; Eric: Ericaceae; Eugn;*Eugenia*; Fagr;*Fagraea*; Garc;*Garcinia*; Gard; *Gardenia*; Glut;*Gluta renghas*; Gony;*Gonystylus bancanus*; Gymn;*Gymnostoma sumatrana*; Hemm: Hammamelidaceae; Ilex;*Ilex*; Ixor;*Ixora*; Legum;Leguminosae; Lith: *Lithocarpus*; Long;*Longetia*; Loph;*Lophopetalum*; Lora;Loranthaceae;Ludw; *Ludwigia*; Lyce;*Lycopodium cernuum*; Lyph;*Lycopodium phlegmaria*; MSa;Meliaceae/Sapotaceae; Maca;*Macaranga/Mallotus* comp.; Madh;*Madhuca* comp.; Meli; Meliaceae; Ment;*Mentangis* sim.; Micr;*Microcos*; Mono:monolete; Mora: Moraceae; Myri;*Myristica*; Myrs;*Myrsine/Rapanea*; Nauc: *Nauclea*; Neph;*Nephelium*; Neos: *Neoscortechnia*; Pal1;*Palaquium* comp. (4 colporate grain); Pand;*Pandanus*; Panda;Pandanaceae; Pent;*Pentace*; Phyl;*Phyllocladus*; Plan;*Planchonella*; Poac;Poaceae; Podo;*Podocarpus*; Poly;Polypodiaceae; Polyos;*Polyosma*; Pome;*Pometia*; Pter;*Pterocarya*; Quer;*Quercus*; Rosa;Rosaceae; Ruta;Rutaceae; Sapi;Sapindaceae; Sapo: Sapotaceae; Sten;*Stenochlaena palustris*; Ste1;Sterculiaceae sim. (three pored type); Ste2: Sterculiaceae (four porate type); Symp:*Symplocos*; Term;*Terminalia* comp.; Trem;*Trema*; Tril; trilete)

Figure 7.13. CA ordination diagram of the DP1 record, showing pollen scores

Table 7.8. Summary results of CA on total pollen spectra from core DP1

Axes	1	2	3	4	Total inertia
Eigenvalues	.352	.123	.061	.053	
Cumulative percentage variance of pollen data	36.9	49.8	56.3	61.8	
Sum of all unconstrained eigenvalues = Total variance of pollen data					.95

The results of the CA ordination are very comparable to those of the unconstrained classification. Axis 1 clearly separates the samples of zones C1-3 from those of zone C4. The second axis distributes out the samples from zone C1-3 in approximate stratigraphic order with the topmost samples 4-16 cm forming a fairly distinct group in the bottom left hand corner of the ordination. The modern samples fall mainly between the C1-3 and C4 groups near the centre of the first axis, with greatest relationship to samples of zones C4 and C3.

The CA ordination diagram for pollen taxa is given in Figure 7.13. The positioning of Poaceae, Cyperaceae, trilete spores, *Lycopodium cernuum,* and *L. phlegmaria* clearly shows their association with samples of zone C1. Riparian taxa are mostly confined to the upper part of the diagram, spreading around samples from zones C2 and C3. Most peatland taxa are associated with samples from zones C4, C3 and C2.

Results of the environmental variable assessment are given in Table 7.9 and the relationship of these variables with pollen spectra is illustrated in Figure 7.12. The tests identified that the charcoal/pollen ratio has the strongest relationship with the composition of pollen spectra and is significant at the 1%

level. The total variance explained by the four variables is about 30%. There is clear positive association between charcoal/pollen ratios and moisture content, and these are negatively associated with inorganic residue, along axis 1. Charcoal concentration variation relates more closely to pollen variation along axis 2 than axis 1.

Table 7.9. Results of environmental assessment for core DP1, based on 9999 completely randomised Monte Carlo permutation tests under reduced model (** significant at the 1 % confidence level, ns = not significant)

Environmental variables	P-value estimate	F-ratio	Variance explained
Charcoal/pollen ratio	<.01**	3.06	.14 (14.7%)
Charcoal concentration	<.1606 ns	1.37	.06 (6.3%)
Moisture content	<.3049 ns	1.08	.05 (5.3%)
Inorganic residue	<.4407 ns	.94	.04 (4.2%)
Residual			.662 (69.5%)
Total inertia			.952 (100%)

7.4.6. Interpretation of the Core DP1 Record

The record suggests that a similar lake bed environment to that of today has most likely existed around this site for much of the recorded period, from the late Pleistocene to late Holocene. There is the possibility that organic lake muds or even peats have been deposited at times within the lake basin and then been removed under changed hydrological conditions, but there is no evidence preserved of such conditions.

Changes within the pollen diagram do indicate, though, that vegetation and environments have changed substantially over the recorded period. In particular, conditions indicated during the period represented by zone C4 were

very different to those in more recent times. The sharp change around the zone C4/3 boundary suggests either a period of rapid environmental change or, most probably in this short sequence, a major discontinuity. The high values for *Quercus*, combined with highest representation of other sub/montane elements in zone C4 suggests that conditions were cooler than today. The association of *Quercus* and *Macaranga/Mallotus* comp., the other major pollen taxon, is not easy to explain but the importance of the later taxon could indicate the existence of a somewhat open forest or one subjected to substantial disturbance, resulting perhaps from erratic river behaviour as well as from burning that is evident throughout the period. A relatively open canopied vegetation may also be consistent with high values for monolete spores (ferns) and Polypodiaceae that could have formed a substantial ground layer. Herbs, particularly Poaceae and Cyperaceae, were largely excluded, perhaps by the ferns under cooler and wetter conditions than present.

Whether the lake basin itself was vegetated is unclear. Unlike spectra from peatland forests, values for individual taxa show little sample to sample variation suggesting that pollen derived mainly from vegetation surrounding the basin or was thoroughly mixed by moving water. In either case, the existence of at least a seasonal lake is suggested. The relatively low values for riverine/peatland taxa may provide supporting evidence for the existence of a lake with less opportunity for forest establishment within the basin than is the case at present. Alternatively, riverine/peatland may have been excluded by a more stable vegetation on the present lake surface. The lack of organics within

the sediment precludes the existence of a permanent lake, but less interannual variability may have prevented establishment of trees.

Another feature of zone C4 is the presence of a large number of peatland/dryland taxa, many of which disappear at the end of this period. It is possible that many of these taxa made up types of heath forest that grow predominantly on non-inundated podsolic, sandy soil, and kerapah that is found today on white-sand that experiences waterlogging. Heath and kerapah forests do occur within the Lake Sentarum region. Thorp *et al.* (1990) and Thomas *et al.* (1999) suggest that white sands in West Kalimantan correspond to in situ weathering and fluvial sedimentation. The origin of white sands is probably from podzolisation of saprolites and sandy colluvium under humid equatorial climate.

Although no surface samples were taken from these vegetation types, a number of features of the fossil record are consistent with their presence. Heath is species rich and has similar vegetation composition to the present peatland forests at the lakes (Giesen 1987). Although *Quercus* is not present today, its occurrence on sandy clay soils above 250 m altitude in nearby mountains (Nooteboom 1987) suggests that it could have been present in such vegetation when temperatures were lower. Other recorded taxa have little diagnostic value, as the general floristic composition of heath is similar to that of peat forests, at least at a palynologically visible level. Thorp *et al.* (1990) dated the formation of white sands associated with heath forest in Mandor reserve, West Kalimantan, to around 50,000 years BP and suggested that this may have been

the last time of widespread fluvial sand deposition in West Kalimantan. The development of the white sand deposit is triggered by more seasonal, cooler and drier climates that might have supported more open vegetation communities in the last glacial. It is possible that the sand sequence recorded in the base of this core was part of this depositional phase and that the period represented by zone C4 records the end part of this activity. The low pollen concentrations certainly suggest that sediment accumulation was relatively rapid.

The vegetation changes around the zone C4-3 boundary are associated with some increase in charcoal values, suggesting that there may have been an increase in burning. Such an increase in burning could have been associated with the increase in representation of herbaceous taxa that may also indicate increased human activity in the area. The continued increase of herbs through the periods represented by zones C3 to C1 certainly suggests increasing human impact, although, unlike the charcoal concentration values that also tend to increase through this period, there is little change in charcoal/pollen ratios. The substantial changes in the composition of forest vegetation suggest also that there was likely to have been a major climate change at the zone C4/C3 boundary. The sharp reduction in submontane/montane taxa, particularly *Quercus*, indicates that increased temperatures are likely to have been a component of this change.

The increase in taxa that are or could be of riverine origin indicates the development or expansion of dwarf forest vegetation within the confines of the

lake, very similar to that occupying the marginal areas of the lake today. Although the landscape appears to become progressively more similar to that of today in the lake area, the ordination appears to indicate that the vegetation has become less similar to surface samples. This could be largely explained by the fact that no surface samples were collected from the middle part of a lake, as surface sampling was undertaken when lakes were filled with water, or by the failure to account for much of the variation in samples on the first two axes. The position of most surface samples close to the axis origins provides some support for the latter interpretation. It is clear that, in terms of well represented taxa, the basal part of the DP1 sequence has high values for fern spores and *Macaranga/Mallotus*, similar to many surface samples, while the high Poaceae values, evident towards the top of the DP1 record, are not achieved in any of the surface samples.

7.5. Core DP4

7.5.1. Sediment description

The retrieved core, only 100 cm long, is composed of humic peat, peaty clay and organic clay. It can be divided into five stratigraphic sections. From 0 to 10 cm, the sediment contains some peat with clay, and a similar type of sediment also occurs in the section from 56 to 70 cm. From 10 to 56 cm and from 70 to 74 cm, the sediment is mainly composed of humic peat, while from 74 to 100 cm organic clay dominates the sediment.

Table 7.10. Results of radiocarbon age (^{14}C) for core DP4

Sample ID	Depth (cm)	Radiocarbon Age (Years B.P.)	σ ^{13}C (‰)	Material dated	Remarks
Wk 5776	1-16	26660±250	-29.8±0.2*	Bulk sediment	Conv.date
OZE 142	21-22	21680±110	-30.0**	Pollen	AMS date
Wk 5775	46-60	36690±610	-30.1±0.2*	Bulk sediment	Conv.date
OZE 143	61-62	38200±450	-30.0**	Pollen	AMS date
OZE 144	80-81	34800±350	-30.0**	Pollen	AMS date
OZE 145	98-99	38800±450	-30.0**	Pollen	AMS date

Note: * measured value; ** estimated value; Wk (Waikato Radiocarbon Laboratory); OZE (ANSTO)

The Munsell colour of this sediment varies from dark olive brown to yellowish brown. The colour of peaty clay section is predominantly olive brown (2.5 Y 4/4), while the humic peat section is dark olive brown (2.5 Y 3/3). The colour of organic clay section is mostly yellowish brown (2.5 Y 5/6).

The upper parts of this core, from 0 to 60 cm are moist (± 80%), while from 60 cm to the base of the core, moisture content varies, ranging from 40 to 65%. On average, moisture content of this core is 67%. Results of loss on ignition (LOI) are strongly correlated with the lithology. Inorganic residue of the peaty clay sections ranges from 50 to 91%, in humic peat from 7 to 41%, and in organic clay from 70 to 77%. Both peaty clay and humic peat sediment sections also contain some unidentified plant remains.

This core has four AMS dates and two conventional radiocarbon (^{14}C), but these radiocarbon dates are not in stratigraphic order. The basal date is around c. 39,000 years BP, while the top date is about c. 27,000 years BP.

Radiocarbon ages between these dates vary between 22,000 to 38,000 years BP. These radiocarbon ages are too variable to be used to reconstruct a core chronology. All dates indicate that this peat core was developed in Late Pleistocene. Table 7.10 presents the radiocarbon dates of core DP4.

7.5.2. Pollen diagram

Results of fossil pollen and microscopic charcoal analyses are presented in three diagrams. Figure 7.14.a is a summary diagram, which includes lithology, moisture content, inorganic residue, charcoal/pollen ratios, charcoal concentrations, pollen concentrations, total trees and shrubs, total herbs, total pteridophytes, and total aquatics. Figures 7.14.b-d present the riparian/peatland/dryland and some peatland/dryland taxa. The remaining groups, including a continuation of peatland/dryland taxa, are given in Figure 7.14.e.

A total of 80 pollen taxa was identified in this pollen record. Indeterminable and unidentified pollen taxa vary between 10 and 25%. The representation of the riparian/peatland/dryland and aquatic groups is highly variable in this core. In the peatland/dryland group, values of Leguminosae type and *Gymnostoma sumatranu* are higher than other pollen taxa. *Quercus* and *Dacrydium* dominate the submontane/montane group and the aquatics *Ludwigia* and Convolvulaceae are confined to the lower part of the diagram. Few secondary taxa, herbs and ferns are consistently recorded.

7.5.3. Pollen diagram zonation

The CONISS classification shows a major division at the 1.6 dissimilarity level, around 48 cm depth. The top group consists of 11 samples, while the lower group is composed of 14 samples. The top group is clearly separated into two zones, while the lower group forms three zones at the 0.8 dissimilarity level. Based on visual inspection, the middle zone of the diagram, D3, is divided into two subzones. This is the point where aquatics abruptly disappear from the record (Figure 7.14.a).

Zone D 5 (100 - 74 cm, seven samples)

The major features of this zone are high and persistent representation of *Mentangis, Gymnostoma sumatrana, Ludwigia,* and both Convolvulaceae types, and consistent presence of *Barringtonia* (small type), that is restricted to this zone. Values for other pollen taxa are generally low. From riparian/peatland/dryland taxa, *Crudia, Melaleuca,* and *Dillenia* appear consistently. From peatland/dryland taxa, *Calophyllum* (type 1) is present in the lower part of the zone. Values for *Garcinia* pollen are inconsistent, high in the lower two samples and in the top two samples but very low in between. Pollen values for submontane/montane taxa are generally low, although *Quercus* pollen is consistently present in the lower part of the zone, while pollen of Ericaceae and *Podocarpus* is scattered throughout the zone.
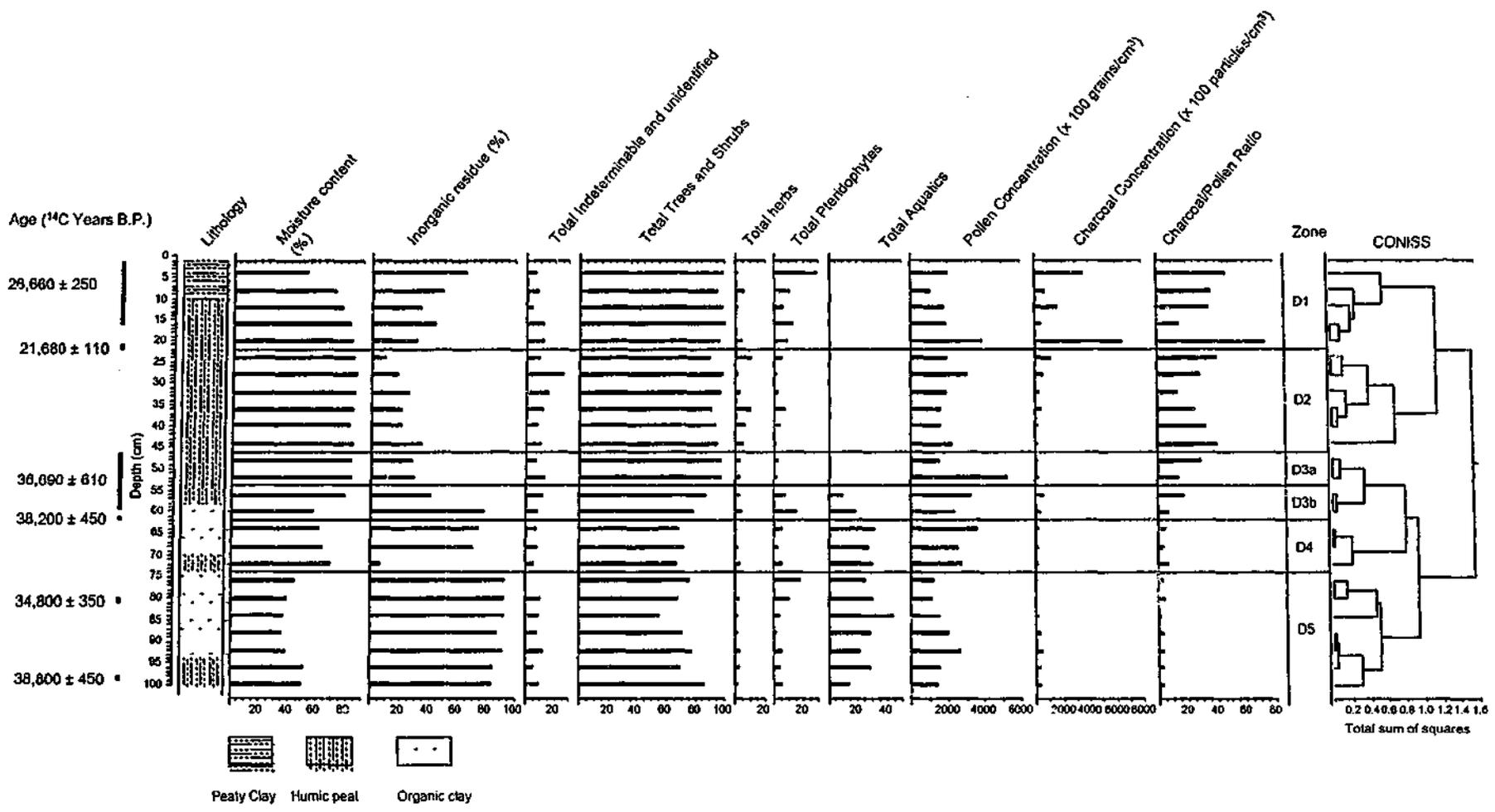
Figure 7.14.a. A summary pollen diagram for core DP4

