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THE LATE HOLOCENE HISTORY OF VEGETATION, CLIMATE, FIRE DYNAMICS AND HUMAN IMPACTS IN JAVA AND SOUTHERN KALIMANTAN

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Agricultural landscape in the Central Java Province, Indonesia. October 2012

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List of Acronyms

AD: Anno Domini
AMS: Accelerator Mass Spectrometry
ASPA: Australian Spore and Pollen Atlas
BP: Before Present (1950)
C^{14} - Radiocarbon, Radioactive Isotope of Carbon
$CaCo_3$: Calcium Carbonate
Cal: Calibrated
Chl-*a*: Chlorophyll-*a*
C_{org}: Organic Carbon
DCA: Defriended Correspondence Analysis
E.G.: *Exemplī Grātiā*; for example
ECC: Equatorial Counter Current
ENSO: El Niño-Southern Oscillation
FAO: Food and Agriculture Organization of the United Nations
GIS: Geoinformation Systems(s)
HCL: Hydrochloric Acid
HE: Halmahera Eddy
HF: Hydrofluoric Acid
I.E.: *Id Est*; that is
IOD: Indian Ocean Dipole
IPWP - Indo-Pacific Warm Pool
ITF: Indonesian Throughflow
KSTF: Karimata Strait Throughflow
LC: Leeuwin Current
LDC: Long Distance Component
LG: Luzon Gyre
ME: Mindanao Eddy
MSTF: Makassar Strait Throughflow
N: North
NEC: North Equatorial Current
NG: Nansha Gyre
NPP: Non-Pollen Palynomorph
N_{tot}: Total Nitrogen Content
NW: Northwest
ODV: Ocean Data View Software, 2014
PA: Procrustes Analysis
PCA: Principal Component Analysis
RBC: Smooth-Walled Round Brown Cysts, *Brigantedinium spp.*
RDA: Redundancy Analysis
Rpm: Rounds per Minute
RV: Research Vessel
S: South
SE: Southeast (Asia)
SEC: South Equatorial Current
SJC: Southern Java Current
SSS: Sea Surface Salinity
SST: Sea Surface Temperature
SW: Southwest
TOC: Total Organic Carbon
VOC: Vietnam Offshore Current
WOA: World Ocean Atlas, 2009
W: West
Yr(s): Year (Years)
$\delta^{13}Corg$: Carbon Stable Isotope
$\delta^{15}N$: Nitrogen Stable Isotope

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Preface

General motivation and the objectives of current studies

This work was aimed to reconstruct the past vegetation patterns and environment conditions on land and in the marine realm with regard to their responses to climate, fire and land use changes in Java and Southern Kalimantan (Indonesia). As natural vegetation communities of the study area has experienced some hundred years of human activity, main focus of current investigation was set on the reflection of human related factors controlling changes in the region. Two sites were chosen for comparison: heavily populated Java with some 5000-7000 yr long (Whitmore, 1984a) history of the human activity and Kalimantan with its relatively thin population and much less changed vegetation. The principal question of our research was: How had all mentioned changes been reflected by the vegetation in Java and Kalimantan and by coastal dinocysts communities in the Java Sea during the Late Holocene? In order to respond this question, the following hypotheses were approached:

(1) Different vegetation patterns on Java and Kalimantan are well reflected in pollen in the sediments.
(2) Natural environmental changes have nowadays a smaller impact on ecosystems then anthropogenic environmental changes.
(3) Changes in land use (specifically changes in vegetation) increased during the Late Holocene and particularly during the Anthropocene.
(4) Environmental changes are reflected both in pollen/spores and dinoflagellates assemblages.
(5) Anthropogenic environmental changes give the stronger signal from the island of Java then from the island of Kalimantan.

Brief description of the content of present studies is provided below.

Structure of the thesis and chapters outline

This thesis consists of seven chapters prefaced by the synopsis given in English (Summary), German (Zusammenfassung) and Indonesian (Rezume) languages that briefly describe principal research questions, work steps and the main outcomes. The first chapter (**Chapter 1**) gives an introduction into the subject of marine palynology, describes material and research methods and provides an overview of the study area.

In **Chapter 2**, the state-of-the-art of marine palynology in SE Asia is addressed and a scholar retrospective is given in terms of pollen and dinoflagellate cyst studies. Additionally, modern investigations are observed.

Next four chapters (Chapters 3-6) build a main part of this thesis and are based on the synthesis of the following manuscripts. **Chapter 3** (manuscript one) describes a pilot study on the abundance and taxa composition of modern pollen and spores collected by the sediment trap in the Indian Ocean off SW Java. It discusses factors, which control deposition of the settling particles, and compares pollen assemblages collected under different monsoon conditions over one year. This chapter gives information on the pollen transport required for further interpretation of marine fossil pollen records.

In **Chapter 4** (manuscript two), outcome of the organic-walled dinoflagellate cysts and pollen assemblages in marine sediments is presented. The study based on the comparison of two marine cores from the Java Sea off S Kalimantan (Jelai River mouth) and off NE Java (Solo River mouth). This chapter describes the last ca 3500 yr of past vegetation changes and peculiarities of environment dynamics in the marine realm in high resolution, allowing detailed reconstruction of the vegetation/sea environment response to the human-induced environmental changes.

Chapter 5 (manuscript three) discusses results of the multiproxy study of a marine sediment core from the mouth of Pembuang River (SE Kalimantan) and presents outcomes from the dinocyst and geochemical sediment analysis. History of the environmental changes between ca 2850 and 990 cal yr BP in the Java Sea is presented.

Chapter 6 (manuscript four) deals with the pollen diversity in marine sediments. It describes the spectra of fossil pollen from the Java Sea and the spectra of modern pollen from one-year sediment trap deployed in the Indian Ocean off SW Java. In this chapter, we provide a brief analysis of the pollen taxa list and support it with the light microscopic photos of pollen and spores at different focal levels.

In **Chapter 7** the most important outcomes of this research are synthesized, response to the research hypotheses is given and overall conclusions are drawn. Furthermore, the issue of open questions is addressed and finally, some perspectives for marine palaeoecological research in Indonesia are envisioned.

The thesis contains Appendix, where complete lists and photographs of all identified pollen, spores (**Appendix A**) and organic-walled dinocysts types (**Appendix B**) are presented. **Appendix C** presents full pollen, spore and microcharcoal records that are referred to in the text, and in **Appendix D** stratigraphy of the four marine sediment cores relevant to this study and radiocarbon dating is provided.

Summary

Detailed analysis of past environmental, climate and land use history in the Indonesian region is essential to obtain better understanding of human-environment relationships and to prevent uncertainties in future development of the region. Indonesia is one of the world biodiversity hot-spots and at the same time it is one of the most heavily populated areas of the planet. Over historical time, the influence of the human activity in the region became more and more intensive. To assess human contribution to the environment change, this project (SPICE III – CAFINDO, subproject 5) was established.

Our work was focused on reconstruction of the past vegetation patterns, environment changes and human-environment interactions as they are reflected in marine sediments of Indonesian waters. Two types of independent proxies were taken for this study: pollen, that originate from land and give diverse information on the vegetation and land use dynamics, and organic-walled dinocysts, that originate from marine environment and reflect changes of both quantitative (e.g. SST, SSS) and qualitative (e.g. trophic state in terms of main macroelements and dissolved water oxygen) water parameters. Moreover, microcharcoal was studied to get insight into the fires history in the region and to obtain additional support for interpretation of pollen and dinocyst data.

Two sites were chosen for comparison: the first, heavily populated Java with its long history of the human activity resulted in widespread agricultural landscapes, and the second, less densely population South Kalimantan less changed by human activity and still, at least partly, barring natural primary vegetation.

Marine palynology as a method requires close attention to the interpretation of data. Factors controlling pollen deposition are of particular importance, especially for the areas with the strong influence of wind and marine currents like the Indonesian region, where the whole climate system is driven mostly by the monsoon reversal. To get some ideas of the sediment transportation in the region, we studied and discussed in detail the differences in pollen assemblages collected under different monsoon conditions as well as during intermonsoon time. Abundance and taxa composition of modern pollen and spores collected by the sediment trap in the Indian Ocean off SW Java became an object of our first manuscript. The results were used in the further interpretation of marine fossil pollen records.

History of the land use intensifications and vegetation change over the last ca 3500 yr revealed from dinoflagellate cysts and pollen assemblages in marine sediments are presented in the second and the third papers. The studies are based on the comparison of two marine cores from the Java Sea off West Kalimantan (Jelai River mouth) and North-East Java (Solo River mouth). In the third manuscript, these records are compared to the more offshore sediment core taken from the mouth of the River

Pembuang. This study discussed the results of biogeochemical and dinocyst analysis in terms of palaeoecology and palaeoenvironment.

The next study gave us some additional understanding of the pollen flora diversity in the region and how adjacent vegetation is reflected by the diversity of pollen and spores. The fifth manuscript deals with the pollen diversity in marine sediment cores from the Indonesian region. It summarizes our knowledge obtained during the work on four sediment cores from the Java Sea and from the Indian Ocean sediment trap study. In a form of pollen atlas, we provide a list of the all registered pollen taxa and supply it with the microphotographs at different focal levels. The overall result of this work will contribute to the knowledge on the ecosystem dynamics and natural history of the Indonesian region and may help for future detailed palaeoecological and palaeclimatological investigation in the area.

Zusammenfassung

Die detaillierte Analyse der Umwelt-, Klima- und Landnutzungsgeschichte in der indonesischen Region ist unumgänglich, um ein besseres Verständnis der Beziehungen zwischen Mensch und Umwelt zu erlangen und desweiteren Ungewissheiten in der zukünftigen Entwicklung der Region vorzubeugen. Indonesien ist einer der Biodiverstitäts-Hotspots und zugleich eines der bevölkerungsreichten Gebiete dieser Erde. Seit historischen Zeiten wurde der Einfluss der menschlichen Aktivität in dieser Region immer intensiver. Daher wurde dieses Projekt ins Leben gerufen, um den Beitrag des Menschen zu den Veränderungen der Umwelt einschätzen zu können.