Figure 7.14.b. Pollen diagram of core DP4, showing riparian/peatland/dryland, and some peatland/dryland taxa
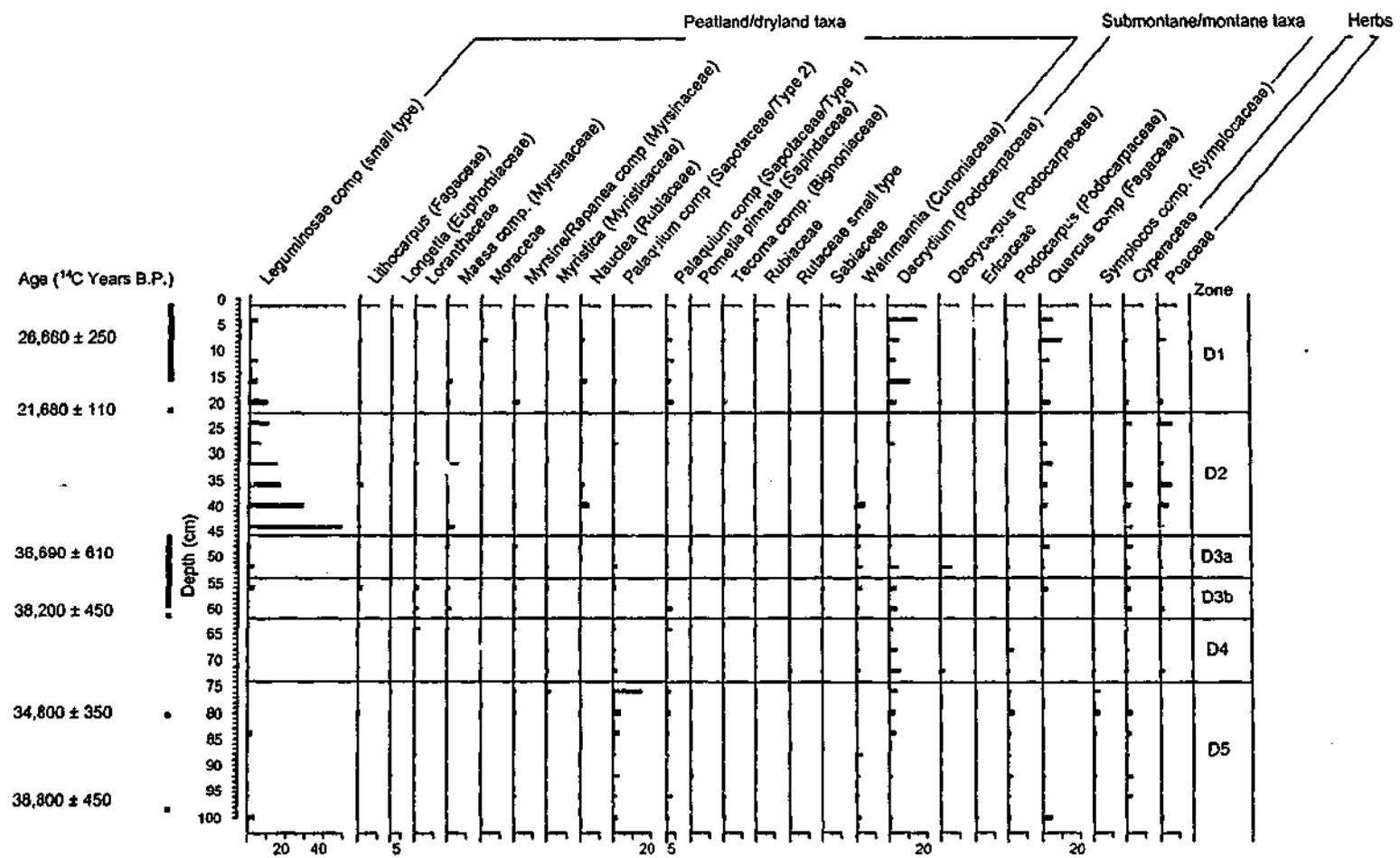
Figure 7.14.c. Pollen diagram of core DP1, showing a continuation of peatland/dryland taxa and submontane/montane taxa
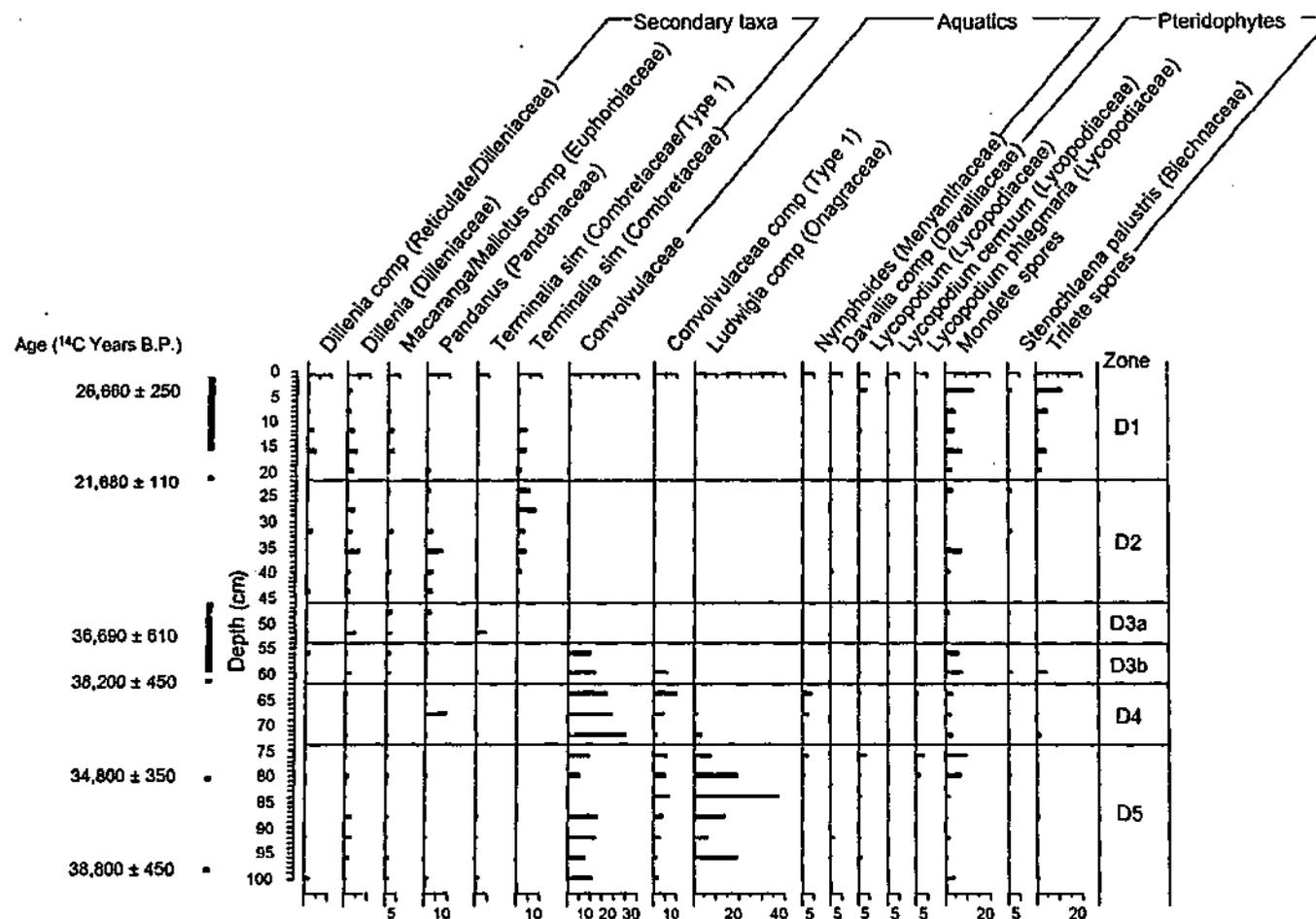
Figure 7.14.d. Pollen diagram of core DP1, showing secondary taxa, aquatics, and pteridophytes

Pollen values derived from secondary taxa are also low. The representation of *Macaranga/Mallotus* is persistent, while pollen of *Terminalia* (type 1) and *Pandanus* is occasionally present. In addition to the high values for *Ludwigia* and the two types of Convolvulaceae have very high values through the whole zone. The aquatic group contains *Nymphoides,* represented in low values. The herbs Cyperaceae and Poaceae, and pteridophytes mainly monolete spores, are poorly represented. Pollen concentrations are moderately high, but charcoal concentrations and charcoal/pollen ratios are extremely low.

Zone D4 (62 - 74 cm, three samples)

Representation within major groups shows little change from the previous zone but there are substantial changes in individual riparian taxa and aquatics. *Crudia* dominates the riparian group, while *Barringtonia* (small type) has disappeared and *Mentangis* has strongly declined. Values for *Ludwigia* have also sharply declined but pollen derived from *Nymphoides* and Convolvulaceae (type 1) have slightly increased in the top part of the zone, and values for the other Convolvulaceae have increased to replace *Ludwigia* as the dominant aquatic pollen type. No substantial changes occur in the peatland/dryland, submontane/montane and secondary taxa. Pteridophytes, Cyperaceae, and Poaceae values remain low. Pollen concentrations have increased slightly, while charcoal concentrations and charcoal/pollen ratios remain low.

Zone D3 (46 – 62 cm, four samples)

The main feature of this zone is a sharp decline of aquatic pollen and total disappearance of all aquatic pollen in subzone D3a. Pollen derived from *Ludwigia* and *Nymphoides* is completely absent from both subzones. At the base of the zone, values for *Crudia* suddenly drop, while pollen values for *Gymnostoma sumatrana* and Hamamelidaceae slightly increase. Other riparian taxa including *Mentangis, Baccaurea, Elaeocarpus, Dillenia, Engelhardia, Eugenia,* and Anacardiaceae are consistently present, while values for *Melaleuca* type increase through the zone. From peatland/dryland taxa, pollen of Dipterocarpaceae is only present in subzone D3a, while pollen derived from Loranthaceae is consistently represented in the whole of subzone D3b, but is poorly represented in subzone D3a. The submontane/montane taxa continue to be poorly represented, although there is a peak around the subzone D3a/b boundary with all recorded taxa represented. Pollen values derived from secondary taxa and pteridophytes remain low. Pollen concentrations remain relatively high and charcoal concentrations remain low but charcoal/pollen ratios increase substantially through the zone.

Zone D2 (46 -22 cm, six samples)

Abrupt changes occur at the base of the zone in riparian/peatland and peatland/dryland groups. Pollen values for *Eugenia/Syzygium* (type 1), *Baccaurea, Carallia,* and Leguminosae (small type) increase sharply, while *Melaleuca* and Hamamelidaceae sharply decrease. *Gymnostoma sumatrana* values fall but then rise again in the upper part of the zone. Of the

submontane/montane taxa, only *Quercus* has consistent representation, while *Symplocos* is occasionally present. Secondary taxa, mainly *Terminalia* and *Pandanus,* and herbs, both Cyperaceae and Poaceae, have increased representation while pteridophyte values remain low. In this zone, charcoal/pollen ratios have further increased while charcoal concentrations remain low and pollen concentrations are moderately high.

Zone D1 (22 - 0 cm, five samples)

Substantial changes occur in most pollen groups. In the riparian/peatland group, values for *Eugenia* substantially decline towards the top part of the zone. By contrast, pollen values for *Artocarpus* comp. increase through the zone. *Barringtonia, Elaeocarpus, Dillenia,* and Anacardiaceae are consistently present, while the other riparian taxa are occasionally found. In the peatland/dryland group, the trends towards reduced values for Leguminosae small type and increased values for *Gymnostoma sumatrana* continue. Percentage values for *Glochidion* pollen are high in the three lowermost samples, but the taxon then completely disappears. *Diospyros* shows a similar though less dramatic trend to *Glochidion.* As a result of increases in *Quercus* and *Dacrydium,* the submontane/montane component achieves highest levels for the diagram, but secondary taxa and herbs have reduced representation and aquatics are absent. There are substantial increases in monolete and trilete spores through the zone but values for other recorded fern taxa remain low. Pollen concentrations are average for the diagram, while charcoal

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concentrations and charcoal/pollen ratios are higher than in all other zones, the former substantially so.

7.5.4. Unconstrained incremental sum of squares cluster analysis

The dendrogram of unconstrained cluster analysis of total pollen data in core DP4 is given in Figure 7.15. There is a primary division at the 1.5 dissimilarity level that clearly separates the upper and lower parts of the diagram, and reinforces the signature of the subzone D3a/D3b boundary. Within the upper samples, a second division divides samples 32 to 40 cm from the others at a dissimilarity level of 1.1, with the top sample at 4 cm separating from the remainder at a dissimilarity level of 0.7.
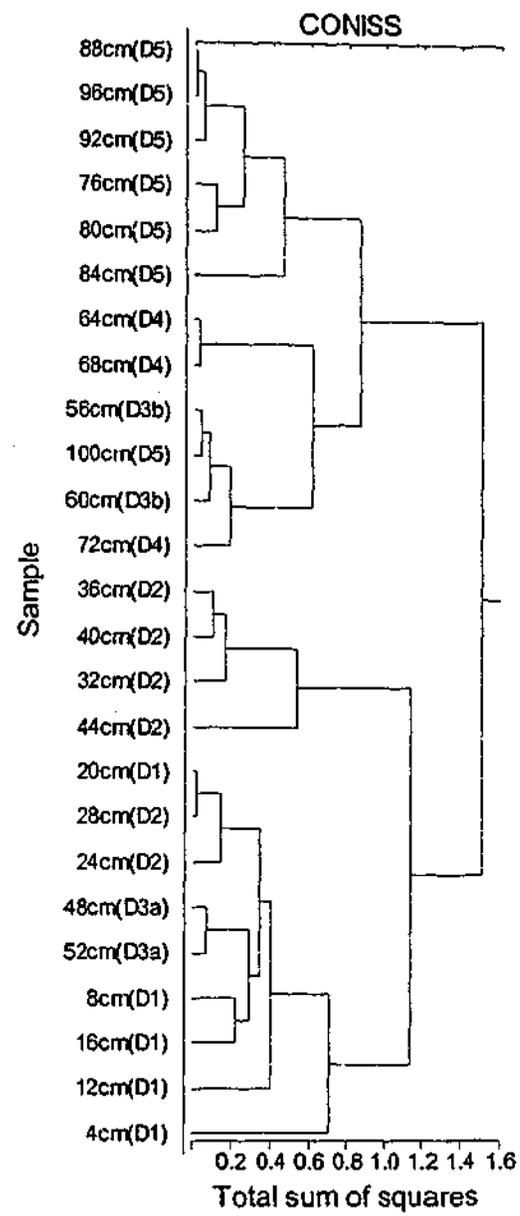
Figure 7.15. Results of the stratigraphically unconstrained classification (CONISS) for core DP4

Within the lower group of samples, the major subdivision is between samples from 76 cm and 96 cm that make up the bulk of zone D5, and the others (samples from zone D4, D3b as well as the basal sample of zone D5). The classification clearly brings out some variations within the diagram that are not evident in the constrained classification.

7.5.5. Results of correspondence analysis (CA) and the assessment of environmental variables

Summary results of CA are recorded in Table 7.11. The eigenvalue of axis 1 is much stronger than those for the other higher axes. The CA ordination diagrams for sample scores and environmental variables based on the first two axes are given in Figure 7.16, while a scatter plot of the pollen scores is presented in Figure 7.17. Results of the assessment of environmental variables by Monte Carlo tests are presented in Table 7.12. The tests show that the influence of moisture content and charcoal pollen ratios on pollen variation are statistically significant.

Table 7.11. Summary results of CA on total pollen spectra from core DP4

Axes	1	2	3	4	Total inertia
Eigenvalues	.514	.246	.230	.182	
Cumulative percentage variance of pollen data	25.0	36.9	48.1	56.9	
Sum of all unconstrained eigenvalues = total variance pollen data					2.06

The clustering pattern in the CA ordination diagram (Figure 7.16) is very similar to that in the unconstrained dendrogram tree. Samples from zone D1 and D2 are located in the right side of axis 1, while almost all samples from the lower zones are on the left, except for sample 52 cm (zone D3a) at the origin. The second axis draws out mainly the samples from the top two zones, in approximate stratigraphically order, with the top 4 samples, separated from all other samples in the record, in the lower right hand corner of the diagram. The modern samples form a largely distinct cluster in this lower-right hand quadrant, and have greatest similarities with fossil spectra from samples 8, 16, 20, and 28 cm. Taxa probably having an important influence on this relationship are *Barringtonia*, Dipterocarpaceae, Anacardiaceae, *Macaranga*, *Dillenia*, *Terminalia*, *Stenochaelena palustris*, and trilete spores (See Figure 7.17). With environmental variables, the significant variables moisture content and charcoal/pollen ratios are most closely related to axis 1, as is inorganic residue that is strongly opposed to moisture content. Charcoal concentrations are more aligned with pollen variation along axis 2.

Table 7.12. Results of environmental assessment for core DP1, based on 9999 completely randomised Monte Carlo permutation tests under reduced model (significant at the 1 % confidence level (ns = not significant)**

Environmental variables	P-value estimate	F-ratio	Variance explained
Moisture content	<.0001**	5.75	.40 (19.4%)
Charcoal/pollen ratio	<.0150**	2.03	.14 (6.8%)
Charcoal concentration	<.2331 ns	1.22	.08 (3.9%)
Inorganic residue	<.9487 ns	.52	.04 (1.9%)
Residual			1.40 (67.9%)
Total inertia			2.06 (100%)

7.5.6. Interpretation of the Core DP4 record

This core appears to represent a history of vegetation change within Lake Pemerak during the later part of the last glacial period. The sediment contains relatively higher inorganic residues than those in core HN3 and HN1 but is clearly more peaty than core DP1.

The earliest recorded period, represented by zone D5, is dominated by non-forest taxa suggesting either an open forest or aquatic environment at the coring site. Although the Convolvulaceae can be derived from either dry land or aquatic vegetation, an aquatic environment is strongly suggested by high values for the swamp taxon *Ludwigia* and by the near absence of Poaceae that generally characterise open terrestrial vegetation. The
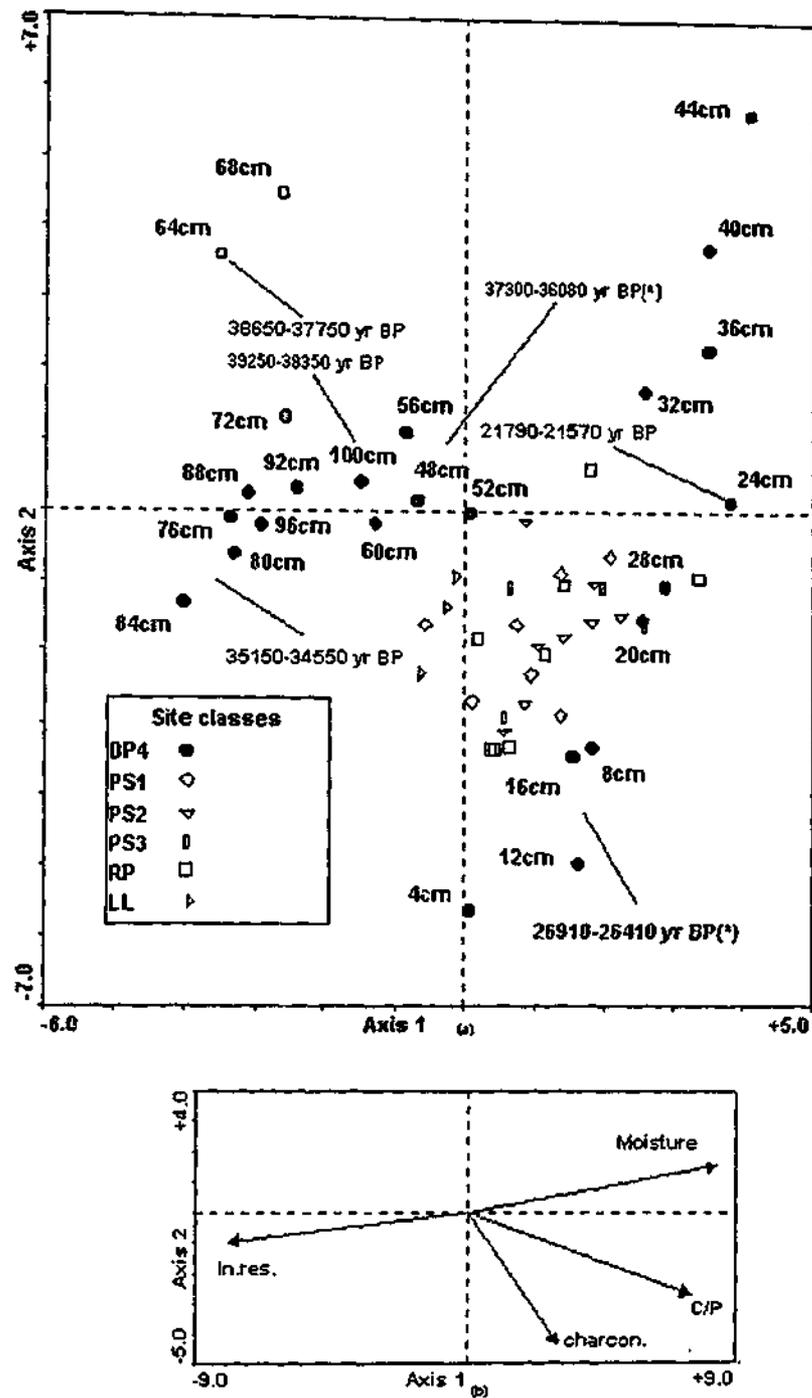
Figure 7.16. CA ordination diagram for the core DP4 record, showing sample scores (a) and environmental variables (b). Lines indicate samples with radiocarbon dates, which are given in the two error range. An asterisk symbol (*) indicates samples with conventional radiocarbon dates.

(Anat; Anacardiaceae comp. (small type); Anac; Anacardiaceae; Bacc;*Baccaurea*; Blum;*Blumeodendron*; Calm;*Calamus*; Calo;*Calophyllum*; Camp;*Campnosperma*; Cara;*Carallia*; Celt;*Celtis*; Clau;*Clausena*; Comb;*Combretocarpus rotundatus*; Conv: Convolvulaceae; Cten;*Ctenolophon*; Cype;*Cyperaceae*; Dacr;*Dacrydium*; Dile;*Dillenia*; Dios;*Diospyros*; Dip;Dipterocarpaceae; Elae;*Elaeocarpus*; Enge;*Engelhardia*; Eric: Ericaceae; Eugn;*Eugenia*; Fagr;*Fagraea*; Garc;*Garcinia*; Gard; *Gardenia*; Glut;*Gluta renghas*; Gony;*Gonystylus bancanus*; Gymn;*Gymnostoma sumatrana*; Hamm: Hammamelidaceae; Ilex;*Ilex*; Ixor;*Ixora*; Legum;Leguminosae; Lith: *Lithocarpus*; Long;*Longetia*; Loph;*Lophopetalum*; Lora;Loranthaceae;Ludw; *Ludwigia*; Lyce;*Lycopodium cernuum*; Lyph;*Lycopodium phlegmaria*; MSa;Meliaceae/Sapotaceae; Maca;*Macaranga/Mallotus* comp.; Madh;*Madhuca* comp.; Meli; Meliaceae; Ment;*Mentangis* sim.; Micr;*Microcos*; Mono;monolete; Mora: Moraceae; Myri;*Myristica*; Myrs;*Myrsine/Rapanea*; Nauc: *Nauclea*; Neph;*Nephelium*; Neos: *Neoscortechnia*; Pal1;*Palaquium* comp. (4 colporate grain); Pand;*Pandanus*; Panda;Pandanaceae; Pent;*Pentace*; Phyl;*Phyllocladus*; Plan;*Planchonella*; Poac;Poaceae; Podo;*Podocarpus*; Poly;Polypodiaceae; Polyos;*Polyosma*; Pome;*Pometia*; Pter;*Pterocarya*; Quer;*Quercus*; Rosa;Rosaceae; Ruta;Rutaceae; Sapi;Sapindaceae; Sapo: Sapotaceae; Sten;*Stenochlaena palustris*; Ste1;Sterculiaceae sim. (three pored type); Ste2: Sterculiaceae (four porate type); Symp;*Symplocos*; Term;*Terminalia* comp.; Trem;*Trema*; Tril; trilete)

Figure 7.17. CA ordination diagram of the core DP4, showing pollen scores on the first two axes

consistently low organic component of the sediments suggests that open water may have prevailed and was surrounded by herbaceous swamp that may have invaded the site during periods of low water level. This lake system would have been very different to that of today where seasonal conditions do not appear to be allowing sediment accumulation and where there is a lack of aquatic plants, apart from opportunistic Cyperaceae. It is likely that the site was a backwater lake with regular inundation from the river providing the predominantly inorganic sediments. The relatively high representation of *Barringtonia* and some other taxa most likely derived from riverine vegetation suggests that the wider area was dominated by riverine vegetation. Low diversity and representation of taxa most likely originating from peatland forest would indicate that this vegetation type was some distance away from the site, probably, as today, beyond the valley area. It is notable that taxa such as *Combretocarpus rotundatus*, *Gonystylus bancanus*, *Lophopetalum* and *Ctenolophon*, which are usually confined to peatland, are not recorded in zone D5. The major, and most consistently represented peatland taxon is *Gymnostoma sumatrana*. This taxon, which has wind dispersed pollen, could provide support for an extra-local peatland source. Its abundance could also indicate that heath forest (kerangas) was an important element of the forest vegetation.

The relatively open nature of the site of deposition could have allowed representation of pollen from more distant areas, including montane environments, however, values for montane-submontane taxa are relatively

low, suggesting that temperatures may have been little different to those of today.

There are major and sustained changes in the record within the period represented by zones D4 and D3. Some changes may be associated with local hydroseral succession as the lake system became infilled. The presence of the floating aquatic *Nymphoides* may reflect lake shallowing before the loss of all aquatics with invasion by riverine forest. The general increase in organic content of the sediment supports this hydroseral proposal as sediment accumulation would tend to reduce the effectiveness of river flooding and the vegetation could filter out suspended inorganic material. The one very high value for organic matter at the base of zone D4 has little influence on pollen spectra and may simply be an isolated patch of inwashed detritus rather than a short phase of peat accumulation. The peak in *Crudia* followed by that in *Melaleuca* may indicate stages in the local terrestrialisation process. The increase in Hamamalidaceae largely parallels that of *Melaleuca*. Although the source plant of this family is unknown, a species of *Rhodoleia* is reported to occur in the lake region (Giesen 1987) and the fact that it grows commonly in primary forest may support a late successional stage in forest development around the site. However, *Melaleuca* tends to be associated with forest disturbance and this is consistent with evidence for increased burning within the vegetation.

Despite the development of a more complete forest cover, there is slightly increased representation of montane taxa with *Quercus* becoming a

consistent component of the pollen spectra. This would indicate regionally changing environments. A reduction in temperature may have been associated with drying conditions that facilitated hydroseral changes and an increase in the occurrence of fires.

The period represented by zone D2 is a relatively stable part of the record with consistently high sediment moisture and organic values, domination of tree pollen and consistent pollen concentration values. Despite overall stability, there is significant variation in values of a number of woody taxa that indicate changes in forest formation in the lake region through the period. Components of both riverine and peatland vegetation are involved in these processes and there could have been a mix of these forest taxa around the site. Although the inorganic component of the sediments is low, it still averages about 20%, higher than in most peatland forests, and almost equivalent to that in freshwater swamps (Anderson 1983). There is also significant evidence of disturbance in the form of notable values for a number of secondary tree taxa, Poaceae and Cyperaceae and the consistent presence of charcoal. The maintenance of temperatures cooler than today is suggested by consistent representation of *Quercus*.

The topmost zone is characterised by trends in both sediments and pollen taxa. The increase in sediment inorganic content through the zone suggests greater riverine influence and is accompanied by similar increases in a number of taxa. Of these taxa, pteridophytes, *Quercus* and *Dacrydium* could suggest attainment of lowest temperatures that would equate with the Last

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Glacial Maximum. In addition to riverine influence, achievement of highest burning levels for the record could indicate greatest level of disturbance. However, this is not reflected in the Poaceae or in secondary taxa, the latter virtually disappearing in the top part of the zone. It is possible that these taxa are less important generally within the vegetation under cooler conditions. *Gymnostoma* makes a comeback after low values in the previous zone and may indicate expansion of heath forest during or towards the Last Glacial Maximum.

A thin layer of inorganic sediments overtop the sequence. These were not sampled due to their dry hardened nature that was considered unsuitable for the preservation of pollen. Although there is increasing inorganic material through zone D1 it is unlikely that there was continuity of sedimentation between these two units. It is more likely that the organic sediments were truncated before deposition of the capping inorganics.

Chapter 8: Discussion

8.1. Record comparison and correlation

In order to be able to reconstruct a regional picture of vegetation and environmental change for the Lake Pemerak area, it is necessary to correlate the four records that have been produced. Although there are a number of radiocarbon dates available for each core that ideally should form the basis of a regional chronology, a number of these are inverted and the older dates have to be treated with caution as they are close to the age limit of the method and radiocarbon ages can be altered substantially by the existence of small amounts of contaminant material. It is clear also from the available dates, and from the condensed nature of the sediments that sequences are likely to be discontinuous. This provides problems of comparison between assemblages if they represent different time periods within different cores. Comparison is also complicated by the different environments from which the cores were taken and it is clear from the pollen that local influences tend to mask those of a more regional nature.

Under these circumstances it was decided to use numerical methods in an attempt to identify relationships between recorded spectra from all four records to see if any underlying patterns could be identified. Ward's method was used to classify pollen spectra, based on all identifiable pollen and spore taxa, and results are presented on Figure 8.1. The major division of the dendrogram separates generally older from younger spectra in the analysed cores. The older section (pre the Last Glacial Maximum) embraces sample

sequences with dates from 24,250 years BP to 42,200 years BP, and is separated into groups 5 and 6. However, group 3, from the section of 'younger' spectra, also falls into this older age range.

All samples from core DP4 fall into the older group, despite one date of 21,660 BP. This date is very suspect, as it is stratigraphically beneath a date of 26,660 year BP. Group 6 covers all spectra from core DP4 and the very base of HN3, while group 5 embraces the basal samples of core DP1 and the lower middle part of core HN1. Despite the overlap in dates between these groups, the stratigraphic positions of groups in core HN1 suggests that group 6 may be older than group 5. Group 3 consists mainly basal samples of core HN3, and the upper middle part of core HN1. Dates covering this group range from 28,250 to 28,900 year BP. Group 4 is most clearly separated. This group is formed mainly of spectra from zones B4 and B5 of core HN3. Dates for group 4 within the HN3 spectra group range from 3,117 (13,070) to 16,840 (28,600) years BP. Spectra from groups 1 and 2 make up the top parts of cores HN3, HN1 and DP1. Although the results of classification indicate that spectra from group 1 and 2 are slightly separated, the radiocarbon (^{14}C) dates on these groups fall within the range 14,810 and 265 years BP.