Unsere Arbeit konzentrierte sich auf die Rekonstruktion vergangener Vegetationsmuster, Umweltveränderungen und Wechselwirkungen zwischen Mensch und Umwelt, so wie sie sich im marinen Bodensediment der Gewässer Indonesiens wiederspiegeln. Es wurden zwei unabhängige Vertreter für diese Studie verwendet: Pollen, die vom Land stammen und unterschiedlichste Informationen über die Vegetation und die Dynamik der Landnutzung liefern und Dinozysten mit organischer Wandung, die aus mariner Umwelt stammen und den Wandel sowohl der quantitativen (z. B. SST, SSS) als auch der qualitativen (z. B. trophischer Zustand, hinsichtlich der Hauptmakroelemente und in Wasser gelösten Sauerstoffs) Wasserparameter wiederspiegeln. Zudem wurde Mikroholzkohle untersucht, um Erkenntnisse über die Brandhistorie in der Region zu erlangen und zusätzlich Unterstützung zur Interpretation der Pollen- und Dinozystendaten zu erhalten.

Zwei Untersuchungsgebiete wurden zum Vergleich ausgewählt: zum Einen das bevölkerungsreiche Java, dessen Landschaft, resultierend aus seiner langen Geschichte menschlicher Aktivität, durch Agrikultur geprägt ist, und zum Anderen das dünner besiedelte Süd-Kalimantan, das durch menschliche Tätigkeiten weniger verändert wurde und nach wie vor die natürliche Primärvegetation beheimatet.

Marine Palynologie als Untersuchungsmethode erfordert besondere Aufmerksamkeit bei der Dateninterpretation. Dabei sind Faktoren, die die Pollenablagerung kontrollieren, wie starker Wind oder Meeresströmungen, von besonderer Bedeutung. Dies ist bei Gebieten, wie Indonesien, wo das gesamte Klimasystem durch den wiederkehrenden Monsun bestimmt wird, besonders zu beachten.

Um Einblick in den Sedimenttransport in der Region zu erlangen, wurden die Unterschiede der Pollenansammlungen, die unter verschiedenen Monsunbedingungen, sowie in der Zwischenmonsum-Periode gesammelt wurden, untersucht und diskutiert.

Die Zusammensetzung und Abundanz der Taxa der modernen Pollen und Sporen, die durch eine Sedimentfalle im indischen Ozean südwestlich von Java gesammelt wurden, war Thema unseres ersten Manuskriptes. Die Ergebnisse wurden für die weitere Interpretation mariner fossiler Pollenaufzeichnungen verwendet.

Die Geschiche der Landnutzungsintensivierung und des Vegetationswandels über die vergangenen ca. 3500 Jahre, die durch die Dinoflagellatenzysten und Pollenansammlungen in marinen Sedimenten aufgezeigt wurden, werden im zweiten und dritten Paper vorgestellt. Diese Studien basieren auf dem Vergleich zweier mariner Bohrkerne aus der Javasee bei West-Kalimantan (Fluss Jelai) und Nordost-Java (Fluss Solo). Im dritten Manuskript werden diese Aufzeichnungen mit einem Sedimentbohrkern aus der Mündung des Pembuang Flussen verglichen, der küstenferner entnommen wurde. Diese Studie diskutierte die Ergebnisse der geochemischen Analyse der Dinozysten hinsichtlich der Paläoökologie und der Paläoumwelt.

Die nächste Studie gewährte zusätzlichen Einblick in die Pollenflora und Vegetationsdiversität der Region und wie diese sich in der Diversität der Pollen und Sporen wiederspiegeln. Das fünfte Manuskript beschäftigt sich mit der Pollendiversität mariner Bohrkerne aus der indonesischen Region. In diesem werden die Erkenntnisse, die während der Arbeit mit den Sedimentbohrkernen aus dem Javasee und der Sedimentfallenstudie aus dem Indischen Ozean erworben wurden, zusammengefasst.

In Form eines Pollenatlas, wird eine detaillierte Analyse der Liste der Pollentaxa vorgestellt, die mit Mikrophotographien verschiedener Ebenen ergänzt wurde. Das Gesamtergebnis dieser Arbeit trägt zu den Erkenntnissen über die Dynamiken des Ökosystems und der Naturgeschichte der indonesischen Region bei und kann bei zukünftigen detaillierten paläoökologischen und paläoklimatischen Untersuchungen behilflich sein.

Rezume

Analisa yang terperinci mengenai lingkungan di masa lalu, iklim dan sejarah penggunaaan lahan di wilayah Indonesia sangat penting untuk memperoleh pemahaman yang lebih baik mengenai hubungan manusia-lingkungan dan untuk mencegah ketidakpastian perkembangan wilayah tersebut di masa depan. Indonesia merupakan salah satu wilayah yang memiliki keanekaragaman terbesar, dan pada saat yang bersamaan juga merupakan salah satu Negara yang mempunyai jumlah penduduk terpadat di dunia. Seiring dengan sejarah, pengaruh dari aktivitas manusia pada suatu daerah menjadi semakin kuat. Penelitian ini dilakukan untuk mengakses peranan manusia terhadap perubahan lingkungan.

Penelitian kami difokuskan pada rekonstruksi pola vegetasi di masa lampau, perubahan lingkungan dan interaksi antara manusia dan lingkungan yang tercermin dalam sedimen laut di perairan Indonesia. Dua macam pendekatan yang digunakan dalam studi ini adalah: polen (serbuik sari), yang berasal dari darat dan diharapkan bisa memberikan informasi yang beragam tentang vegetasi dan dinamika penggunaan lahan, dan organic dinoflagelata yang berasal dari lingkungan laut dan merefleksikan perubahan parameter air secara kuantitatif (misal. SST, SSS) dan kualitatif (mis: kondisi tropic dilihat dari segi makro-elemen utama dan oksigen terlarut dalam air). Selain itu, arang mikro dipelajari untuk mendapatkan data mengenai sejarah kebakaran di wilayah tersebut dan untuk memperoleh data tambahan untuk interpretasi polen dan data dinoflagelata.

Penelitian dilakukan di dua situs sebagai perbandingan: pertama, di wilayah Jawa yang padat penduduk dengan sejarah panjang dari dampak aktivitas manusia yang menghasilkan lanskap pertanian yang luas, dan yang kedua, di wilayah Kalimantan Selatan dengan kepadatan penduduk yang tidak terlalu tinggi dan tidak banyak perubahan akibat pengaruh aktivitas manusia dan masih merupakan vegetasi alami.

Metode yang digunakan, palinologi laut memerlukan perhatian khusus dalam interpretasi data. Faktor pengendapan polen adalah sangat penting, terutama untuk daerah-daerah dengan pengaruh kuat dari angin dan arus laut seperti wilayah Indonesia dimana sistem iklim secara keseluruhan didorong sebagian oleh pergantian musim.

Untuk mendapatkan beberapa pemikiran mengenai transportasi sedimen di wilayah ini, kami mempelajari dan membahas secara rinci perbedaan jumlah polen yang dikumpulkan pada kondisi musim hujan yang berbeda serta selama waktu perpindahan musim. Subyek manuskrip pertama kami adalah kemelimpahan dan komposisi taksa modern polen dan spora yang didapat dari sedimen yang terakumulasi di Samudera India sebelah barat daya Jawa. Hasil yang diperoleh digunakan untuk interpretasi lebih lanjut dari fosil polen laut.

Sejarah intensifikasi penggunaan lahan dan perubahan vegetasi lebih dari 3500 tahun yang lalu yang diperoleh dari dinoflagelata dan kumpullan polen dari sedimen laut dipresentasikan dalam jurnal yang kedua. Studi ini didasarkan pada perbandingan dua core laut dari lepas Laut Jawa dekat Kalimantan Barat (Sungai Jelai) and bagian timur laut Jawa (Sungai/Bengavan Solo). Pada manuskrip yang ketiga, hasil ini diperbandingkan dengan sedimen core dari lepas pantai yang diambil dari bagian hulu sungai Pembuang. Studi ini membahas mengenai hasil analisa geokimia dan analisa dinoflagelata dalam cakupan paleoekologi dan paleoenvironment.

Manuskrip kelima membahas tentang keragaman polen dalam core sedimen laut dari wilayah Indonesia. Studi ini merangkum pengetahuan yang diperoleh selama meneliti core sedimen dari Laut Jawa dan dari studi perangkap sedimen di Samudera Hindia. Dalam bentuk atlas polen, kami memberikan hasil analisis secara rinci dari daftar taksa polen dan dilengkapi dengan foto mikro pada tingkat fokus yang berbeda. Hasil keseluruhan dari penelitian ini akan memberikan kontribusi pada pengetahuan tentang dinamika ekosistem dan sejarah alam di wilayah Indonesia dan dapat membantu investigasi paleoekologi dan paleo-iklim di masa depan secara lebih rinci.

CHAPTER 1

Introduction

1.1. Marine palynology. Pollen transportation and translocation in marine realm

Pollen analyses of marine sediments contributes to reconstructions of the vegetation and climate, particularly in regions where long continuous terrestrial records are scarce or problematic (e.g. Sánchez Goñi et al., 1999; Mudie et al., 2002; Heusser and Oppo, 2003; Moss and Kershaw, 2007). First, because the vegetation patterns can well reflect rapid or abrupt climate change events, rather than showing a lagged response as had been widely assumed previously (Harrison and Sánchez Goñi, 2010). Second, due to the fact that pollen signals in marine records may directly correlate with terrestrial sequences and therefore can provide a basis for transferring marine age-models directly to terrestrial records (Hope et al., 2004; Ryan et al., 2012) and can help to establish a correlation of the changes in marine and terrestrial realm.

Additionally, marine palynological records, unlike terrestrial ones, provide broad regional pictures of vegetation on adjacent landmasses, often collecting pollen from a number of different biomes. They are suitable for the investigation of large shifts in vegetation over long periods, while pollen data from terrestrial deposits give much more detailed information of local or regional vegetation patterns (Dupont, 1999).

Marine pollen diagrams, however, cover often more than one climatic cycle that makes them not always suitable for tracing short-scale climatically induced vegetation change. Careful interpretation of this kind of diagrams places emphasis on transport and sedimentation processes, as these have a strong impact on the results (e.g. Sun, 2002). In the interpretation of pollen data, several aspects must be taken into account: these include source of production of pollen, its transport to the sea and through the water column, displacement by ocean currents, sedimentation processes, fossilization and accumulation in the sediment. Production of pollen grains varies strongly between different species. After pollen and spores reach the sediments, they still can be displaced by sedimentological processes such as bioturbation or sediment movement. Embedded within very slowly accumulating sediments at great water depths, pollen and spores may decay if bottom waters over the site are rich in oxygen and therefore corrosive, or the pollen and spore content may become enriched by the dissolution of calcium out of the sediment (Keil et al., 1994).