Despite the differences in pollen composition between the sequences, the general positions of the groups, shown in relation to the pollen zonations of the records on Figure 8.2, suggest that there may be an underlying biostratigraphy that, in combination with the radiocarbon dates, will allow the tentative establishment of a chronostratigraphy.
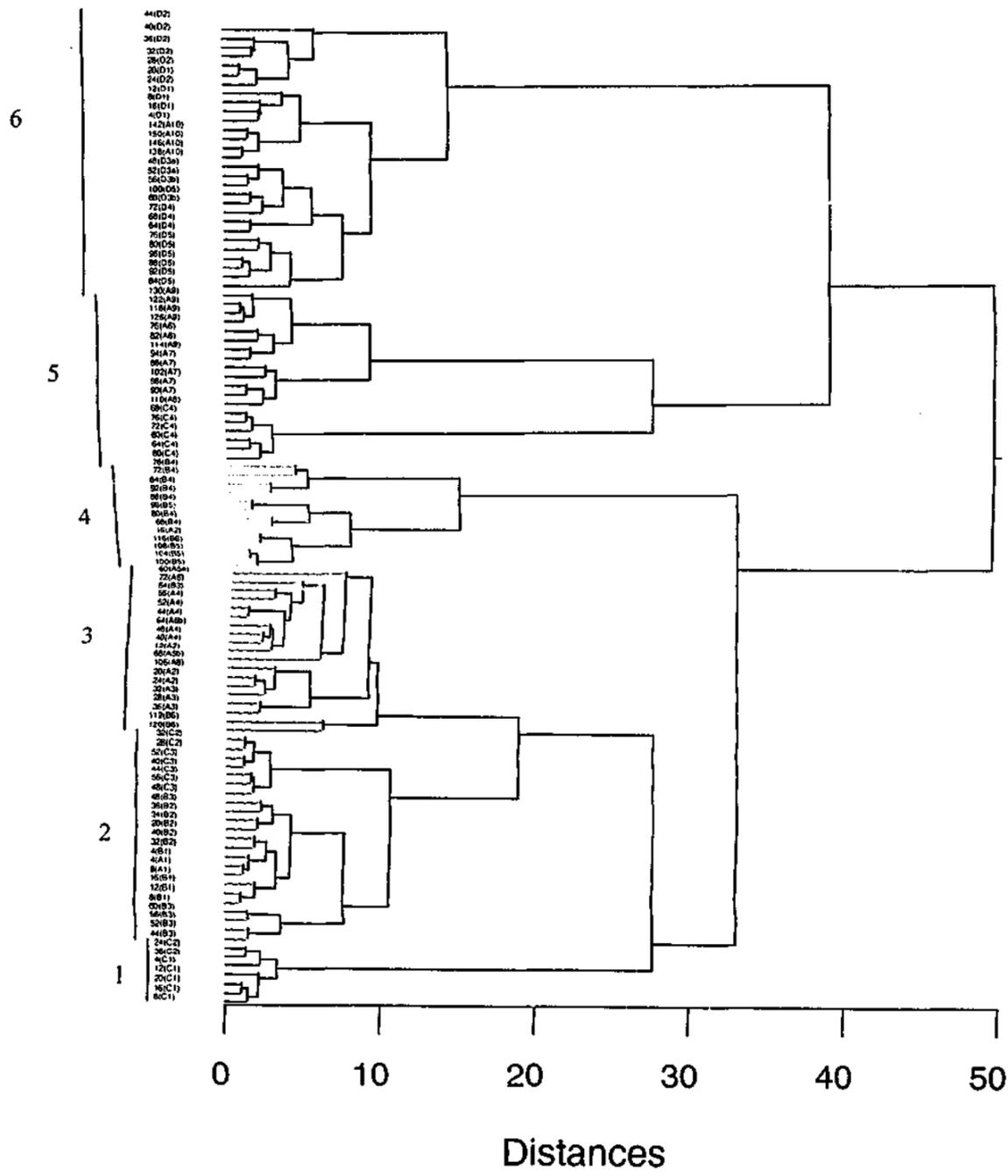
Figure 8.1. Hierarchical cluster tree of pollen spectra from cores HN3, HN1, DP1 and DP4
(Ward's method)

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considered reliable. Prior to this time, ages are very uncertain. The oldest date of 42,200 years BP relates to group 5, at the base of core DP1, but this may be too old as group 5 spectra are stratigraphically above those of group 6 in core HN1, although successional influences through landscape change cannot be dismissed. All other dates older than 30,000 years BP relate to group 6.

With respect to the degree of continuity of representation, it appears that certain periods of time are not, or only poorly, represented. There are a number of dates that relate to the late Holocene but none to be period late glacial to mid-late Holocene between about 12,000 and 4,000 years BP. The very latest part of the Pleistocene is covered by four dates between 12,000 and 17,000 years ago but then there is a gap to 26,000 years BP apart from three dates that are stratigraphically inverted and therefore unreliable. The majority of dates fall beyond 26,000 years BP and, although many are statigraphically inverted, provide good coverage back to about 40,000 years BP.

Based on the numerical analysis of pollen data and radiocarbon dates, a tentative chronology is given in Table 8.1.

Table 8.1. The chronology of major vegetation and environmental changes in the Lake Pemerak area deduced from radiocarbon dating and pollen stratigraphy of the four analysed cores.

Pollen grouping	Palynological zones	Inferred ages (years BP)
Group 1 and 2	A1, B1- B3, C1- C3	0 – c. 12,000 (4000)
Group 3	A3 - A5, B6	c. 26,000 – c. 30,000
Group 4	A2, B4, B5 , (B6)	c. 12,000 – c. 26,000 (17,000)
Group 5	A6 – A9, C4	> 30,000
Group 6	A10, D1 – D5	> 30,000 BP - > 40,000

8.2 Modern-fossil sample comparisons

Some overview of the nature of modern pollen spectra from the region in comparison to those from fossil pollen assemblages is discussed in chapter 7 (See Figures 7.4, 7.5, 7.8, 7.9, 7.12, 7.13, 7.16, and 7.17). The initial impression is that there is more variation within the modern assemblages than there is within any of the fossil diagrams. Higher sample to sample variation is to expected to some degree in surface samples because all are taken from vegetated plots and probably represent a limited period of time. By contrast, many fossil samples represent a significant period of time. However, overall variation does suggest that, for the major riparian and peatland forest components at least, spatial variation in the vegetation of the Lake Sentarum region vegetation is greater than any temporal variation over at least the last 30,000 years. Greatest variation is in pteridophyte representation where that shown in the modern samples is also found in most of the fossil records.

Major differences between modern and fossil samples are recorded in secondary forest taxa, herbs and aquatics. Generally much higher values for secondary taxa in the modern samples reflect the relatively high degree of anthropogenic disturbance to the vegetation at the present day and may suggest that this is unprecedented. By contrast, dry land herbs, composed almost exclusively of Cyperaceae and Poaceae, have relatively low values in modern spectra compared to some fossil spectra. The representation of secondary taxa, Cyperaceae and Poaceae in fossil pollen spectra is not totally associated with human impact, but may also reflect natural forms of disturbance.

There are also virtually no aquatics recorded in the modern spectra whereas high values have occurred in the past. Giesen (1987; 1996) also reported that aquatic plants were not common in the lakes, except introduced *Echicornia crassipes*, that is mostly found near human settlements along Kapuas river. High values for aquatic pollen in the past suggest that there may have been some past environments that are not, or are only poorly, represented in the landscape today.

Some support for changing vegetation through time is provided by the ordinations on individual fossil records, with modern spectra included as passive, presented in the previous chapter. In all records the modern spectra tend to group together and cover only a small proportion of the ordination space. In all records, except for DP1, these modern spectra also tend to group with, or occur closest to, the most recent fossil spectra. In DP1, there is little overlap between modern and fossil spectra and, even though the majority of pollen spectra appear to be derived from the Holocene, pollen spectra in the modern samples indicate a more open vegetation than Holocene vegetation.

An examination of major or notable pollen taxa in different fossil assemblages helps provide some explanation for these patterns. Of those major or notable taxa characteristic of presumed Holocene spectra (Anacardiaceae, *Combretocarpus, Carallia, Elaeocarpus, Crudia, Engelhardia, Pandanus* and *Trema*), all except *Combretocarpus* and *Engelhardia* are represented in the modern samples. By contrast, none of the characteristic taxa of those spectra derived from presumed Last Glacial Maximum (LGM) to late glacial times (*Ilex*, Meliaceae, *Fagraea, Dacrycarpus, Phyllocladus, Lycopodium cernuum*

and *L. phlegmaria*) or from this period together with pre LGM spectra (Sterculiaceae, *Gluta, Quercus, Dacrydium, Symplocos, Podocarpus, Ericaceae* and Polypodiaceae) are present or conspicuous in the modern spectra. Of those taxa that characterise pre LGM spectra alone, the majority (*Fagraea, Melaleuca, Madhuca, Pentace,* Meliaceae/Sapotaceae sim, *Gonystylus, Ludwigia* and Convolvulaceae) are rare or absent in modern spectra. Only *Eugenia/Syzygium,* Arecaceae and Leguminosae in these pre LGM spectra have good representation in modern samples and these could be derived from a wide range of species and genera.

Uniting the modern and fossil spectra and helping to provide a general picture of vegetation similarity are a number of well represented taxa. These include *Gymnostoma, Palaquium* and *Planchonella* of the Sapotaceae, Dipterocarpaceae, *Calophyllum, Macaranga/Mallotus,* Cyperaceae and Poaceae, in addition to monolete and trilete ferns. In addition, *Barringtonia, Mentangis, Baccaurea, Dillenia* and *Terminalia* are conspicuous in all but identified LGM to late glacial spectra.

8.3. Reconstruction of environments in the Lake Pemerak area

The fossil records demonstrate that there has been systematic change in the Lake Pemerak region over at least the last 40,000 years. However, this change appears to have not influenced significantly the general landscape of the area. Those records from the Lake Pemerak peatland indicate that this type of environment is likely to have existed continuously, in proximal lacustrine locations, through this period and the fact that coring did not reach to the base of the peat suggests that they have been present for a longer period. Similarly,

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the two records from the fluvio-lacustrine system suggest that this system has been present in some form over this period. Despite a great deal of overlap in pollen composition, it has been rare for inorganic sediments, that may have derived from river transport, to be recorded in present peatland forest sediments, and cores from the lake system have rarely achieved organic matter contents consistent with the presence of peatland forests.

Pollen spectra falling into group 6 of the classification on all fossil spectra (Figure 8.2) may provide evidence of the oldest recorded environments (the core DP4 record, particularly). At this time the presence of high values for aquatics in the lower part of core DP4 suggests the presence of backwater swamp or lake environments over the present valley floor. This would suggest more stable hydrological conditions than today, probably due to lower rainfall seasonality. However, without a thorough geomorphic study of this complex region, it cannot be ascertained for certain whether this single deposit was characteristic of environments over the whole basin at this time, and of no other recorded period from this region. The presence of significant levels of aquatics in core DP1 might suggest the existence of such environments until well into the Holocene.

The drying of the lake in the middle part of the DP4 sequence and partial replacement of the aquatics by herb taxa may represent an increase in climatic variability, natural succession within the basin or increased forest disturbance. The increases in secondary taxa and charcoal support the idea of increased variability or forest disturbance. Whatever the influence, it may not have extended to the peat forest around core HN1, as those spectra from this

phase show little evidence of herb pollen and little change in secondary taxa and charcoal representation.

An additional feature that characterises group 6 spectra, is low levels of pteridophyte spores. These levels contrast with those from most other spectra from last glacial times. There is no evidence that moisture availability was significantly different to later glacial times and, considering that pteridophyte values are equally low in Holocene spectra, this period may have experienced rather higher temperatures.

Group 5 pollen spectra appear to have succeeded those of group 6, despite the fact that the base of core DP1 records the oldest radiocarbon date. The dates on this core were considered potentially the most unreliable due to the nature of the sediments and core location. The lack of in situ peat made conventional dating impossible, and it is likely that the dated residue from pollen analysis, used for AMS dating, contained a significant component of water transported material. In this fluvial environment, material could have been reworked from peat deposits bordering the fluvio-lacustrine system making the dates artificially old. It is of course possible that there is a contaminant pollen component to these sediments. However, the sharp change in the pollen spectra at the zone C4/C3 boundary suggests that pollen contamination may not be substantially influencing contemporary pollen spectra.

All dates that do not show reversals on spectra from group 3 spectra fall between 28,250 and 28,900 years BP, and this may fairly embrace a particular

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set of environments, although the base of this assemblage is not reached in core HN3.

In general terms, the vegetation composition during the pre-LGM period was rather different to that of the Holocene. Montane to submontane taxa indicate regionally more extensive highland forests or encroachment into dryland and peatland forests due to lower temperatures than present. Kerapah/kerangas forests may have been an extensive component of the Pleistocene landscape in the Lake Sentarum. Within the drainage basin, shallow open water and swamp were present with riverine and peatland forests.

The latest part of the Pleistocene including the latter part of the LGM is distinguished most clearly by group 4 spectra in the peatland cores. Lower temperature levels are indicated by peaks in montane and submontane taxa that almost certainly indicate the inclusion of the elements in lowland forests. In addition to those taxa known to be best represented in, or restricted to, high altitudes, such as Ericaceae, *Podocarpus, Dacrycarpus, Phyllocladus, Symplocos,* and *Quercus,* additional taxa such as *Ilex,* Meliaceae, and *Fagraea* appear also to have expanded during this time. Despite the higher degree of continentality of Borneo in this Pleistocene ice age and potential for lowered water tables due to a lowering of the baseline of the Kapuas River with much lower sea levels, there is no consistent evidence for reduced effective precipitation. However, the lower temperatures would have increased the effectiveness of existing precipitation. Neither secondary taxa nor herbs show a response to the changed climatic conditions while fern spores actually increase,

a change that could be a response to an increase in moisture levels as well as a decrease in temperature.

The lake sites are not represented in the group 4 spectra and it is most probable that the LGM is not recorded in these sequences. However, submontane-montane taxa and pteridophyte spores are recorded in relatively high values through the lowest zone of DP1 and in the topmost one or two samples of HN1 that could suggest representation of the LGM. Certainly, there is no real contradiction with the available dates. A problem with separating pre-LGM and LGM spectra is that, despite their classification in different groups within the hierarchical classification, they do share a number of taxa, a situation that is not evident between LGM and Holocene spectra.

The floristic distinctiveness of the Holocene is not only indicated by the disappearance of submontane/montane taxa and changes in the composition of peatland and riverine vegetation, but also by relatively high values for secondary taxa, particularly *Pandanus*, and *Trema*. These secondary taxa are accompanied by increased values for herb taxa (Poaceae and Cyperaceae) indicating significant disturbance to the vegetation. There is little doubt that people would have been a major cause of this level of disturbance but increased climatic variability may also have been a factor.

8.4. Peat formation and degradation

Sedimentation rates have been very variable within and between sites and it is unlikely that the whole time period has been recorded. It is estimated that the records cover mainly the late Holocene and the period before about 26,000 years BP. This record indicates that the older period was the time most

conducive to sediment accumulation both within the valley basin and in the peat swamps.

This pattern of peat accumulation contrasts strongly with that in most of the Malesian region where peat formation can be related mainly to the rise in sea level during the early to mid Holocene. The reasons for the bulk of peat accumulation during the last glacial period, prior to the LGM, in this area are a matter of speculation. One important factor could have been climatic conditions that are likely to have been as wet but cooler than today, with possibly less variable rainfall. During this period, there is also evidence for the more extensive distribution of kerangas/kerapah forests that have been suggested to have formed a major peat forming habitat in interior Borneo (Morley 2000). A combination of cooler Pleistocene temperatures and kerapah vegetation would have slowed decomposition rates. Sclerophyllous and xerophyllous communities occurring in kerapah forests, with their high tannin contents, promote incomplete biochemical decomposition, leading to peat initiation (Bruenig 1990). Based on the lengths of sediment cores and results of radiocarbon dates, it is estimated that peat accumulation rates in this glacial period in this region ranged between 0.1 - 1 mm/yr, characteristic of slow growth rates from kerapah forest. These are less than half those estimated from the Holocene material, although the slow rate would have been compounded by any breaks in sedimentation. Both these rates contrast with estimates from Holocene coastal peats at between about 2.2 and 2.8 mm/yr (Anderson 1983).

Since about 26,000 years ago, peat growth has been intermittent. The lack of peat between this time and the 17,000 years BP may have been due to

reduced rainfall with lower water tables during the early part of the LGM. High temperatures may have inhibited peat accumulation during the early-mid Holocene but, considering the extensive nature of peat formation in coastal areas at this time, this factor alone is unlikely to have been critical. Throughout the basin, there is a limit to the amount of peat that can accumulate and there must be a delicate balance between accumulation and degradation. The effects of erosion must also not be overlooked, and lack of representation may relate to subsequent times of erosion of accumulated sediment, perhaps resulting from occasional disturbance associated with droughts, increased fluvial activity and wildfires. These influences may have led to the alteration or the loss of habitat for peat accumulation.

The poor representation of peat generally during the Holocene and particularly at the present day must also take into account the impact of human activities within this high rainfall area. These are likely to have resulted in substantial erosion and peat degradation. They may also have magnified the impact of climatic variability that results in seasonal droughts associated with El Niño events. Drought would have promoted fires resulting in peat degradation while extreme droughts would have lowered water tables and possibly accelerated lateral drainage from the peat domes. Under conditions of regular inundation, peat particles can retain water and maintain peat growth. However, once dried out, peat particles shrink, leading to irreversible water loss. Excessive water drained from peat particles has significant impact on peat degradation as the aerobic layer, favourable for microorganism activity, increases (Moore 1989).

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8.5. The influence of fire

There is great deal of debate over whether fires could occur naturally within lowland tropical forests and if they could, whether they could influence the nature of the vegetation (Kershaw *et al.* 1997b). There are also debates about the degree to which people have contributed to past burning and the impact that various past land uses have had on the dynamics and distribution of the forests. Answers to these questions are important to future management of forest systems in there regions that are increasingly exposed to anthropogenic burning. In Borneo, the only published evidence of prehistoric fires comes from Goldammer and Seibert (1989), who reported the occurrence of forest fires as early as 17,500 years BP in east Kalimantan.

In this study there is some evidence of burning in all records and an indication that fire activity has increased through time. This activity can be compared with the archaeological evidence for the presence of people within the region. The oldest evidence for occupation comes from the Niah caves in Sarawak, nortwest Borneo that dates to about 40,000 years BP (Harrison 1967, 1970, 1971) and this site also demonstrates that people had the capacity to use fire. A later date of about 20,000 years BP is recorded from Sireh cave in Sarawak. Both sites are located in forest within the interior of the country and during the LGM would have been a substantial distance from the coast, some 500 km in the case of Sireh cave (Datan and Bellwood 1993). Considering that the Lake Pemerak records indicate that forest vegetation was dominant throughout the last 40,000 years, it is likely that people were exploiting forested environments and associated lakes, rivers and swamps from a very

early date. However, it cannot be ascertained that the use of fire resulted in forest clearance.

The pollen records show that burning levels were generally low during initial phases. Highest values are in DP1. The basal date of 42,000 years BP, could suggest early high levels of burning but, as mentioned, this date is considered unreliable and probably much too old. Charcoal/pollen ratios are also notable at the base of HN3, considered to date to at least 30,000 years BP, but these levels are not supported by charcoal concentrations and reflect very low pollen concentration values. In both cases, herb values remain very low and there is no evidence for the establishment of open vegetation. A substantial part of the HN1 record, considered to provide evidence of oldest environments, shows consistently low charcoal values and, although it cannot be determined, for certain, that the record does extend beyond the time of arrival of people, it is most likely to represent natural burning levels. These low burning levels were insufficient to create open vegetation communities. They may, however, have contributed to the dynamics of forest vegetation as secondary taxa have notable representation through this early period although these taxa would have also responded to other disturbance facto   such as those resulting from fluvial and climatic variability.

A major increase in burning is recorded in three of the records within the late Pleistocene. In core HN1 the increase corresponds with a radiocarbon age of about 28,000 year BP, while in DP4 it relates to dates around 36-38,000 years BP, though these could be regarded as too old, by comparison with dates at the top and base of the sequence. The increase is less well marked in HN3

and could have occurred from beyond 30,000 years BP, around 27,000 years BP and as late as the LGM. It is possible that these increases were the result of the additional ignition source introduced with the activities of people.

The impact of fires on the landscape appears to have been variable in space and time. In the swamp environment around core DP4, there is an immediate and generally sustained increase in both herbs and secondary taxa while there is no marked change in these vegetation components of the peatland forest around core HN1 until possibly the late Holocene. The peatland HN3 core clearly demonstrates that impact has been greatest within the last 1,400 years, and this may relate to the development of more intensive agricultural activity in the area, as well as an increase in climatic variability. However, comparison of modern and fossil pollen spectra indicate similarities in forest communities back to at least 3,850 years BP, and this date is close to the proposed onset of rapid cultural change from hunting and gathering to slash and burn farming communities around 5,000 years BP (Bellwood *et al.* 1993). This time also relates to a suggested intensification of El Niño Southern Oscillation (ENSO) activity (Shulmeister and Lees 1995; McGlone *et al.* 1999; Correge *et al.* 2000; Woodroffe and Gagan 2000). The large increase in herb pollen within the lake basin core of DP1 may relate to this late Holocene period, and clearly demonstrates the development of hydrological variability within the basin, with drought periods allowing the establishment of Poaceae and Cyperaceae over the dry lake surface.

8.6. Broader implications of the Lake Pemerak record

The record is one of the few from tropical lowland forest environments to extend back through the LGM and contribute to debates on late Quaternary patterns of climate and vegetation change in lowland areas of the southeast Asian region and globally.

Within southeast Asia, the climate debate has primarily centred on precipitation levels during glacial periods and particularly the LGM, largely because of the importance of climate change to the explanation of problematic distribution patterns of fossil and extant biota within the region (eg. Medway 1972; Brandon-Jones 1996, 1998; van Steenis 1961). It has been hypothesed that climate throughout much of the region must have been substantially drier than today with a dry corridor through the Malayan Peninsula to Java (Medway 1972; Morley 2000; Heaney 1991). Based on geomorphic data and limited palaeoecological evidence, a regional decrease in precipitation of some 30-50% has been proposed with extreme seasonality (Verstappen 1975, 1980, 1994; Thorp et al. 1990), the result mainly of low sea levels that united Sundaland, and the global change of wind circulation and ocean current in LGM. It is thought that the position of intertropical convergence zone (ITCZ) in LGM over this region might shift further south in northern winter (January), and further north in northern summer (July).

Pollen data have contributed to an assessment of the general picture but, until recently, palynologists have avoided those lowland environments that make up the proposed dry corridor. The majority of data are from high altitudes and, as reviewed in chapter 2, indicate that the highlands of West Java (eg.

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Stuijts 1993), northern and central Sumatra (eg. Maloney 1980, 1981; Newsome and Flenley 1988; Stuijts *et al.* 1988) remained wet through the last glacial period. However, it has been noted that a significant reduction in precipitation may have had little influence on the vegetation of these perhumid environments. By contrast, marine records from the Banda Sea (van der Kaars *et al.* 2000) and the Lombok Ridge (van der Kaars 1991; Wang *et al.* 1999) support a reduction in precipitation of at least 30% in the lowlands of the region during the last glacial period, although the high contribution of grasses and eucalypts from the Australian region may have distorted the climate picture from Sundaland. However, the low altitude terrestrial records from West Java (Bandung basin: van der Kaars and Dam 1995; Rawa Danau: van der Kaars *et al.* in press) do confirm dry conditions and more open vegetation in the southern part of the dry corridor during the LGM.

Evidence for dry glacial conditions in the northern part of the corridor have been based, to some extent, on the presence of *Pinus* savanna in Peninsula Malaysia (Morley 2000). However, this record is poorly dated and probably relates to the Middle Pleistocene or earlier. By contrast, a recent marine palynological record from the southern part of the South China Sea (Sun *et al.* 2000) shows no evidence of drier conditions than today during the last 30,000 years and they postulate that a strong winter monsoon, blowing across the South China Sea would have resulted in the maintenance of high rainfall over the exposed continental shelf between Borneo and Sumatra, making up the central part of the proposed dry corridor, during glacial periods. Furthermore, a long palynological record from the Mahakam Delta, Central Kalimantan,

within the proposed dry corridor, suggests predominantly wet climatic conditions and maintenance of evergreen lowland forest through much of the Quaternary (Caratini and Tissot 1988). However, this sequence records mainly high sea level stands and is therefore limited in the degree to which it records glacial conditions (Morley 2000).

In the reconstructions of Heaney (1991) and most recently Morley (2000), the Lake Sentarum region is shown as occurring on the margin of this dry corridor and may be critically placed to test the dry corridor hypothesis. The data presented for this area indicate that, although precipitation could have been lower than today through at least part of the LGM, it must still have been over 1,500 mm and probably over 2000 mm to maintain a complete forest cover beyond the lake border. This suggests that the proposed reduction in rainfall and degree of replacement of forest vegetation may have been overestimated for this region, unless the Lake Sentarum region is unrepresentative of the region. It is possible that moisture levels in the lake region were more influenced by river water derived from the surrounding highlands and fed by orographic rainfall than by rainfall within the localised area. More extreme seasonality may then have resulted in reduced peat accumulation during the LGM. Clearly, it is necessary to locate lowland sites within the corridor to really determine climatic conditions within the dry corridor area.

In relation to understanding global climates and atmospheric circulation patterns, a major controversy in the tropics is the degree of temperature lowering during glacial periods. Original estimates of sea surface temperatures

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by CLIMAP (1981) indicated little difference between present and the LGM, and subsequent reexamination of CLIMAP cores for the southeast Asian region (Pinot *et al.* 1999, Thunell *et al.* 1994, Wang 1994) have supported the CLIMAP reconstructions. The maximum lowering was in the order of 2°C. By contrast, estimates for temperature lowering at tropical high altitudes during the LGM, from the degree of lowering of ice caps and vegetation belts (eg. Hope 1983, Walker and Flenley 1979), are in the order of 6- 10° C (Flenley 1998), although there is debate as to whether decreased CO_2 concentrations (eg. Ficken *et al.* 1998; Huang *et al.* 1999) or increased ultraviolet-B light (Flenley 1998) could account for at least part of the vegetation belt lowering. Although a few recent papers on LGM SSTs have suggested that the CLIMAP reconstructions may be underestimates (eg. Guilderson *et al.* 1994), the debate continues. Resolution of this debate is critical for understanding the factors forcing glacial climates and, in particular, the role of tropical influences on global circulation patterns.

Lake Sentarum is well placed to contribute to the resolution of this debate in that it is one of the few terrestrial sites almost at sea level that can be compared directly with sea surface temperature estimates and with data comparable to those from high altitude sites. Despite the fact that the Lake Sentarum region is surrounded by mountains and expansion of montane vegetation regionally would have increased pollen representation of high altitude taxa, it is considered that values are sufficiently high to demonstrate a local presence. This situation contrasts with that at Rawa Danau (van der Kaars *et al.* in press) where more open vegetation during the LGM would have

allowed increased representation of anemophilous montane taxa. Consequently van der Kaars *et al.* were equivocal about estimating the degree of temperature depression. Other sites used to assess LGM temperatures in the tropical lowlands have tended to be from rather higher altitudes (Colinvaux *et al.* 2000) and therefore have not provided estimates totally comparable with sea surface temperatures. Assuming that the altitudinal lapse rate was similar to the 0.61° C lapse rate of today, a reduction of at least 6° C is suggested for the Lake Sentarum region during the LGM, similar to the estimates some 1,000 m higher in the Amazon region (Colinvaux *et al.* 2000).

In relation to glacial vegetation as a whole, the presence of high altitude taxa did not displace tropical lowland taxa that still dominated assemblages of fossil pollen spectra. However, numerical analyses demonstrate that the nature of most pre-Holocene assemblages has no modern analogue and reassortment between highland and lowland taxa must have taken place at low altitudes. Some lowland taxa may have found refuge at even lower altitudes on the continental shelf but presumably many of the most heat-demanding taxa became restricted in the their distribution to lowland areas. Similarly, it may be surmised that particular environments have allowed the restricted survival of heat intolerant montane taxa at low altitudes during the present, and presumably previous, interglacial periods, with some taxa, such as *Dacrydium*, finding a niche within extreme environments such as kerangas and kerapah forests.

The nature of the lowland forests may also have some bearing on vegetation patterning during glacial periods. Although it is demonstrated that

the Lake Sentarum area remained forested, even at the LGM, there is little doubt that grasslands were regionally more extensive at these times. Although lower rainfall was the major contributing factor, it is hypothesised that the presence of montane taxa may have facilitated forest break up in that the moisture gradient of lowland forest with its semi-evergreen and deciduous elements is broader than that of montane forest which has, historically, not been exposed to the same degree of rainfall reduction. It is thought that rainfall reduction in late glacial might be associated with the development of dry pockets in this ever-wet region. In addition to the influence of rainfall variability, the degree of grassland representation may also have been greater during the later part of the last glacial period than in previous glacials due to the presence and burning activities of *Homo sapiens*. The Lake Pemerak records clearly show increasing representation of open vegetation through this period, while the Banda Sea record of van der Kaars *et al*. (2000) demonstrates a major and sustained increase in grasses, relative to rainforest, particularly the Dipterocarpaceae, from about 37,000 years ago. These vegetation changes were accompanied by an increase in burning to levels higher than any within the last 160,000 years.

Chapter 9: Conclusions and recommendations

9.1. Vegetation and environmental change

This study has achieved the major aims of providing a vegetation and environmental record for the Lake Sentarum region and thereby contributing to the documentation and understanding of the history of a little known part of the world – the lowland tropics of southeast Asia and more specifically the island of Borneo.

The combined record from four pollen analysed sequences taken from the bed of Lake Permerak and surrounding peat forests is considered to cover a large part of at least the last 40,000 years, although there are probably significant gaps of which the early part of the LGM and the very late Pleistocene to the mid-late Holocene are the most recognisable. Patterns of accumulation, still stand and erosion appear complex and, due to the dynamics of peat forest and fluvio-lacustrine systems, are difficult to relate to particular climatic conditions.

Despite the availability of a reference pollen collection for the region, expanded by collections made for this study, and the expertise in tropical rainforest palynology within the Centre for Palynology and Palaeoecology, many taxa, between about 10 and 30% of those recorded, could not be assigned to an extant taxonomic group, and very few could be identified beyond genus level. This, in association with the poorly known ecology of most taxa within this region, limited the degree to which vegetation types and habitats could be

separated from modern pollen spectra and consequently the precision of interpretation of fossil records in vegetation and environmental terms. As a result, reconstructions were based on a limited number of indicator taxa, and general pattern matching using a number of classification and ordination based numerical techniques.

It is revealed that the Lake Pemerak area remained predominantly forested throughout the recorded period although the nature and composition of the forests which included peat, swamp and riparian forests and perhaps, during the last glacial period, extensive heath forests, were constantly changing. Surface sample data suggest that forest types similar to those of today only occurred during the Holocene and that last glacial forests had no modern analogues. Part of the reason for Pleistocene assemblages being different was the invasion of lowland forest by elements now largely restricted to higher altitudes, or the much closer proximity of these elements, as well as suspected heath forests.

Throughout the recorded period, there is no little evidence of significant change in the extent or position of peat forests and fluvio-lacustrine environments. However, the nature of the lake basin did change through time, with much greater evidence prior to the Last Glacial Maximum of relatively permanent open water areas and sediment accumulation. It is hypothesised that relatively stable conditions were maintained by relatively constant hydrological conditions. Since this time, climatic and hydrological conditions have probably been more variable, over both long and short time scales, and resulted in periods of erosion as well as non-deposition. The present highly variable

hydrological system, with strong seasonal variation in lake water level and frequent drying, could be a result of increased ENSO variability within the mid-late Holocene.

In addition to changes in hydrology that most likely relate to both regional variation in mean annual precipitation and seasonal to interannual variability, there is evidence, from the presence of predominantly submontane/montane taxa, of temperature variation through the record. During the Last Glacial Maximum it is estimated that temperatures could have been up to 6° C lower than those of today, with those during the period prior to the LGM being slightly lower than present.

Burning has been a factor in the landscape throughout the recorded period, although there is a general increase in the abundance of charcoal particles through time. The earliest part of the record may be recording low burning levels prior to the presence of *Homo sapiens*, with an increase around 30,000 years BP indicating the arrival of people within the area. Some evidence of increased burning during the LGM may have been a response to slightly drier conditions and more open vegetation, but highest charcoal levels in the mid-late Holocene most probably relate to increased human activity with the establishment of slash and burn agriculture. The present level of burning may have been achieved around 1,400 years ago. There is no indication that fire, or any other human activities, had a major influence on the nature of the vegetation until the mid-late Holocene, when there are generally high values for secondary tree taxa.

9.2. Wider implications

As one of the few truly lowland sites from tropical regions providing a record that extends through the Last Glacial Maximum, Lake Pemerak is an important contributor to debates on climatic conditions and vegetation patterns during this period. Inferred climatic conditions support the view that the tropical lowlands experienced temperature reductions close to the global average, rather than maintaining temperatures close to those at present, as deduced from most marine records. Although it is possible that precipitation levels were lower than today, any lowering was insufficient to dislodge rainforest formations, although these were different in their floristic composition to those of today. The Lake Sentarum region demonstrates the integrity of lowland rainforest in some areas, and would have been part of an extensive rainforest block. The maintenance of such a rainforest area perhaps through the period of severe global climate oscillations, may have been an important factor in the development of high forest biodiversity within the humid southeast Asian region. Without a more refined estimate of effective precipitation during the LGM, and greater knowledge of existing climate circulation patterns in the region, it cannot be ascertained how extensive this rainforest was. However, it does bring into question the postulation of a dry glacial corridor, supporting open canopied vegetation, through the Peninsula of Malaysia south to Java.

9.3. Management considerations

It was considered that this research might have a direct input into the formulation of management decisions within this area of high conservation value, from an assessment of recent changes in the vegetation and environments as a result of intensification of human activities in recent times. However, the nature of the sites and material prohibited the fine temporal resolution required to address these issues. This study indicates that there has been significant human impact on the area for the past 1400 years and that this has had some influence on the forests through encouragement of secondary forest taxa. There is insufficient evidence to determine whether this impact has had any effect on the viability of any plant taxa, or whether it has substantially altered the nature of the drainage system.

However, the conservation significance of the area is enhanced by the recognition of its forest 'refugial' status and by its potential to reveal a substantial history of environmental and vegetation change for the lowland tropics. The records also demonstrate the impact that both people and climate change can have on the area that is informative to both an understanding of landscape patterns in the area and to the potential for the area to change with predicted Greenhouse climates. The contribution that the area could make to future climates should also be recognised from the demonstrated importance of the area as a significant carbon store.