The distribution of many pollen types in the modern marine surface sediments reflects the average course of the trajectory of the major wind belts (Hooghiemstra et al., 1986). Transport of pollen and spores from their source areas to the marine sediments involves several steps. After pollen grains are released by the plants they disperse into the air and are transported by winds, or the grains fall into a lake or a river and are then carried by the river into the ocean. Aeolian transport of pollen and spores predominates in deep-sea sediments located far from the coast and along arid areas with no or small river discharge into the ocean (Heusser and Morley, 1985; Hooghiemstra et al., 1986). In contrast to desert margins, fluvial transport of pollen and spores is high in the humid tropical areas. The role of fluvial transport has been shown by an increased pollen concentration in sediments sampled from the vicinity of river mouths (Muller, 1959; Heusser and Balsam, 1977; Davey and Rogers 1975; Heusser, 1988; Bengo, 1997).

Pollen that has eventually got into the upper layers of the ocean has to be transported down through the water column to the sea floor. Pollen grains are too small and too light to have an effective sink velocity by themselves. However, pollen is caught in larger aggregates - in faecal pellets or large filamental aggregates - that can have sink velocities of 100 m per day or more (Schrader, 1971; Silver et al., 1978; Honjo, 1980; Wefer, 1991, 1993; Wefer and Fischer 1993). The transport through the water column is more efficient in areas with a high marine surface productivity where the incorporation of palynomorphs in the food chain is enhanced (Ratmeyer et al., 1999). The increased sink velocity reduces drifting by ocean currents. However, along continental slopes, strong boundary currents may displace pollen and spores (Heusser and Balsam, 1985; Dupont and Agwu, 1991).

The importance of transport processes from the continent into the ocean varies from region to region (Dupont, 1999). Palynological studies on modern sediments of continental shelves reflect the influence of both river input and sorting of particles, whereby the sedimentation of pollen and spores can be compared to that of the medium to fine silt fraction, because of their size and density (Rossignol, 1961; Davey, 1971). Because pollen grains from marine sediments are typically transported over long distances, the evaluation of transport agents is always part of the interpretation of marine pollen diagrams (Dupont, 1999). The marine record also provides valuable chronological control for the terrestrial record (Hope et al., 2004). Morover, pollen grains can be used as tracers for the origin of organic matter (Wagner and Dupont, 1999).

1.2. Material and research methods

This study is based on the analysis of four marine sediment cores (Table 1.1; Fig 1.1) taken from the Java Sea during the scientific cruises of the RV “Baruna Jaya” and unknown RV in 1995-1998 off South

Kalimantan (Jelai and Pembuang rivers) and off North-East Java (Solo River). The age schemes of the marine sediment cores are presented in the Fig. 1.1.

Table 1.1. Summarized information on the sites and sediment material studied.

		1412-19	1612-23	1612-26	1609-30	JAM-2
Type of material		Sediment core	Sediment core	Sediment core	Sediment core	Sediment trap
Core site		Off Jelai River, SW Kalimantan; Java Sea	Off Pembuang River, S Kalimantan; Java Sea	Off Pembuang River, S Kalimantan; Java Sea	Off river Solo, E Java; Java Sea	off SW Java; SE Indian Ocean
Core position	Latitude	S3° 15' 28.8"	S3° 35' 21.84"	S3° 47' 39.48"	S6° 29' 49.729"	S 08° 17' 30"
	Longitude	E110° 38' 59.399"	E112° 44' 13.56"	E112° 34' 6.96"	E112° 28' 31.328"	E 108° 02' 00"
Water depth, m		9.7	20	56,3	50	2200
Core length, cm		91.5	134	100	96	-----------
Year(s) of collection		1998	1995	1998	1995	2001-2002
Approximate age, cal yr BP		1200	2850	6500	3600	modern
Proxies studied		Pollen, dinocysts, microcharcoal	Pollen, dinocysts, microcharcoal	Pollen, dinocysts	Dinocysts, biogeochemical parameters	Pollen
Chapter		4, 6,7	5, 6,7	6,7	4, 6, 7	3, 7

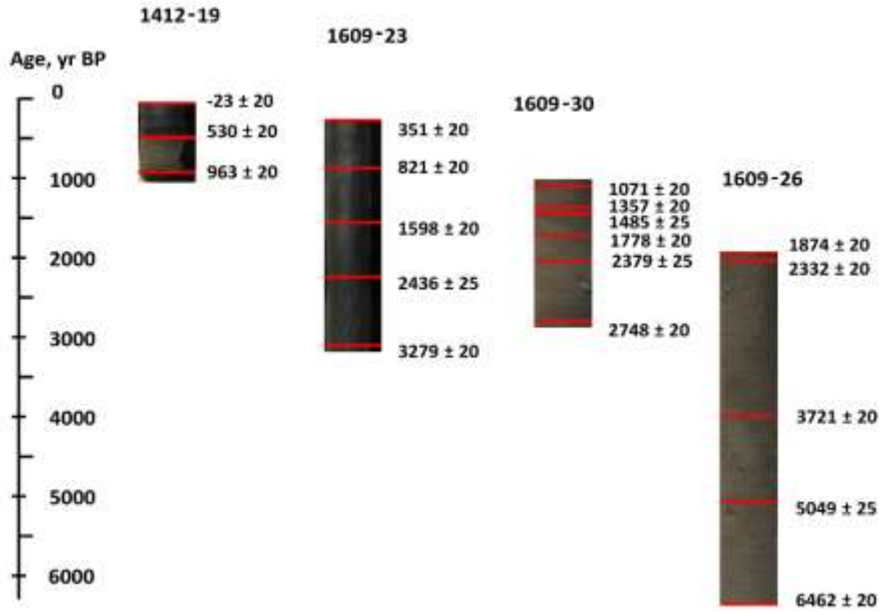


Fig. 1.1. Age scheme of the marine sediment cores used for the present study. Radiocarbon dating (Stuiver and Polach, 1977) and calibration (CALIB 7, marine 13: Stuiver and Reimer, 1993) considering a reservoir age of 90 yr (Southon et al., 2002).

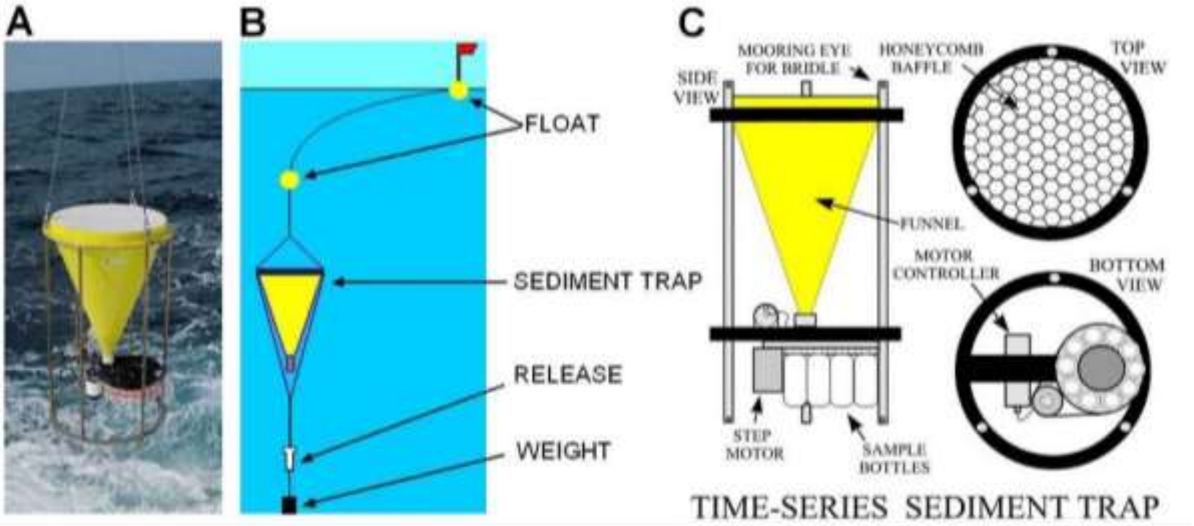


Fig. 1.2. Marine time-series sediment trap Parflux Mark 7G-21 (A) general view, from http://www.mbari.org/expeditions/Smith2011/logbook/day4.htm; (B) scheme of the trap mooring, slightly modified after: https://depts.washington.edu/soundcit/about/oceanographic-equipment/sediment-trap-schematic; (C) principal scheme of the time-series sediment trap, from: Gallery of common sediment sampling devices, http://woodshole.er.usgs.gov/openfile/of2005-1001/htmldocs/sediment_traps.

Besides, in the second chapter was used the material collected with help of the sediment trap JAM-2 that was moored in the Indian Ocean off SW Java (scheme of trap is given above, see Fig. 1.2) between December 2001 and November 2002 and collected in 2005 during the cruise SO-184, PABESIA, of the research vessel SONNE. Trap mooring water depth was about 2200 m; sampling intervals were 16 days each.

1.2.1. Laboratory methods

After subsampling the core material, 3 g of each sample, was dried overnight at 60°C and afterwards weighted to determine the dry bulk density. The material was brought into suspension in distillate water and sieved over a 100-150 µm sieve. In order to remove carbonate, cold hydrochloric acid (HCL 10%) was applied in amounts depending on the intensity of the reaction. To determine concentration and/or accumulation rate, one *Lycopodium clavatum* tablet with known number of spores (20,848 ± 1546) was added to each sample (Stockmarr, 1971). At the next step, hydrofluoric acid (HF 72%) was added to the washed and centrifuged (5 min, 3200 rpm) samples for one day in order to remove silicate.