9.4. Recommendations for future research

Clearly there is a great deal of potential for future research into the Quaternary history of the Sentarum Lakes as this study may have only scratched the surface in both temporal terms and in relation to the geographical area as a whole.

In the first place, there is still the need to undertake the research originally planned – to produce a high resolution record of the last few thousand years to examine the timing and patterns of impact resulting from cultural changes and climatic variability, and to examine the degree to which presumed changes in the last few years had impacted the system.

Potential sites, including Danau Merbung Besar, Danau Lukuk and Danau Burung, were located during reconnaissance fieldwork. These lakes are considered by the local Iban never to completely dry during drought periods and are little disturbed and therefore should contain continuous sedimentary sequences appropriate for high resolution study. Short cores collected from Danau Lukuk demonstrated the existence of suitable pollen-bearing sediments.

None of the analysed cores reached to the base of unconsolidated sediments, and it is very likely that much longer records can be constructed from other sites within the basin and from these sites with heavier coring gear. River and lake access to much of the basin make such coring feasible, at least during appropriate times of the year or ENSO cycle.

In this complex environment, palynology can only contribute to an overall historical understanding of the lakes and their responses to climate

change. It is considered essential for refinement of patterns of climate change to address the questions of the origin of the basin and its development through time from a landscape evolution perspective.

It is hoped that future research, along the lines suggested, can be undertaken by collaboration between the University of Tanjungpura in Pontianak and overseas universities.

Appendix A: Pollen photomicrographs

The pollen photomicrographs were taken with a Zeiss MC 80 DX camera on a Zeiss Axioskop microscope, using a Zeiss Plan-Apochromat 100 x/1.40 oil DIC objective (440782). Kodak Techpan films were used. Selected negatives of the films were scanned, using a Nikon SF-200, and the digital files were saved in TIFF format.

The magnification of photomicrographs is 1,000 times, except where mentioned otherwise. The description of pollen taxa and spores presented in this appendix follows the terminology of Huang (1972), Maury *et al* (1975), Muller (1975), Muller and Caratini (1977), Punt *et al.* (1994), and Tissot *et al.* (1994).
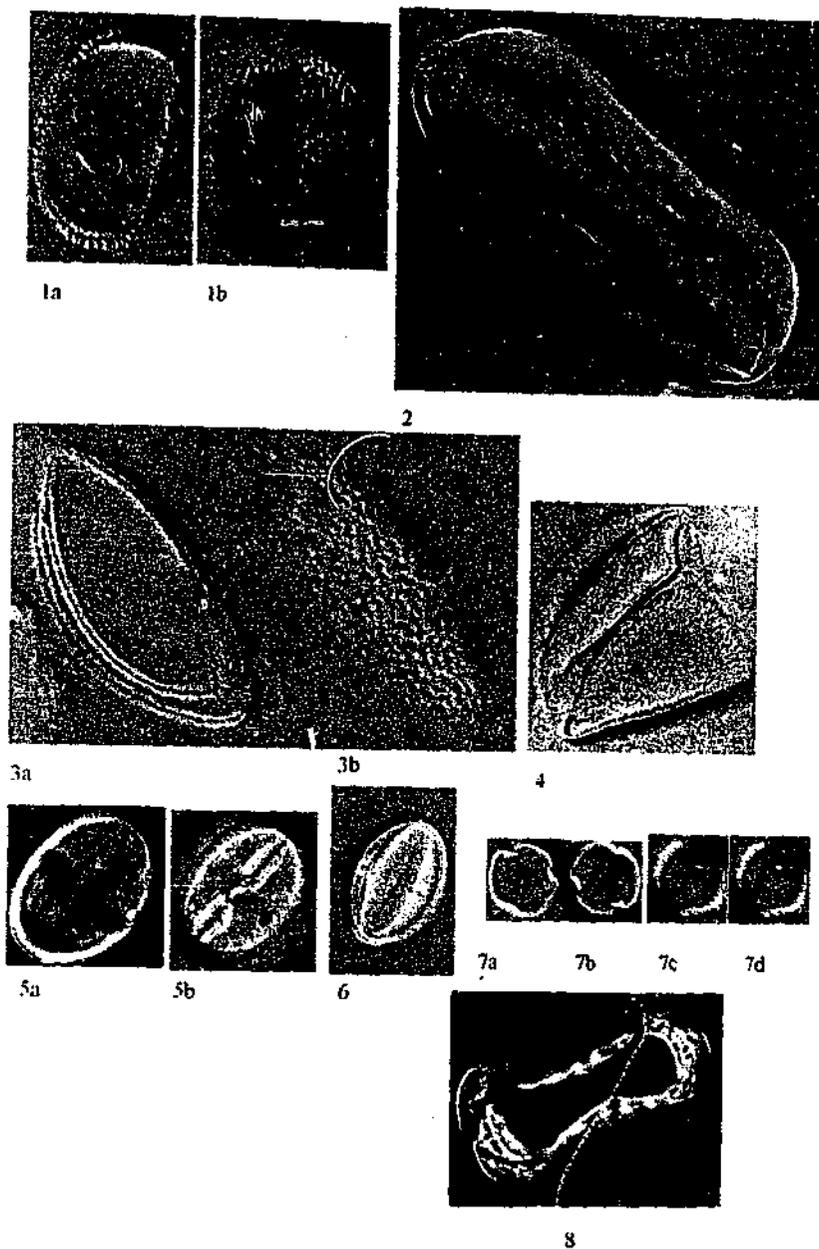
1a-b. Anacardiaceae comp, 19x34 µm, fossil HN3, pollen: tricolpate, prolate, colpi as long as polar axis, sexine striato-reticulate; 2. Arecaceae, 34x 77µm, fossil HN3, pollen: monocolpate, sexine psilate; 3a-b. Arecaceae, 25x53 µm, fossil HN3, pollen: monocolpate, sexine finely reticulate; 4. Arecaceae, 27x34 µm, fossil HN3, pollen: monocolpate, sexine finely reticulate; 5a-b. *Baccaurea*, 19x25 µm, fossil HN3, pollen: tricolporate, prolate, sexine scabrate; 6. *Baccaurea* reticulate, 15x21 µm, reference; 7a-d. *Baccaurea*, 11x10 µm, fossil HN3, pollen: tricolporate, prolate, sexine finely scabrate
8. *Barringtonia*, 30x42 µm, fossil DP4, pollen: prolate-spheroidal

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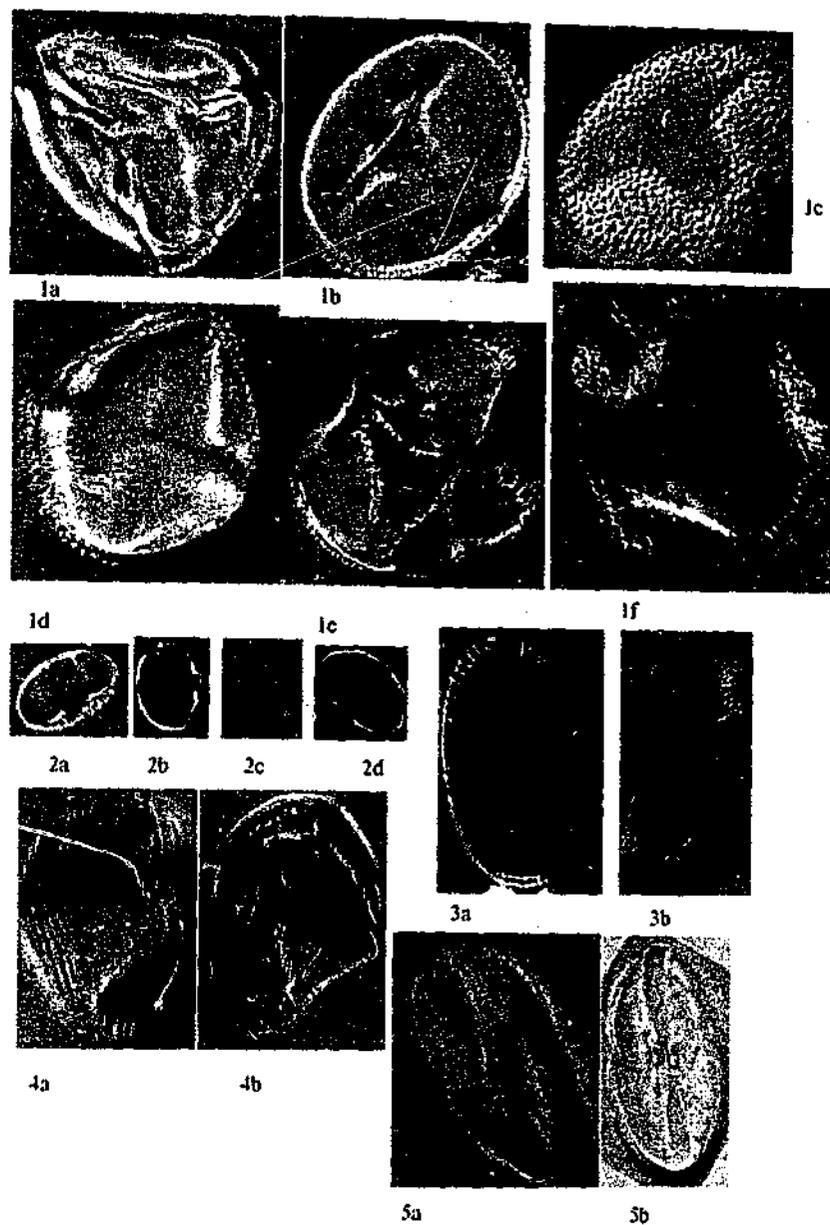
Plate 2:

1a-f. *Calophyllum*, 23-24x34-49 μm, cores HN1 and HN3, pollen: tricolporate, subprolate, sexine coarsely reticulate; 2a-d. *Carallia*, 12x17 μm, fossil HN3, pollen: tricolporate, sexine psilate; 3a-b. *Combretocarpus rotundatus*, 25x40 μm, fossil HN3, pollen: tricolporate, prolate, sexine reticulate; 4a-b. *Crudia*, 36x43 μm, fossil DP4; 5a-b. *Crudia*, 23x44 μm, fossil DP1, pollen: tricolporate, prolate to subspheroidal, sexine striate.

**Plate 3:**

1a   1b
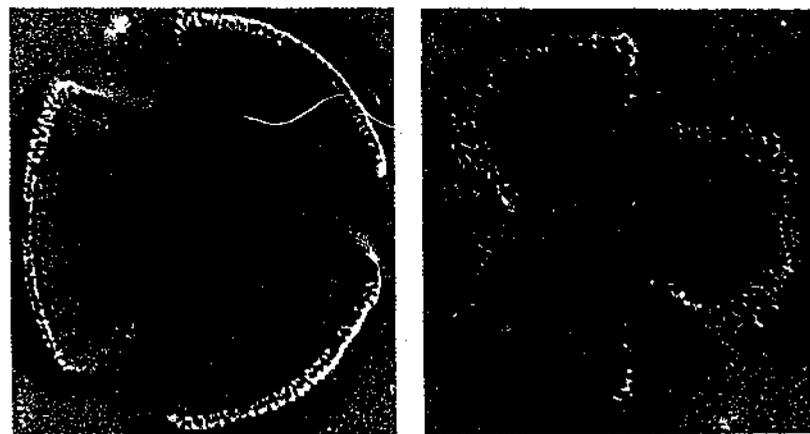
2a   2b

3a   3b

1a-b. Dipterocarpaceae, 49x31 µm, fossil HN3; 2a-b. Dipterocarpaceae, 52x45 µm, fossil HN3; 3a-b. Dipterocarpaceae, 21x27 µm, fossil HN3, pollen: tricolpate, long colpi, columella densely arranged, sexine rugulate

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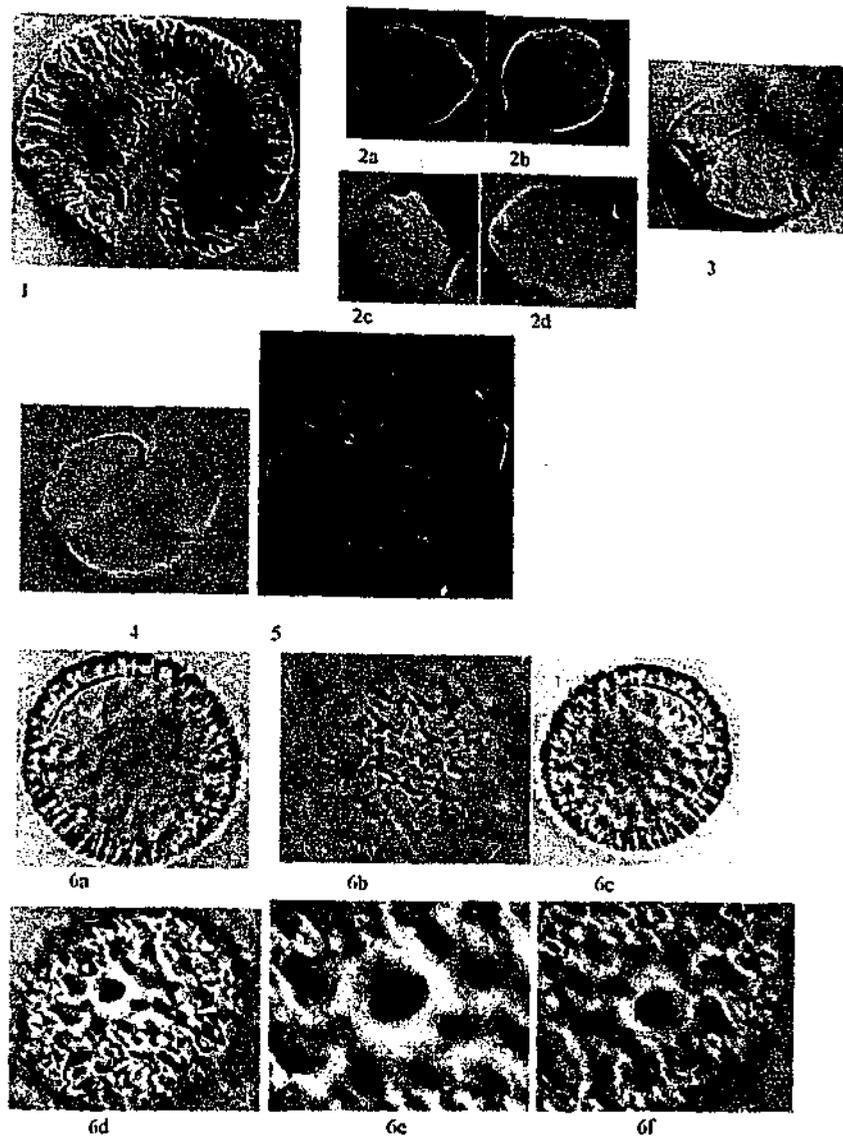
1. *Dacrydium*, 38 x 48 μm, fossil DP4, pollen: bisaccate, sexine scabrate. 2a-d. *Engelhardia*, 19x21 μm, core HN3, pollen: triporate, oblate to suboblate, aperture atrium type, sexine psilate or almost micro-reticulate; 3. Ericaceae, 29x30 μm, core HN3; 4. Ericaceae, 25x33 μm, core HN3; 5. Ericaceae, 37x47 μm, core HN3, pollen: tetrad, tetragonal, sexine psilate, 6a-f. *Fagraea*, 34x34 μm, fossil HN1, pollen: tricolporate, spheroidal, sexine coarsely reticulate, columella distinct.