After decantation and washing (X2 times) with distillate water, the residue was centrifuged again and transferred to 1.5 ml Eppendorf tubes. The fraction smaller than 10 µl were removed sieving over a nylon filter. In order to avoid damage to the dinocysts no acetolysis and other oxidation treatments was applied. The material was embedded in glycerin gelatin and isolated from air by transparent nail polish. Pollen, spores and dinocysts were counted under a light microscope (Zeiss Axiostar Plus) at X400 and X1000 magnification. In case of the core material, counting kept up to 200 identified pollen grains and 100 dinocysts, relative abundance of taxa were calculated on the basis of the total sum of pollen grains and dinocysts respectively, excluding indeterminate grains/cysts, fern spores and other algae, which have been also counted.

In case of sediment trap material, each sample was counted to a minimum of 100 identified pollen grains. For the charcoal analysis, all black organic particles were counted. Charcoal concentration was calculated on the base of bulk dry weight (particles per g).

1.2.2. Methods of data analysis

The percentages diagrams for pollen/spore and dinocysts were created in TILIA/TGView and subdivided into local zones, which were established empirically by comparing dynamics of the principal taxa, supported by the results of constrained cluster analysis by sum-of-squares using CONISS for TILIA (Grimm, 1987). The stability of the classification and the sharpness of the clusters were checked with the help of bootstrap resembling performed in MULTIV (Pillar and Orlóci, 1996; Pillar, 1999).

To study relationship between pollen taxa and dinocysts, multivariate data analysis with the programs CANOCO and CanoDraw (ter Braak and Šmilauer, 1997; Leps and Šmilauer, 2003) was carried out. If a detrended correspondence analysis (DCA) had revealed a gradient length less or equal to 2.0 for the first PCA axis, principle component analysis (PCA, **chapter 3**) or redundancy analysis (RDA, **chapter 4**) was carried out as recommended by Leps and Šmilauer (2003) for data sets with short environmental gradients. If not state otherwise, standardization and logarithmic transformation was applied to species and palaeorelevé data.

To obtain insight into the similarity/dissimilarity of the pollen and dinocyst datasets and to estimate how well the two datasets match to each other in terms of compositional gradients, Procrustes analysis (PA, **chapter 3**) (Jackson, 1995) was applied using the CANOCO 5 software package (Gower, 1975; Peres-Neto and Jackson, 2001; Šmilauer and Lepš, 2014). In order to evaluate the significance of the RDA axes (**chapter 4**), the null hypothesis test was applied using the nonparametric Monte Carlo permutation test (Manly, 1992).

1.2.3. GIS Methods

This thesis presents a number of original maps created in order to show present patterns of the most important sea water parameters in the Java Sea (Fig. 1.3), winds and marine currents in the area (Fig. 1.4) and geospatial distribution of main vegetation types (Fig. 1.5) in Indonesia as well as the peculiarities of modern tree-cover and burnt vegetation (Fig. 1.7). Environmental data were derived from the World Ocean Atlas (2009) and The Giovanni Ocean Colour Radiometry Portal (http://gdata1.sci.gsfc.nasa.gov/daac-bin/G3/gui.cginstance_id=ocean_8day). Maps presenting oceanographic information were created using World Ocean Atlas (2009) and Ocean Data View software (Schlitzer, 2014). Maps of vegetation (Fig. 1.5) and tree cover/burnt vegetation patterns (Fig. 1.7) were created in Quantum GIS (http://qgis.osgeo.org). Data were partly derived from GEONETWORK open source (http://geonetwork-opensource.org) and partly from Stibig et al. (2002). All data were standardized and divided into classes.

1.3. Overview of the study area

1.3.1. Geography of the Java Sea

The Java Sea is a large (310,000 km^2) sea on the Sunda Shelf which lies between the islands of Borneo to the north, Java to the south, Sumatra to the west, and Sulawesi to the east (Fig. 1.4). In its western part, it is connected with the Indian Ocean by the Sunda Strait, and northward to the South China Sea by the Karimata Strait. The eastern part is connected with the Flores Sea and the Makassar Strait (Durand and Petit, 1995; Genia et al., 2007). Because of its geographical position, the Java Sea is strongly influenced by the tides from both the Pacific and Indian Ocean through the Malaka and the Makassar Straits respectively (Wrytki, 1961; Genia et al., 2007).

Being shallow (average depth is about 40 m), the Java Sea allows a good mixing of water masses, creating homogenous layer from the surface to the bottom. Sea surface temperature (SST, Fig. 1.4A) has a small variation during the year, about 2°C (Wrytki, 1961). Sea surface salinity (SSS, Fig. 1.4B) is relatively constant throughout the year as well, with the average minimum salinity being 31.8 from January to June and maximum average salinity being about 34 in September (Veen, 1953). As a result of local evaporation, in the eastern part salinity varies between about 30.8 to 34.3 (Durand and Petit, 1995).

In the western part of the sea, where a number of the rivers discharge from Sumatra (e.g. Asahan, Rokan, Kampur, Batangan, Musi), Java (e.g. Bengawan Solo, Brantas, Citarum) and Kalimantan (e.g. Pembuang, Seruyan, Mendawai, Barito), SSS is lower, from 30.6 to 32.6. The average minimum of salinity is near 32 occurring from January to June, while the maximum is about 34 and taking place in September (Veen, 1953).

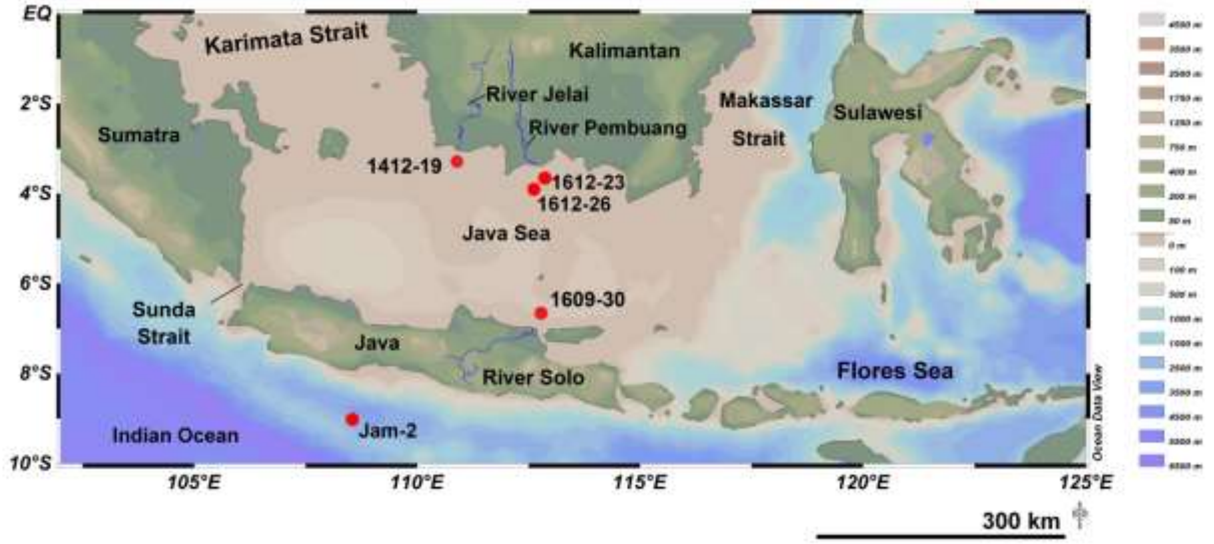
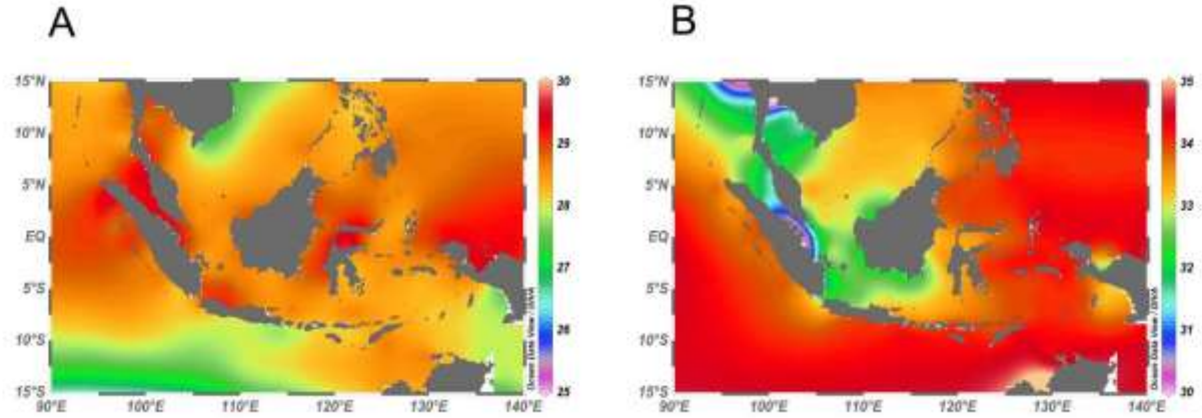


Fig. 1.3. Schematic map of the study area. Positions of marine sediment cores and a sediment trap are shown with red dots.

Whole water mass of the Java Sea is well oxygenated (Fig. 1.4C). Measured water dissolved oxygen is about 4.5-4.7 ml l^{-1} near by the bottom and up to 5 ml l^{-1} at the surface (Doty, 1963; Boely et al.,1991). The water is relatively rich in nutrients. According to the World Ocean Atlas (2009), the average content of nitrates is 0.27-0.75 ml l^{-1} with relatively high concentrations off S Kalimantan (Fig. 1.4D). The phosphates concentration varies from 0.2 ml l^{-1} in the central part to 0.4 ml l^{-1} between the coastal lines of W Java and E Sumatra (Fig. 1.4E). The highest concentrations of the chlorophyll *a* are observed in the eastern part of the sea between Java and Madura as well as off S Sulawesi (Fig. 1.4F).