Plate 5 :

1a · · · 1b · · · 1c · · · 1d · · · 1e

2a · · · 2a · · · 2c

3a · · · 3b · · · 4a · · · 4b · · · 4c

5a · · · 5b · · · 5c

6a · · · 6b · · · 7
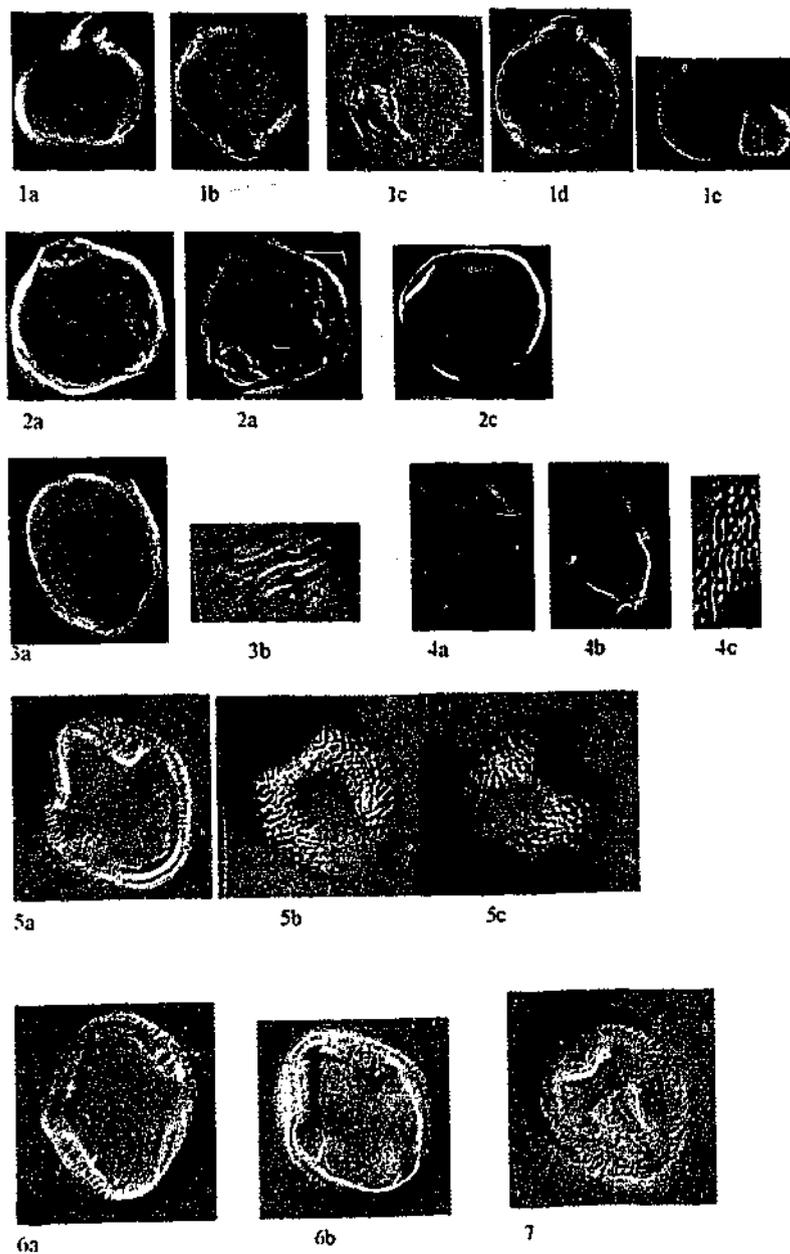
1a-e. *Garcinia*, 11-17x12-21 µm, core HN3 & DP4; 2a-c. *Garcinia*, 25x24-27 µm, core DP4, pollen: tricolporate, oblate, pore distinct, sexine psilate; 3a-b. *Gluta renghas*, 19x25 µm, core DP1; 4a-c. *G. renghas*, 15x23 µm core DP1; 5a-c. *G. renghas*, 23x29 µm, core HN3; 6a-b. *G. renghas*, 21x30 µm, reference; 7. *G. renghas*, 24x30 µm, core HN3, pollen: tricolporate, oblate, sexine striato-reticulate

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Plate 6 :
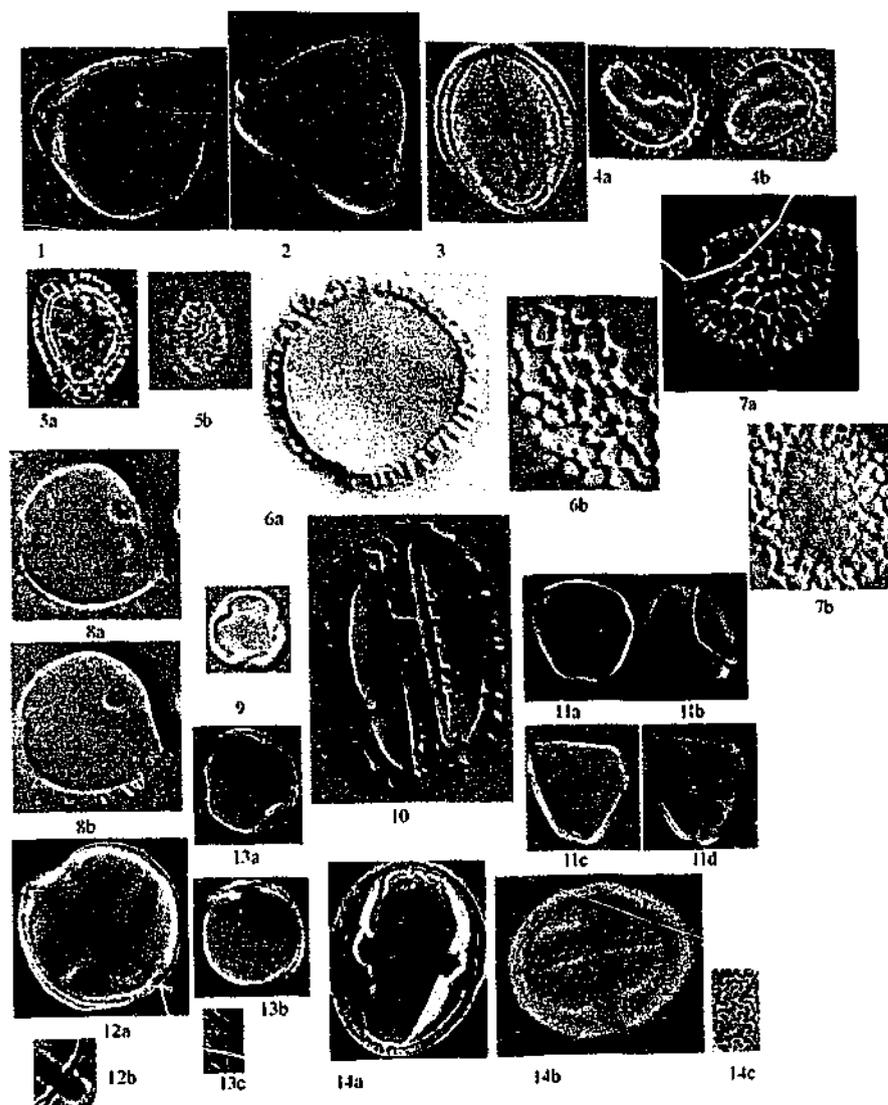
1,2 *Gymnostoma sumatrana,* 30x32 and max. 34 μm, core DP1 and DP4, pollen: triporate, spheroidal, aperture atrium type, sexine psilate; 3. Hamamelidaceae, 27x34 μm, core DP4, pollen: tricolpate, columella distinct, sexine reticulate; 4a-b. *Ilex,* 15x19 μm, core HN1, pollen: tricolporate, oblate, colpi long, tectum with gemmate, sexine coarsely granulate; 5a-b. *Ixora mentangis* comp., 15x23 μm ,core DP4; 6a-b. *I. mentangis* comp., 35x35 μm, core DP1; 7a-b. *I. mentangis* comp., 27x27 μm, core DP1, pollen: troporate, spheroidal to oblate, columella distinct, sexine largely reticulate; 8a-b. *Khortalsia,* 25x27 μm, core HN3, pollen: diporate, oblate, tectum, with clava, sexine psilate; 9. Leguminosae (small type), 14x14 μm, core HN1, pollen: tricolpate, spheroidal, sexine psilate, 10. *Myristica,* 23x40 μm, core DP1, pollen: monosulcate, prolate, sexine rugulate; 11a-d. Myrtaceae, 10-20x17-19 μm, cores DP1 and HN3, pollen syncolpate, sexine psilate; 12a-b, 13a-c, and 14a-c. *Macaranga/Mallotus* comp., 17-28x18-35 μm, cores DP1 and HN1, pollen: tricolporate, spheroidal to oblate, sexine scabrate.

Plate 7:
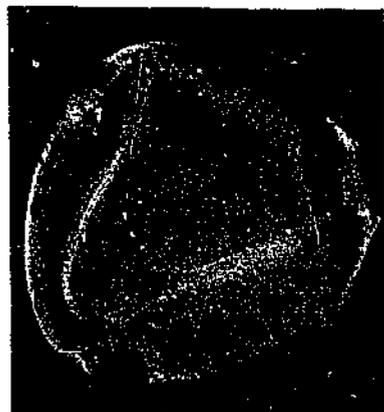

1a   1b
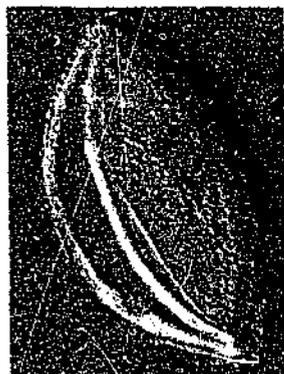
2a   2b
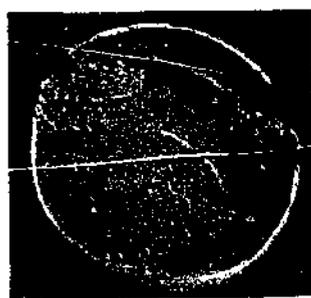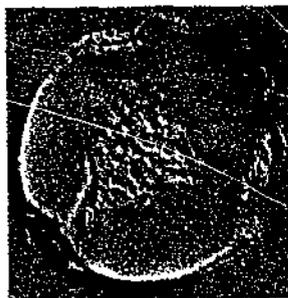
3a   3b

1a-b. *Neesia* comp. (x700), 77x84 μm, core HN3; 2a-b. *Neesia* comp., core HN1; 3a-b. *Neesia* comp., 42x46 μm, core HN3, pollen: tricolporate, colpi very short, spheroidal, sexine psilate, folded

Plate 8:

1a   1b

2a
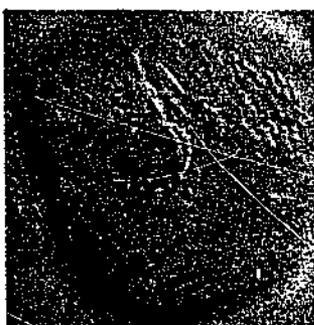
2b   2c
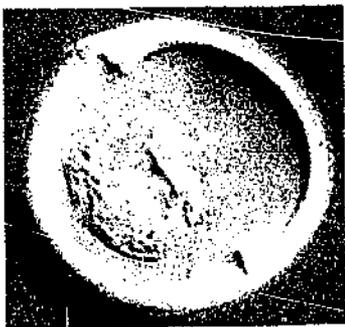
3

4

1a-b. *Palaquium*, 19x34 μm, core HN3, pollen: zonocolporate, prolate, sexine psilate; 2a-c. Sapotaceae/Meliaceae, 44x49 μm, core HN3; 3. Sapotaceae/Meliaceae, 38x42 μm, core DP1; 4. Sapotaceae/Meliaceae, 41x47 μm, core HN1, pollen: zonocolporate, spheroidal, sexine psilate to rugulate

Plate 9:
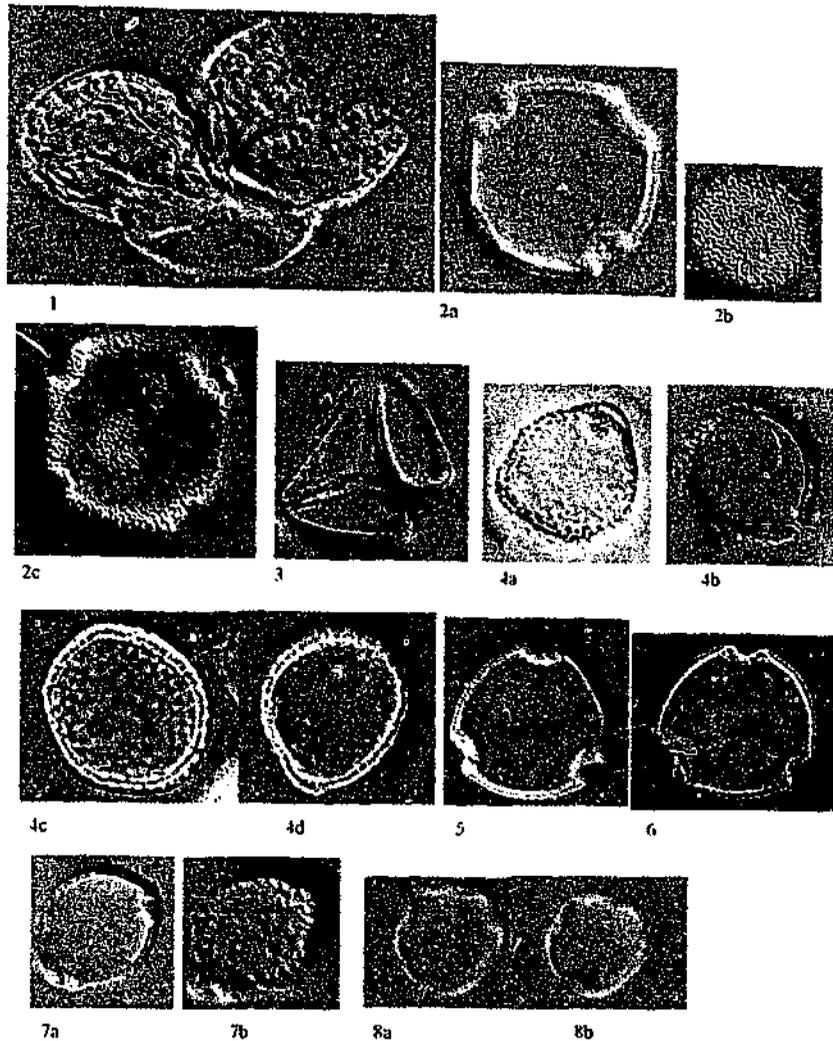
1. *Podocarpus*, 34x21 µm, core HN1, pollen: bisaccate, sexine fine reticulate; 2a-c. *Pterocarya* comp., *34x34* µm, core HN3, pollen: tetraporate, spheroidal, sexine micro reticulate; 3. Sapindaceae, max. diameter 30 µm, core HN3, pollen: tri-syncolpate, sexine psilate; 4a-d. Sterculiaceae (three pored type), 27x27 µm , core HN3, pollen: triporate, spheroidal, sexine granulate; 5. Sterculiaceae, 28x26 µm, core HN3; 6. Sterculiaceae, 30x26 µm, core DP4, pollen: triporate, oblate, pores with thickening, sexine granulate; 7a-b. *Symplocos*, 23x27 µm, core HN3, pollen: tricolporate, oblate, colpi very short, sexine micro reticulate; 8a-b. *Terminalia*, 19x19 µm, reference, pollen: heterocolporate, subprolate to spheroidal, sexine psilate

Plate 10:

1a

1b

1c

2a
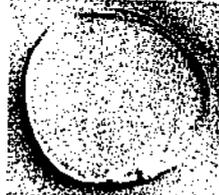
2b

2c

3
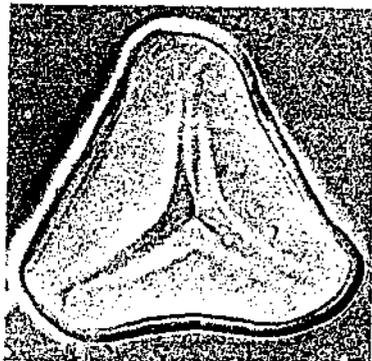
4a

4b

1a-c. Cyperaceae, max. diameter 29-34 μm, core DP1, pollen: monoporate, sexine scabrate, aperture mostly indistinct; 2a-c. Poaceae, max. diam. 25-30 μm, core DP1, pollen: monoporate, spheroidal to oblate, sexine psilate to scabrate, pores circular with distinct annuli; 3. Monolete (undiff.) 27x38 μm, core HN3, pollen: an elongated spore with single laesura, commonly psilate, exoporium is destroyed due to fossilation and/or acetolysis; 4a-b. Trilete (undiff.) max. diam. 46 μm, core HN1, pollen: a spore with tri-laesurae.