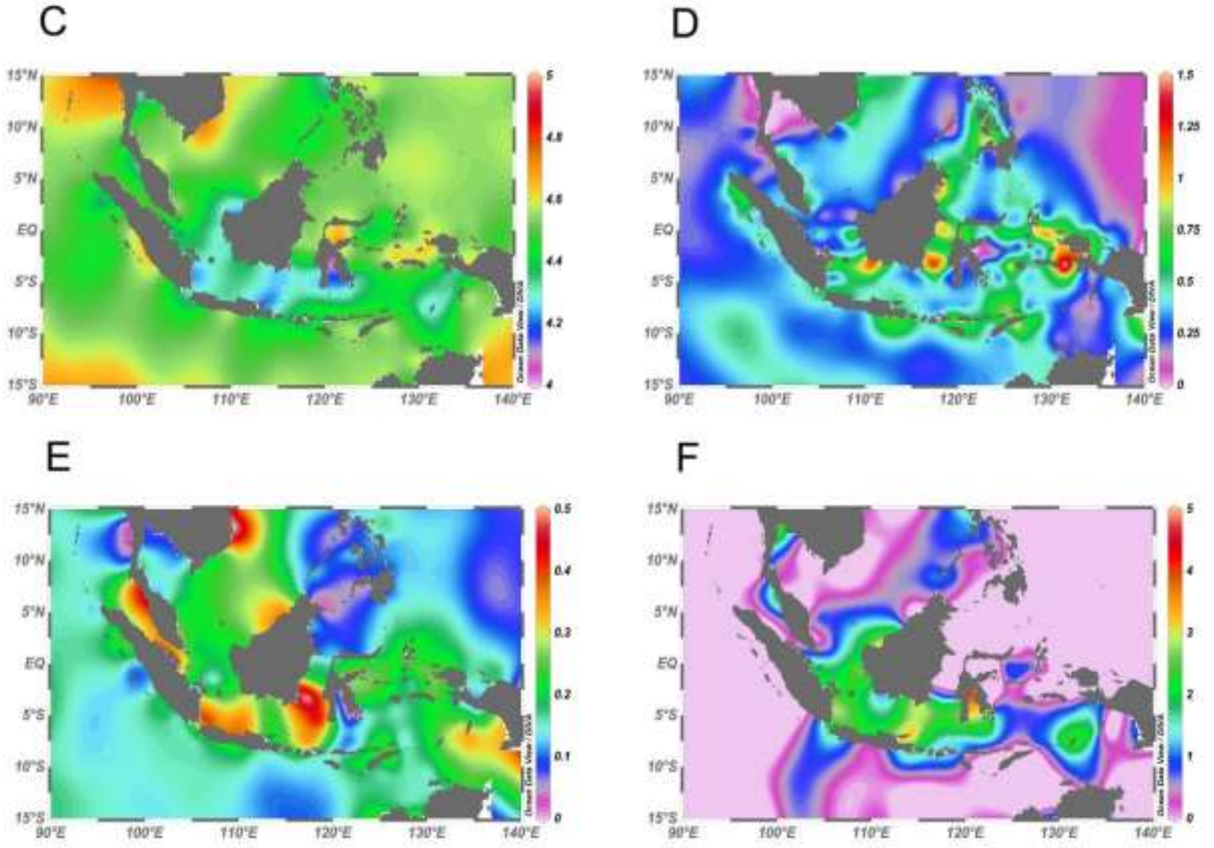


Fig. 1.4. Annual see surface temperature, SST (A), annual sea surface salinity, SSS (B), and concentrations of the oxygen (C), nitrates (D), phosphates (E), and chlorophyll-a concentration (F) in the surface waters of Java Sea. Environmental data (SST, SSS, oxygen, nitrate and phosphate concentrations) are derived from the World Ocean Atlas (2009); data on chlorophyll-a concentration derived from The Giovanni Ocean Colour Radiometry Portal).

1.3.2. Modern climate and marine currents

The region has a typical monsoon climate marked by a reversal of the winds. This phenomenon is caused by differences in temperature between the continental and oceanic areas. The NW monsoon reaches its peak in December to February and it is usually characterized by frequent rainfall and windy period, when the rate of precipitation in some areas is up to 3000 mm. In contrast, the SE monsoon occurs in June to August and it is usually characterized by low rainfall, sometimes less than 50 mm. The rate of precipitation is strongly influenced by the climate anomaly known as ENSO (El Niňo Southern Oscillation), with its two extreme faces, El Niňo and La Niňa, it can respectively decrease and increase precipitation rates over Indonesia (Ropelewski and Halpert, 1987).

The ocean currents in the Java Sea show the same directions (Writky, 1961). From November to March, the water flows eastwards (Fig. 1.5A). Oppositely from May to September, it flows westwards (Fig. 1.5B). Waters are spiced by the Karimata Strain Throughflow (KMST) that has its origin in the South China Sea (Fig. 1.5). In the most eastern part of the Java Sea, additional inflow comes from the

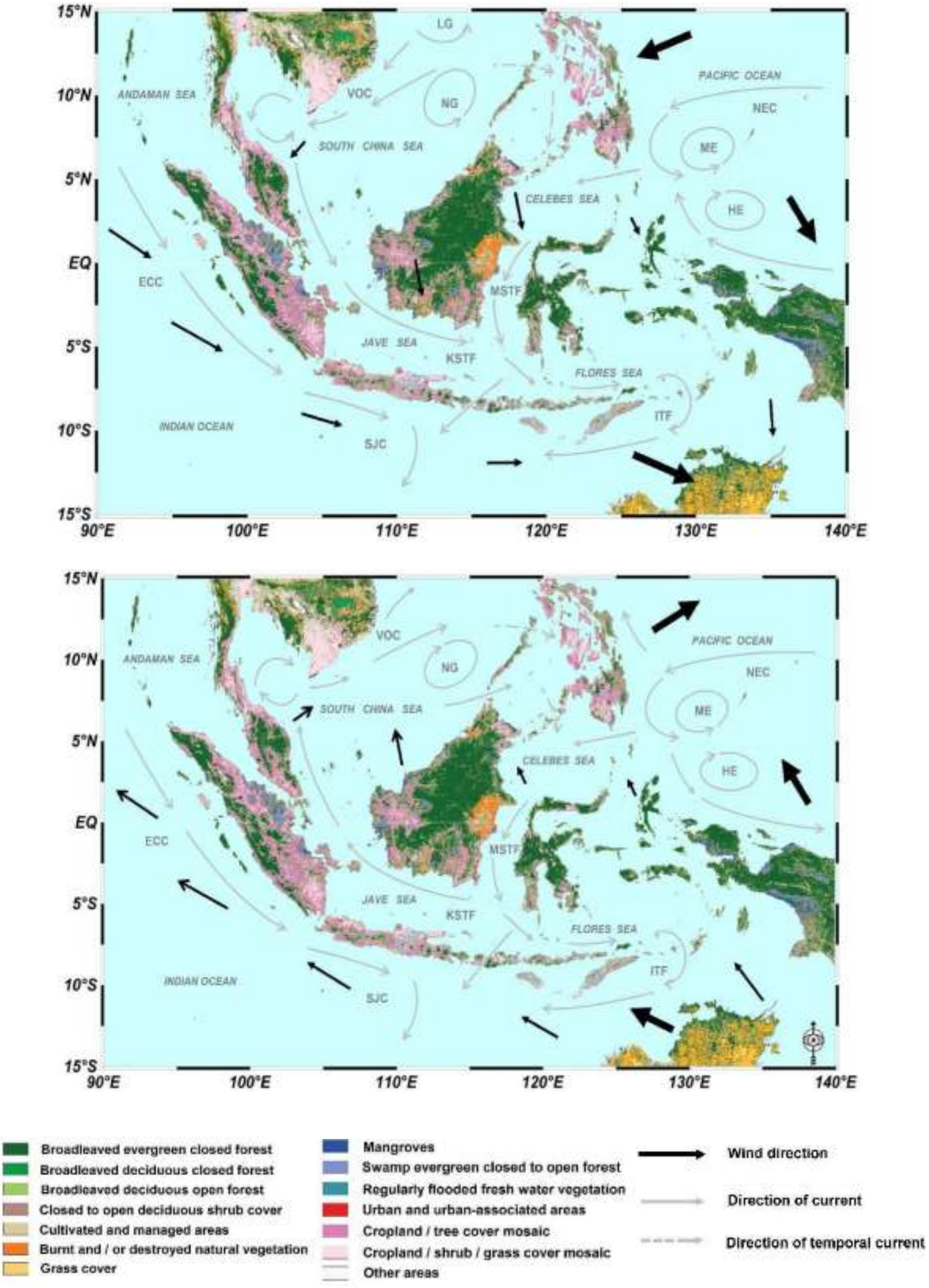


Fig. 1.5. Schematic map showing main forest types in Indonesia (after Stibig, et al., 2002) main oceanic currents and winds in the source area during the NW (upper picture) and SE monsoon (lower picture). Patterns of winds are followed Black (2002) and P. Wang et al. (2000, 2005); directions of currents are modified after Schott and McCreary (2001), Zheng et al. (2006), Fang et al. (2009). The abbreviations stand for the following: ITF, Indonesian Throughflow; ECC, Equatorial Counter Current; KSTF, Karimata Strait Throughflow; LG, Luzon Gyre; MSTF, Makassar Strait Throughflow; NG, Nansha Gyre; VOC, Vietnam Offshore Current.

north in form of the Makassar Strait Throughflow (MTSF). These waters mix with the KMST and leave the basin through the Flores Sea. During the period of SE monsoon (May-September) their direction changes and waters go western direction (Fig. 1.5B). Waters of the Java Sea are then formed by MTSF waters that leave the Sea through the Karimata Strait. During the intermediate months (April and October) when the current direction changes numerous eddies are formed. In these months the currents off the coast of Java generally flow in easterly direction whereas at the same time a western current is present off the coast of Kalimantan (Genia et al., 2007).

The Indonesian Throughflow (ITF) flows through the Lombok Strait and neutralizes lower sea surface temperatures off Java during the upwelling season (Romero, 2009). The Indonesian region is referred to as ‘a key area along the return branch of the global conveyor belt’ and the only low-latitude pathway between the Pacific and Indian Ocean basins, with major climatic importance on a global scales (Gordon, 2005). Advection of fresher Java Sea waters through the Sunda Strait and run-off from Sumatra and Java are responsible for the low-salinity ‘tongue’ in the South Java Current (Qu et al., 2005).

1.3.3. Bottom sediments

The most of bottom sediments of the Java Sea is represented by silt and formed by highly dense mud layer, with large muddy bed in the North-East and central area where it is mixed with coral and shell debris (Emery, 1972; Boely et al., 1991; Sadhatomo, 1996). North of Madura and near the coast of Java, rocky outcrops associated with coral formations are observed (Boely el al., 1991). A line extending from east to west through the Java Sea roughly divides the bottom sediments of the region into two distinct groups: sediments to the north are largely derived from the non-igneous formations of Borneo, while those to the south were derived from the volcanic rocks of Java. Coarse quartz sand is found in the vicinity of the several entrances to the sea, but the great central basin is mainly composed of soft mud that is rich in calcium carbonate originated from the coral reefs (Genia et al., 2007).

1.3.4. Geography and natural conditions of Java and Kalimantan

The island of Java is of about 130,000 km^2 supporting 136,563,000 inhabitants with the average density of 862 people/km^2 (2010, http://www.bps.go.id; Whitten et al., 1996). Java is the world's most populous island, and one of the most densely-populated places in the world. It is the home of 60% of the Indonesia population.

Kalimantan (539,760 km^2, http://www.geohive.com) in English, is the name for the Indonesian part of Borneo, while in Indonesian the term "Kalimantan" refers to the whole island of Borneo (MacKinnon et al., 1997). It is the largest island in Indonesia, 73% of the country lies within its territory. Non-Indonesian territories of the island consist of the states of Sarawak and Sabah forming together East Malaysia and independent sultanate Brunei Darussalam (http://www.bps.go.id). The climate on both of islands is tropical: hot and humid. Kalimantan is situated on the equator, within the wettest part of the Indonesian archipelago, and mostly its climate has less seasonal variability, than on Java.

1.3.5. Relief and Geology

On its origin, Java is a volcanic island with some 155 centers of active volcanism. Together with Bali, Java is the most volcanically active place on the Earth. The relief of Java is not uniform. Two large chains of mountains are found which are up to 3200 m high. In the north of the island, Karang, Dieng and Muria volcanic complexes are situated. Lowlands in the north of Java are represented by northern foothills and alluvial plains. Although volcanic rocks on Java dominate, the rocks in northern lowlands are almost entirely sedimentary in origin (Whitten et al., 1996). The basic lithography of the region is one of young, mixed volcanic and calcareous marine sediments lying on the southern flank of series of young volcanic piles aligned along the centre of the islands (Van Bemmelen, 1970). The island's main rivers flowing into the Indian Ocean are the Cimandiri, Cibuni, Ciwulan, Citanduy, Serayu, Progo, and Opak (after Whitten et al., 1996).

In contrast to Java, Kalimantan is rather flat and has vast areas of low costal and river plains, especially in the south (MacKinnon et al., 1997). Over half of the island lies below 150m in altitude. Moreover, Kalimantan Kalimantan has no active volcanoes, although its main mountains are igneous of origin and are mainly concentrated in the northern and in the central part of the island. Southern Kalimantan is in great part swampy lowland, stretching from around Banjarmasin and Aluh-Aluh in the south to around Amuntai in the north (Sumawinata, 1998a, 1998b). Only highland area can be found in Kalimantan, the Meratus Mountains (highest point Gunung Besar, 1892 m) which extends along the coast and separates Central and East Kalimantan. Much of island consists of consolidated and semi-consolidated rocks, including Quaternary limestones, old volcanic rocks and Tertiary sediments. Large areas of Southern Kalimantan are composed of sedimentary rocks such as sandstones and shales. Loosely consolidated sands and gravel terraces, often overlain by yang, superficial deposits of peat and alluvial fans deposited by flooding rivers can be found almost in all area. The most important rivers in the south part of the island are the Pembuang, Barito, Mendawai, and Jalai.

1.3.6. Soils

Soil conditions are important in affecting the development and diversity of the vegetation. Soils of Java vary from undeveloped, soft muddy hydraquents and sandy tropopsamments to vitradepts, slightly weathered volcanic ash soils with dominantly coarse textures and thick, black topsoil, and highly productive tropical mature soils. Most of soils in the hilly parts of Java are relatively immature, however, and because they retain moisture, mineral nutrients, organic matter and phosphorus, they are potentially very productive. Exceptions are the soil over limstones and marls (Whitten et al., 1996).

The majority of Kalimantan soils have developed on rolling plains and dissected hills on sedimentary and old igneous rocks. These soils range from strongly weathered and acid ultisols to yang inceptisols. In the south, extensive alluvial plains and peat soils extend into the Java Sea. Accretion is still occurring on the shallow shelf of southern Kalimantan, with alluvial sediments building up behind coastal mangroves. Weathering is very strong in the humid tropics, favored by both warmth and moisture. High levels of weathering, leaching and biological activity, e.g. degradation of organic material, are characteristic of many soils in both islands (Burnham, 1984; MacKinnon et al., 1997). The soils of Kalimantan are generally much less fertile than the rich volcanic soils of Java.

1.3.7. Flora and vegetation

Floristically, Java and Kalimantan are among of the richest sites on earth. Taxa from East Asian and Austral-Antarctic floristic regions can be found in mountains, while Indo-Malaysian elements are reviling and are rich in species in the hot lower altitudes (e.g. Dipterocarpaceae), East Asiatic taxa (e.g. Fagaceae) progressively become more diversified upslope to mid altitudes. Austral-Antarctic taxa (e.g. *Ranunculus*, *Dacrycarpus,* and *Leptospermum*) are found at higher elevations (Hotta, 1974). Forest types of the area include mangroves, peat swamp and freshwater swamp forests, extensive heath forests, lowland dipterocarp forests, ironwood, forests on limestone and ultrabasic soils, hill forest and various montane formations (e.g. Flenley, 1979; Whitten et al., 1996; Collins et al., 1991) (Fig. 1.5). Other plant communities are represented by beach vegetation, grassy shrublands, grasslands, estates and agricultural ecosystems (MacKinnon et al., 1997).

The vegetation of Java can be classified in a number of different ways (Campion and Seth, 1968; Whitmore, 1984; MacKinnon et al., 1982; MacKinnon and MacKinnon, 1986; Whitten et al., 1996). Natural forests include several forest subtypes, i.e. extensive evergreen rainforest (monsoon forest), semi-evergreen rainforest, moist deciduous forest along the northern coast, and dry deciduous forest. The differences are mostly related to the seasonality of rainfall. No single tree family dominates the forests of Java, as is the case with the dipterocarps in Kalimantan (Whitten et al., 1996). The most common species in the rainforests of Java are *Artocarpus elasticus* (Moraceae), *Dysoxylum caulostachyum* (Meliaceae), *Lansium domesticum* (Meliaceae) and *Planchonia valida* (Lecythidaceae). Semi-evergreen rain forest differs from evergreen rain forest by being slightly more seasonal, with two to four dry months each year (Whitten et al., 1996).

Java's deciduous forests generally are lightly closed, with few trees exceeding 25 m. *Borassus* and *Corypha* palms are good indicators of the seasonal climates that generate deciduous forests in the region. Moist deciduous forests have 1500 to 4000 mm of rainfall annually, with a four- to six-month dry season. Dry deciduous forests have less than 1500 mm of annual rainfall and more than six dry months. Common lowland deciduous trees found in eastern Java and Bali are *Homalium tomentosum, Albizia lebbekoides, Acacia leucophloea, A. tomentosa, Bauhinia malabarica, Cassia fistula, Dillenia pentagyna, Tetrameles nudiflora, Ailanthus integrifolia,* and *Phyllanthus emblica*. Many herbaceous plants are confined to the deciduous forests (Whitten et al., 1996). Patches of freshwater swamp forest found throughout the ecoregion are relatively poor in species (Whitten et al., 1996). Rawa Danau, Banten in west Java is the largest remaining area of swamp forest in Java and Bali, and it contains many tree species now nearly extinct elsewhere in Java, such as *Elaeocarpus macrocerus, Alstonia spathulata*, wild mango (*Mangifera gedebe*) and *Stemonurus secundiflora*.

According to Stuijts (1993) and Stuijts et al. (1988), mountain vegetation of Java has a distinct belt structure and can be described it is shown at the scheme (Fig. 1.4). Submontane forest is closed, with little moss and poor ground flora. It is represented by seasonal mountain forest, growing above 1000-1400 m following evergreen or semi-evegreen forest, and mountain aseasonal forest, at the same elevation above monsoon forest. Common trees are *Celtis, Altingia* and Myrtaceae. Lower montane forest differs from the previous forest type by very rich ground flora and lower number of tree species. It is observed at the level of 1400-1800 m. This zone is often caller ‘Lauro-fagaceous belt’ as *Castanoptis* together with *Quercus* and Lauraceae predominant. Many lowland families no longer appear (Backer et al., 1963, 1968), more temperate genera, including *Lonicera, Nertera, Gaultheria* appear (Whitmore, 1975). Mountain vegetation is upper mountain forest growing at the elevation of 1800-2400 m is described as closed, high-stem, floristically rich mossy mesophyll forest with *Podocarpus, Dacrycarpus, Engelhardia* being characteristic trees. Ericoid montane forest can be found on the level of 2400-3000 m. It is mossy microphyll forest, consisting of a single low canopy with rich ground flora and few lianas. Device Ericaceae, *Rapanea* and on volcanic soils *Myrica* can be found there. Subalpine ericoid scrub appeared when elevation riches 3000-3600 m. Herbs and low microphyll shrubs, dwarf forms of trees found in below vegetation are recognized there. In the uppermost sites alpine rock-desert occurs.