Plate 11:
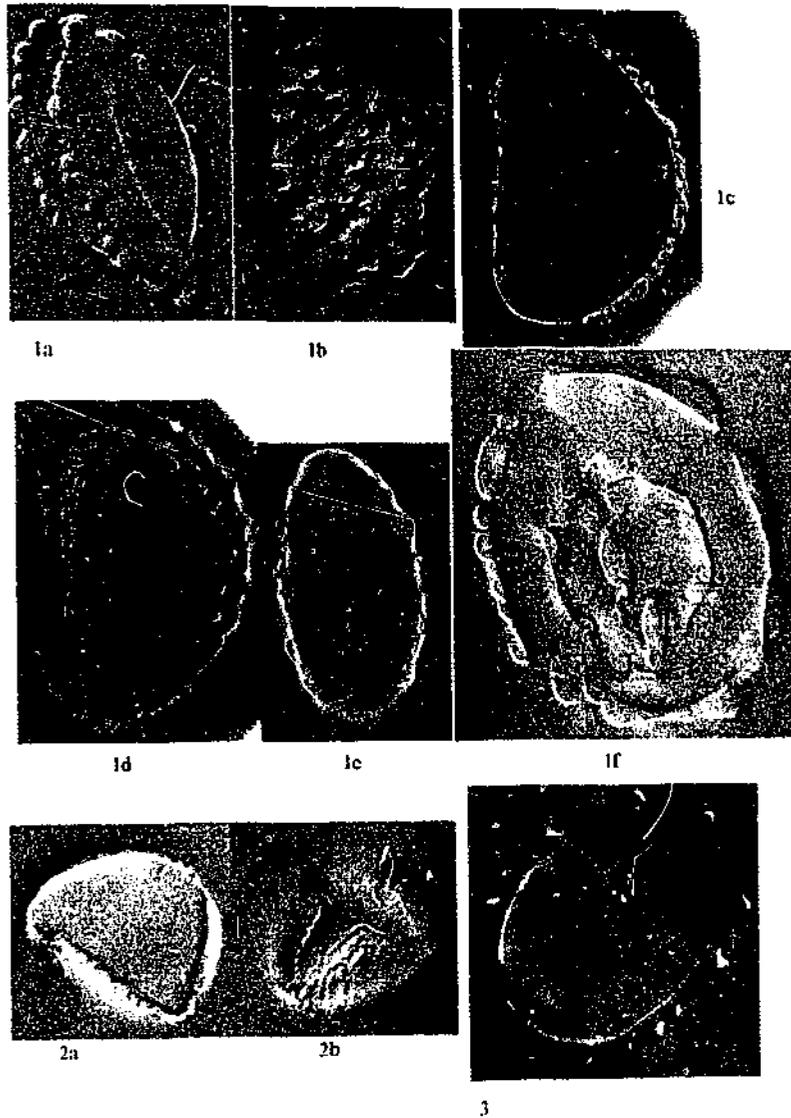
1a-f. Polypodiaceae, 25-49x44-48 μm, cores HN1, HN3, & DP4, pollen: monolete, sexine coarsely rugulate; 2a-b. *Lycopodium*, 23x32 μm, core HN3, pollen: trilete, almost circular in polar view, sexine rugulate; 3. *Stenochlaena palustris*, 34x46 μm, core HN3, pollen: monolete, sexine sparsely echinate, echinae with blunt ends.

Plate 12:
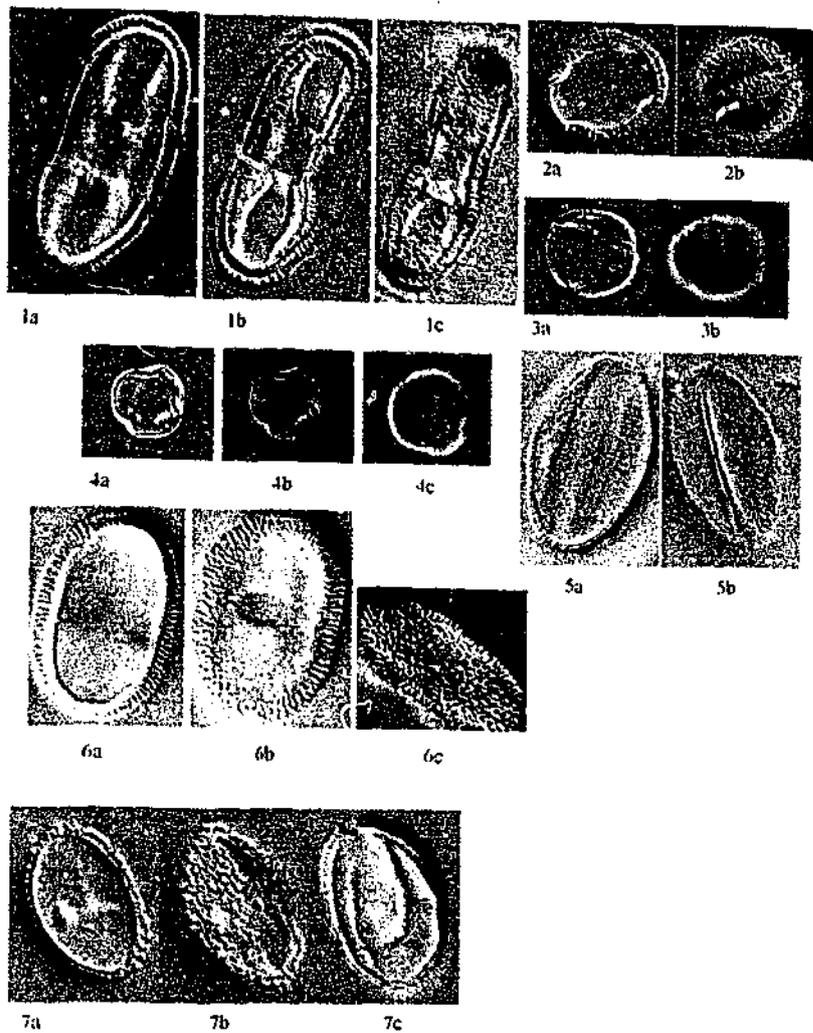
1a-c. Unknown 1, 19x44 µm, core HN1, pollen: tricolporate, prolate, sexine finely reticulate; 2a-b. Unknown 2, 17x19 µm, core DP1, pollen: tricolporate, subprolate, sexine granulate; 3a-b. Unknown 3, 15x15 µm, core HN1, pollen: tricolporate, spheroidal, sexine finely reticulate; 4a-c. Unknown 4, 15x15 µm, core HN1, pollen: tricolporate spheroidal, sexine psilate; 5a-b. Unknown 5, 23x38 µm, core HN3, pollen: tricolpate, prolate, colpi long, sexine micro reticulate; 6a-c. Unknown 6, 21x32 µm, core DP1, pollen: tricolporate, prolate, columella distinct, tectum psilate, sexine reticulate; 7a-c. Unknown 7, 17x27 µm, core HN3, pollen: triporate, prolate, sexine scabrate.

Appendix B: Ecology of selected plant taxa

Pollen Taxa	Source Taxa	Family	Ecology
Artocarpus	*Artocarpus* spp *A. kemando* *A. teysmannii*	Moraceae	At Lake Sentarum, this taxon is found in the riparian habitat. Generally, it occurs scattered in lowland mixed dipterocarp forests.
Baccauarea	*Baccaurea* spp *B. javanica* *B. racemosa* *B .reticulum*	Euphorbiaceae	This taxon may be an important element of the lower storey of primary forest. It occurs in the peatland, kerangas and secondary lowland forests. *Baccaurea* grows up to 1,000 m ASL.
Barringtonia	*Barringtonia* spp *B. acutangula* *B. reticula*	Lecythidaceae	At Lake Sentarum, *Barringtonia* is a component of the dwarf swamp forest, between 5 and 8 meters tall forest. It is commonly found on river banks below 600 m ASL. *Barringtonia* may associate with *Calophyllum, Casuarina* and *Hisbicus*.
Bluemodendron	*Blumeodendron* spp	Euphorbiaceae	The taxon has wide ecological ranges, from kerangas, peatland and hills. It usually occurs at low altitude, but it may occur up to 2,700 m ASL.
Calophyllum	*Calophyllum* spp *C. macrocarpum* *C. sclerophyllum*	Guttiferae	This species has a variety of habitats, from lowland mixed dipterocarp forests, (seasonally) inundated peatland, and coastal forests. A few species occur in montane forest.
Campnosperma	*Campnosperma* spp *C. auriculata*	Anacardiaceae	The taxon is often found in swampy lowland forest and in stagnant water
Carallia	*Carallia* spp *Carallia bracteata*	Rhizoporaceae	At Lake Sentarum, *Carallia* is a common constituent of dwarf swamp forest. The taxon occurs scattered in lowland mixed dipterocarp forest and montane forest up to 1800 m ASL.

Combretocarpus rotundatus	*Combretocarpus rotundatus*	Anisophylleaceae	The taxon is a typical species of inundated peatland forest and kerangas forest up to 300 m ASL. It commonly occurs in open canopy and secondary forests.
Crudia	*Crudia* spp *C. teysmannii*	Leguminosae	It generally occurs in the lowland primary forests, up to 550 m ASL. The species may grow in well drained sites, riverine habitat and seasonally inundated soils. At Lake Sentarum, *C. teysmannii* is common in the stunted swamp forest.
Ctenolophon	*Ctenolophon* spp	Ctenolophonaceae	The taxon has a wide ecological range. It occurs in kerangas, mixed swamp, and swamp forests (up to 850 m ASL)
Dacrycarpus	*Dacrycarpus* spp	Podocarpaceae	Most species are restricted to sub-montane and montane forests at 800-2500 m ASL, but may occur almost at sea level, too. They often occur in the peaty sites.
Dacrydium	*Dacrydium beccari*	Podocarpaceae	The taxon is a common element in lowland forest, especially in the peatlands. The majority is found from 600 to 2500 m ASL.
Dillenia	*Dillenia* spp *D. excelsa* *D. beccariana*	Dilleniaceae	The taxon is a common component of riparian forest at Lake Sentarum. *Dillenia* is also found in lowland and dipterocarp hill forest, swamp forest and old secondary forest.
Dipterocarpaceae	*Dipterocarpus* spp *Hopea* spp *Shorea* spp *Vatica* spp	Dipterocarpaceae	Dipterocarps are dominant taxa of lowland forests (up to 1,000 m ASL) in this region. This taxon has a wide ecological range and may be also found in peatland forests, kerangas and kerapah forests.
Diospyros	*Diospyros* spp *D. maritima* *D. coriaceae*	Ebenaceae	The taxon is found in primary lowland and hill rainforest. Several species

			are found in the peatland forest, kerangas, and on limestone soils.
Elaeocarpus	*Elaeocarpus* *E. mastersii* *E. submonoceras*	Fagaceae	This taxon has various types of habitat, eg. coastal, freshwater swamp, kerangas forest, and may occur on ultrabasic soils. It is more common in secondary forest than primary forest. The species grows at low to medium altitude, but may occur up to 3500 m ASL. At Lake Sentarum, *Elaeocarpus* (Menyawai) is common in the riparian forest.
Engelhardia	*Engelhardia* spp	Juglandaceae	The taxon is found in both dry land and swamp. It commonly forms an association with oak (*Quercus*), *Casuarina*, and *Nothofagus*.
Ericaceae	*Rhodondendron longflorum* *Vaccinium* spp *V. bigibbum* *V. elementis*	Ericaceae	The taxon is a common epiphyte of primary and secondary montane rainforest. It also occurs in the peatland forest.
Eugenia	*Eugenia* spp *E. bankanensis* *E. ecostulata* *Syzygium* spp *S. claviflora* *S. durifolium*	Myrtaceae	Both *Eugenia* and *Syzygium* prefer a perhumid climate, and tolerate water-logging. Many grow in river bank and peatland forest. Some *Eugenia* may resist a short period of frost (-3° C).
Fagraea	*Fagraea* spp *F. fragrans* *F. ceilanica* *F. elliptica* *F. racemosa*	Loganiaceae	A common taxon in open canopy habitats. At Lake Sentarum, *F. fragrans* is often encountered in secondary growths, ex-shifting cultivation fields. The species occur in a wide range of habitats, from sea level up to 1,500 m ASL, and from perhumid to seasonal climates.
Garcinia	*Garcinia* spp *G. bancana* *G. borneensis* *G. pervifolia.* *G. rostrata*	Guttiferae	This is a common taxon in secondary lowland forest, the taxon requires shade and a regular water supply. At Lake Sentarum, *G. bancana* occurs in the stunted swamp forest.

Gluta renghas	*Gluta* spp *G. renghas* *G. walichii* *G. pubescens*	Anacardiaceae	A taxon common in riparian forest, but that is also found scattered in other primary lowland forest.
Gonystylus bancanus	*Gonystylus* spp *G. bancanus* *G. velutinus*	Thymelaeaceae	The taxon is an endemic in the mixed peatland forest in Borneo. The species prefer non-inundated sites.
Gymnostoma sumatrana	*Gymnostoma sumatrana*	Casuarinaceae	The taxon occurs in kerangas, peatland forest, and beach forest, and prefers sandy soils.
Ilex	*Ilex* spp *Ilex cymosa*	Aquifoliaceae	Habitats of this taxon are widespread, including montane up to 2,400 m ASL, mangrove and swamp.
Ixora	*Ixora* spp *I. mentangis* *I. ithyoides* *I. Paludosa*	Rubiaceae	At Lake Sentarum, *Ixora* is found in dwarf swamp forest together with *Barringtonia* and *Carallia*. The taxon may be found up to 1,700 m ASL.
Lithocarpus	*Lithocarpus* spp *L. curtisii*	Fagaceae	This taxon is a major element of montane forests, up to 1,500 m ASL. It also occurs at sea level. Often, the species are found together with *Quercus*.
Lophopetalum	*Lophopetalum* spp	Celastraceae	The taxon has a wide range of habitat types, eg. freshwater swamp, hills, and riparian forests. It may occur from sea level up to 1,500 m ASL
Loranthaceae	*Dendrophthoe falcata* *D. pentandra* *Elythranthe* spp *Helixanthera* spp *Korthalsella* cf. *germinata* *Lepeostegeres* spp *Lepidaria forbesii* *L. epidaria* spp	Loranthaceae	The taxa are common epiphytes in the perhumid rainforests.
Macaranga/ Mallotus	*Macaranga* spp *M. denticulata* *M. gigantosa* *Mallotus sumatranus* *Mallotus* spp	Euphorbiaceae	*Macaranga*/Mallotus are common pioneer species in secondary, disturbed lowland rainforest. At Lake Sentarum, the taxon is found in the riparian habitat. These taxa also occur in the peatland forest. A few species

			occur in the montane forest.
Madhuca comp	*Madhuca* spp	Sapotaceae	The taxon is commonly restricted to lowland forest, and may occur up to 1,000 m ASL.
Melaleuca	*Melaleuca* spp	Myrtaceae	The taxon is very common in the freshwater swamp forest of the Malay Peninsula.
Myristica	*Myristica* spp	Myristicaceae	The majority is found in the lowland rainforest, up to 800 m ASL. Several species occur in peatland forest, but they do not tolerate water-logging.
Myrsine/Rapanea	*Myrsine* spp *Rapanea porteriana* *R. umbellulata*	Myrsinaceae	Most *Rapanea* are found in the montane forests. This medium size plant sometimes forms an association with *Podocarpus* or *Phyllocladus*. Only a few occur in the lowland.
Nauclea	*Nauclea* spp *N. purpurea* *N.subdita*	Rubiaceae	*Nauclea* is commonly found in the secondary lowland and hill forest, often along streams and swampy sites.
Nephelium	*Nephelium* spp *N. cuspidatum*	Sapindaceae	Many are found in well-drained soils, and some in peatland forest. The species occur in a range of altitude between sea level and 900 m ASL.
Palaquium	*Palaquium* spp	Sapotaceae	The taxon is common in lowland mixed dipterocarp forest. Several species, such as *P. ridleyi* and *P. maingayi*, are common in freshwater swamp forest.
Pandanus	*Pandanus* spp *P. helicopus* *P. artocarpus*	Pandanaceae	At Lake Sentarum, *Pandanus* is common in the peatland forest, kerapah forest and in the banks of the lakes. Pandans have a wide range of habitat preferences.
Phyllocladus	*Phyllocladus* spp	Podocarpaceae	This taxon is a major element of montane forests, between 900-2,000 m ASL.
Planchonella	*Planchonella* spp *P. obovata*	Sapotaceae	The taxon mainly occurs in lowland mixed dipterocarp forest. *Planchonella* is also found

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			in peatland forests.
Podocarpus	*Podocarpus* spp	Podocarpaceae	The taxon is commonly found in montane forests, between 750 and 2,500 m ASL, in the fagaceous and conifer forests. *Podocarpus* is individually found in kerangas and peatland forests.
Polyosma	*Polysoma* spp	Escalloniaceae	The species occurs from sea level up to 3,750 m altitude.
Pometia	*Pometia* spp	Sapindaceae	*Pometia* rarely grows in swamp forest. The taxon is mainly confined to dryland dipterocarp forests below 500 m ASL.
Quercus	*Quercus* spp	Fagaceae	*Quercus* is a common taxon of lower montane forest, between 600 and 1,500 m ASL. It can be found in mixed peatland forests, kerangas, and dipterocarp forests.
Terminalia	*Terminalia* spp *Melastoma affine* *M. malabatrichum*	Combretaceae Melastomataceae	*Terminalia* has a variety of habitats. Most species occur, under perhumid climate, in swamps or seasonally inundated riverine habitats. *Melastoma* is commonly found in the secondary forests.
Trema	*Trema* spp	Ulmaceae	The taxon is common in open disturbed sites.
Weinmannia	*Weinmannia* spp	Cunoniaceae	The majority occurs in the upper montane forest. Only a few are found in lowland rainforest.
Xanthophyllum	*Xanthophyllum* spp *X. affine* *X. flavescens* *X. vitellinum*	Polygalaceae	At Lake Sentarum, *X. affine* is commonly found in the stunted swamp forest. The taxon has a wide range of habitat types, such as riverine, kerangas, and monsoon forest. It rarely occurs at high altitudes.

Source: Giesen 1987, 1996; Verheij and Coronel 1992; Keßler and Sidiyasa 1994; Soerianegara and Lemmens 1994; Lemmens *et al.* 1995; Sosef *et al.* 1998

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