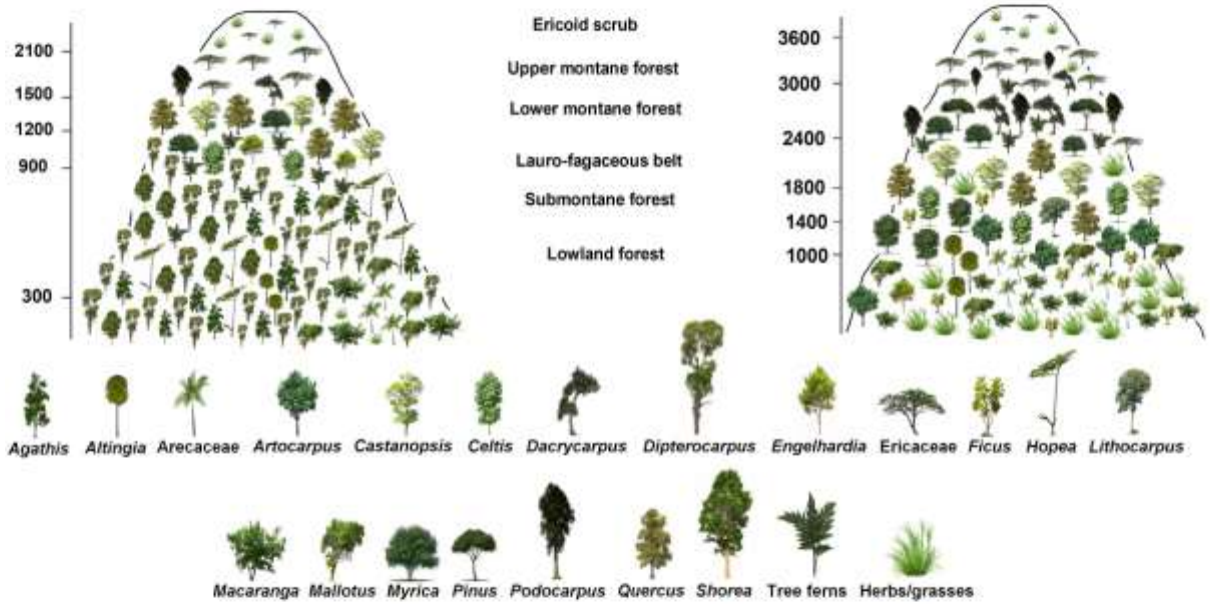


Fig. 1.6. Vertical zonation of Javanese (based on Stuijts, 1993 and Stuijts et al., 1988) and Kalimantan (based on Whitmore, 1984a and MacKinnon et al., 1997) mountains with the characteristic taxa and vegetation belts.

The vegetation of Java has been strongly changed by humans during the last few hundred years. Over the half the original area has been turned into grassy shrubland with *Trema*, *Malotus, Melastoma, Lantana,* and *Eupatorium*. Extensive palm plantations and rice fields as well as abandoned estates and aquaculture land occupy nowadays large territories. Strongly reduced area of mangroves is now limited to the stands along the northern coasts of Java (e.g. around Ujung Kulon), in Segara Anakan lagoon (White et al., 1989; Yani et al., 2004; Hinrichs, 2006; Noor et al., 2006; Hinrichs, et al., 2009; Geist, 2007, Geist et al., 2012;) and in Grajagan Bay, Segoro Anak (White et al., 1989; Whitten et al, 1996). The most important families in mangrove forest of Northern Java are Rhizophoraceae with *Rhizophora, Bruguiera, Ceriops* followed by Avicenniaceae (*Avicennia*) and Sonneratiaceae (*Sonneratia*).

Kalimantan supports some of the largest expanses of tropical rainforest is SE Asia, providing some of the most spices-rich habitat on earth. Most of Kalimantan is covered by species-rich closed-canopy forests with high endemism (e.g. Whitmore, 1984; Jacobs, 1988; MacKinnon et al., 1997) very high productivity (Ashton, 1982; MacKinnon et al., 1997), long history (Muller, 1970) and a great diversity; there are as many as 240 different species of trees growing within a hectare (Kartawinata et al., 1981; Ashton, 1989). Main types of lowland rainforest of southern Kalimantan are *Dipterocarp* forest, heath forest (Kerangas), ironwood forests predominating by *Eusideroxylon zageri* as well as forests on limestones and ultrabasic rocks. The general characteristics of these forests are canopies 24-36 m high with emergents reaching up to 65 m. Dipterocarpaceae is a dominant family in the emergent stratum. In the richest forests, up to 80% of the emergent trees are dipterocarps: *Dipterocarpus, Dryobalanops, Shore*a, *Hopea* and *Vatica* together with species from Berseraceae and Sapotaceae are usually found in the main canopy as well. A third layer occurs below the canopy of shade-tolerant species, adorned with lianas, orchids, and epiphytic ferns. This layer includes many species from the Euphorbiaceae, Rubiaceae, Annonaceae, Lauraceae, and Myristicaceae families. In some cases Euphorbiaceae is more common than dipterocarps, being the second most common family in Kalimantan. On the forest floor, herbs, seedlings, and shade-tolerant palms exploit the few places that receive sunlight.

In mountains of Kalimantan Whitmore (1984) described five altitudinal floristic zones (Fig. 1.6). These are already described lowland dipterocarp zone (less than 300 m), the hill dipterocarp zone (300-800 m), the upper dipterocarp zone (800-1200 m), the oak-chestnut zone with Fagaceae and Lauraceae predominant (1200-1500 m), and the montane ericaceous zone (higher than 1500 m). Upper montane forests share many species and features of the structure and appearance with heath forests (*Eugenia, Rhododendron, Vaccinium*), yet none of the heath forest dipterocarps expends above 1,500 m. Only few plants span the complete altitudinal range from lowlands to upper montane forest, e.g. *Dacrydium* (MacKinnon et al., 1997). The highest altitudes of Southern Kalimantan bare closed-canopy scrubs.

Mangroves fringe most of Kalimantan coastline. They occur almost in all bays and lagoons, along the deltas of major rivers, with particularly extensive stands at mouths of the Kapuas, Mahakam and Sebuku. The most important taxa in mangroves of Southern Kalimantan are *Rhizophora, Bruguiera* and *Xilocarpus*. In older stands they may be an understory of *Ceriops tagal* (Soegiarto and Polunin, 1980). *Sonneratia alba*, *Avicennia alba* and *A. marina* and are important for pioneer communities. Dryer areas are colonised by *Bruguera, Lumnitzera, Aegiceras, Exocoecaria,* and *Osbornia. Acantus ilicifolius* can appear along the edge of estuarine mangroves. Along tidal rivers *Sonneratia caseolaris* grows. Stands of *Nypa fruticans*, only mangrove palm, flourish inland, along tidal creeks and estuaries; a few leans may occur (e.g. *Derris*), and ferns, grasses and sedges sometimes colonise openings (Chapman, 1977). In sites where mangroves have been disturbed, the giant fern *Acrostichum aureum* may form dense undergrowth, so thick that the mangrove trees cannot regenerate. Main agricultural landscapes of the Kalimantan are oil palm plantations with minor rice field development compare to Java.

1.3.8. Anthropogenic Impact

Very small areas of natural habitats remain in Java (MacKinnon and MacKinnon, 1986). Anthropogenic fires are common (Fig. 1.7), and over the centuries burning has resulted in monospecific stands of fire-resistant species in some areas, usually *Tectona grandis* (FAO, 1981) and *Casuarina*. In many annual cropping systems, soils are left exposed, resulting in extensive erosion.

In freshwater swamp forests, the exotic *Mimosa pigra* has the potential to become a very serious pest because it is fire-resistant and capable of forming impenetrable thickets. Plans to construct a dam at the outlet of the Cidanau River will potentially destroy Rawa Danau, the only remaining extensive area of freshwater swamp in Java (Whitten et al., 1996). Illegal farming and logging (Fig. 1.7) even within protected areas are widespread, and an important timber tree *Altingia excelsa* has been nearly eliminated from the lowland forests (Whitten et al., 1996).

Reforestation takes place on Java since the colonial time period, while in Kalimantan tree gain is going on due to a natural recover (Fig. 1.8). Planted species include *Swietenia macrophylla, Pinus merkusii, Agathis damara* and some native taxa, such as *Altingia excelsa, Schima noronhae,* and *Quercus sp.* (Smiet, 1990). These plantations are established mostly in areas where restoration of forest cover was deemed essential for the reason of watershed protection (Whitten et al, 1996).

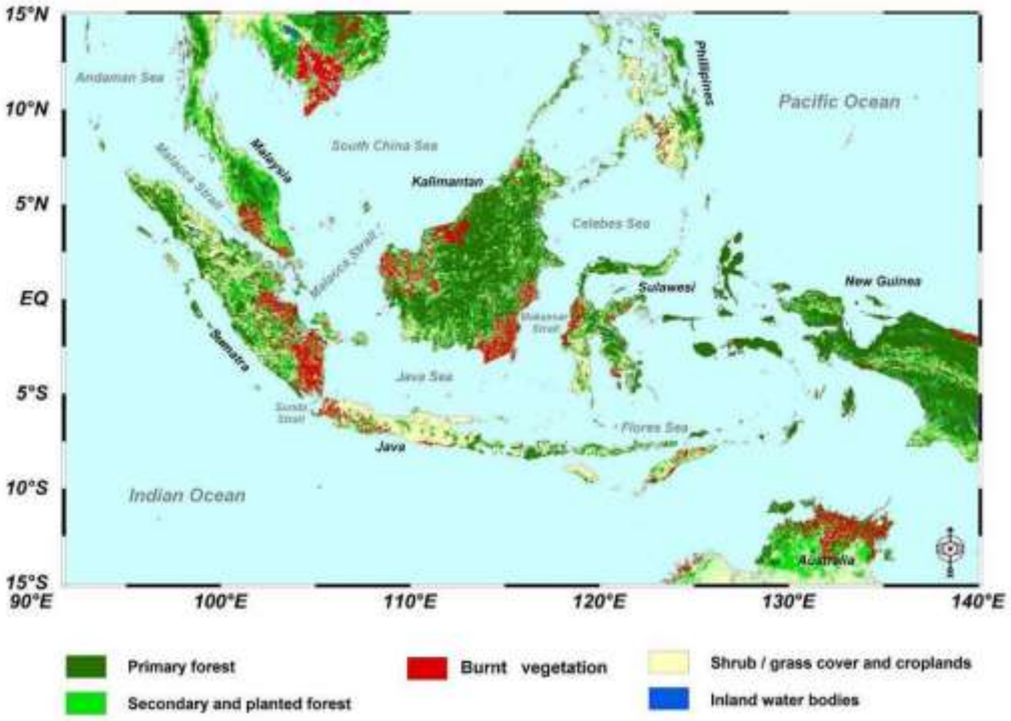


Fig. 1.7. Tree cover in Indonesian archipelago in comparison with shrub/grass cover, secondary/planted vegetation and burnt vegetation.

In Kalimantan, rapid logging, fires and periodical droughts, that take place due to the warm phase of the El Niño Southern Oscillation (ENSO), cause a problem of deforestation (Goldammer and Seibert, 1989; Cleary and Priadjati, 2005), although, in pristine forests fire rarely escape the ground vegetation because of the high humidity.

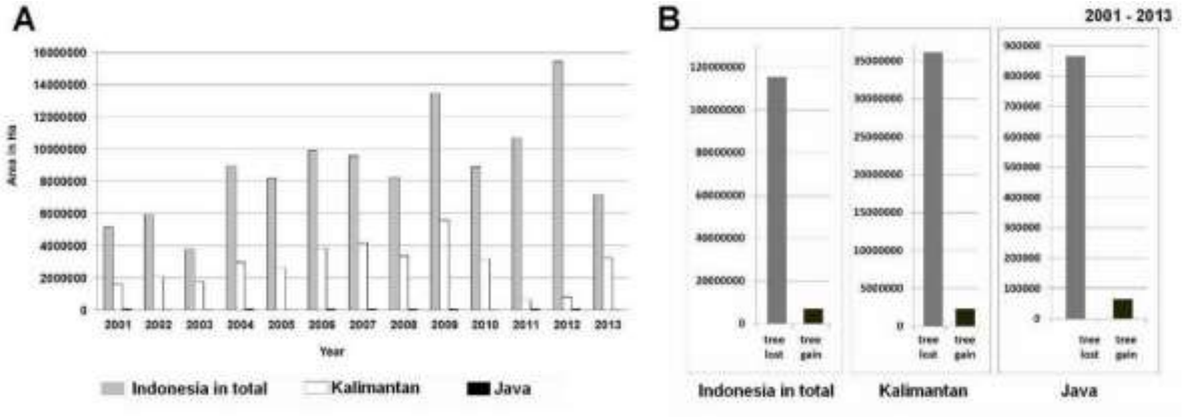


Fig. 1.8. Forest cover lost in Indonesia in total, Kalimantan and Java from 2001 and 2013 (A) and comparison between tree cover lost and tree cover gain (B). Data are derived from Margono et al., 2014; http://nfms.dephut.go.id/ipsdh.

However, tropical rainforests that have been previously logged are fire-prone because large amounts of wood are left on the forest floor, and the forest canopy is opened, drying out the ground vegetation. Oil and sugar palm plantations development as well as aquaculture (shrimp and fish ponds) are also the drivers of deforestation in the Kalimantan contributing directly and indirectly. About half of all presently productive plantations (over 6 million ha) were established in secondary forest and bush areas. Protection laws are in ‘effect throughout Borneo but are often inadequate or are violated, usually without any consequences‘ (Fatawi and Mori, 2000).

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CHAPTER 2

Marine palynology in SE Asia: State of knowledge

2.1. Studies on fossil pollen

Marine palynology in general, is a yang branch of research. Jan Muller was probably the first in science who linked pollen and spore distribution in marine surface sediment samples to the modern vegetation in his study on sediments from the Orinoco delta (Muller, 1959). In Indonesia, compared to the terrestrial studies, the number of publications on marine sediment records is still limited; especially it is true for the studies related to the Anthropocene and investigations of the pattern of modern pollen distribution.

In the study area, the first work on the marine palynomorphs apparently was the study undertaken by I. Van Waveren (1989) who focused on the palynological residues of the surface sediments from the Banda Sea. In that paper, 'a series of 27 palynomorph types are described and informally categorized' (Van Waveren, 1989). The author indicated a high plankton production and high sedimentation rate, although the paper does not contain any analysis of palynomorphs.

First analytical works and reconstruction of the past vegetation and climate for Indonesian region were published just in the beginning of 90s (Van der Kaars, 1991, 1989; Barmawidjaja et al., 1993; Van Waveren, Visscher, 1994). The authors indicated the practicality of marine palynology in the reconstruction of the history of this region.

2.1.1. Mid-Holocene (ca 7000 – 4000 cal yr BP)

Warmer periods from 6300 to 6000 yr and after 4000 yr, were evidenced in the coral records from the southern periphery of the IPWP, along with evidence for freshening after 4000 yr, indicating a stronger monsoon (Gagan et al., 1998; Stott et al., 2004; Abram et al., 2009). The Banda Sea records, including pollen and coccoliths, show a significant shift in the position of the monsoon around 6000 yr, suggesting low-latitude insolation forcing (Beaufort et al., 2010). Wang et al. (2007) indicated the warm phase between 7000 and 3600 yr BP as well.

Reeves et al. (2013) in their review on the vegetation and climate change of the region also referred to the thermal maximum of IPWP 6800-5500 yr BP and less extreme El Niño at about 5500-4300 yr Peak wet conditions achieved about 5000 yr in Borneo. Additionally, some drier conditions were indicated there.

2.1.2. Late Holocene (ca 4000 cal yr BP to the present)

Ganssen et al. (1989) indicated increased monsoonal intensity at about 2700 yr, while later, between 2500 and 1700 yr; at about the same time extreme and longer El Niño events were recorded (Tudhope et al., 2001; Moy et al., 2002; Woodroffe et al., 2003; McGregor and Gagan, 2004; Gagan et al., 2004; Reeves, 2013). Coral reconstructions of ENSO for the past 1100 yr demonstrate the links between ENSO and changes in the mean climate of the Pacific region (Cobb et al., 2003). For Borneo, warmer and fresher period are indicated (Reeves et al., 2013) up to 2500 yr with some more extreme El Niño 2300-1700 yr, compared with present.

2.2. Palynological studies of marine surface sediments

According to the study on modern pollen distribution pattern in the surface sediments in the South China Sea off Borneo, we learned that pollen is mainly transported by rivers from the south islands, e.g. Borneo (Sun et al., 1999; Sun et al., 2003). Because of the long distance from the coast, pollen amount deposited in the modern South China Sea is very little (Wang, 2007).

Palynological analysis of box-core samples collected from surficial deep-sea sediments along three transects in the Banda Sea (Van Waveren and Visscher, 1994), demonstrated that 'associations of palynomorphs, palynodebris and diffuse organic aggregates are mainly composed of terrigenous and zooplanktonic constituents'. Organic remains of phytoplankton and benthos attributed a subordinate role in the study area.

Pollen analysis on box-core sediment form the south-eastern Indonesian waters were presented by S. Van der Kaars (2001). The author described general trends in pollen transport and indicated that pollen and, at a lower rate, Pteridophyta spore tend to decrease with increasing distance from the shore line. Despite the complex nature of vegetation and pollen transport in the region patterns, it was evidenced during the research, that the onshore distribution of individual taxa and major vegetation types are well reflected in marine sediments. Low values of mangroves were indicated as their values within the source area tend to decrease with distance to shore (Muller, 1959; Hooghiemstra et al., 1986; Sun et al., 1999; van der Kaars et al 2000, 2001; Sun et al., 2002). In our studies (**Chapter 2**) we described the similar trend.

2.3. Studies on dinocysts

Within the SE Asian region, a number of studies exists that dill with the composition of dinocyst assemblages in marine surface sediments. Some publications are available from the northern part of the Philippine Sea (Matsuoka, 1981), Bay of Bengal (Kumar, 1996), Manila Bay, the Philippines (Azanza, 2004), coastal waters of Sabah, Malaysia (Furio et al., 2006) along transect in oligotrophic tropical waters of the South China Sea (Kawamura, 2004).

In Indonesia, a number of studies on dinocysts are limited to only three studies. The investigation of in surface sediments of Jakarta Bay (Matsuoka et al., 1999) focused mainly on the patterns of the red tide dinoflagellates. The study on the stratigraphic distribution of dinocysts in the Tertiary of Indonesia, described two Oligocene surface sections in West Java. The first is the Batuasih Formation located near Cibadak, and the second is a section close to Padalarang where dinocysts were 'abundant in phosphatic nodules, but are heavily affected by thermal metamorphism, past overheating of the section, in the claystones and sandstones' (Morgenroth et al., 2011).

The most modern study was focused on the relationship between the spatial distribution of dinocysts and modern local environmental conditions (e.g. SST, SSS and productivity) in the eastern Indian Ocean (Hessler et. al., 2013). According to the composition of dinocysts, three environmental and oceanographic regions were described as a result of the last study. The first region located in western and eastern Indonesia and controlled by high SST and a low nutrient content of the surface waters. The second, Indonesian Throughflow (ITF) region, is dominated by heterotrophic dinocyst species reflecting the region's high productivity. The third region is located offshore north-west and west Australia which is characterized by low STT, high SSS and high oxygen content in the water.

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CHAPTER 3

Eleven Month High Resolution Pollen and Spore Sedimentation Record off SW Java in the Indian Ocean

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Abstract

Settling particles collected in a sediment trap 60 km off SW Java in the Indian Ocean at a 2200m deep site, about 830 m above the sea floor, between December 2001 and November 2002 (intervals of 16 days for 11 months) were analyzed for the abundance and taxa composition of pollen and spores. Several factors control their deposition such as the monsoon-driven reversal of the wind directions and ocean currents as well as flowering periods. Long distance transport plays a particular role during the monsoon seasons. During the NW monsoon (mid-December-beginning of March), maxima of *Picea* type, *Alnus*, *Pinus* and *Quercus* pollen occur in the trap samples, which correspond to wind and marine currents coming from the north, probably the Equatorial Counter Current and Southern Java Current, transporting pollen from the southern part of continental Asia and Sumatra to the research area. During the SE monsoon (end of July-mid-November), an increase of pollen originating from southeast Indonesia and Australia was observed. Pollen grains were probably transported by the South Equatorial Current and partly by the Leeuwin Current. Casuarina and, in part, Eucalyptus are most abundant during this period. During the intermonsoon period, assemblages are mainly composed of pollen originating from West Java. Maxima of some pollen taxa, such as *Elaeocarpus*, *Myrica, Dacrycarpus* type, *Casuarina, Eucalyptus* and *Podocarpus* type probably reflect their flowering periods. The transportation time from the pollen source area to the sediment trap is about 1–2 months. The extrapolated pollen accumulation rate of the marine sediment trap would be about 1670 grains/cm^2/yr. The trap collected low concentrations of mangrove pollen, which might be the result of the strong destruction of the mangrove belt in Java during recent decades. High values of Poaceae pollen are probably related to the land use, forest canopy opening and development of the secondary vegetation in West Java. The majority of the pollen and spores collected by the sediment trap reflects the vegetation of SW Java, but long distance transport, in particular by the marine currents during the SE and NE monsoons, needs to be considered when interpreting marine pollen records off SW Java in the eastern Indian Ocean.

3.1. Introduction

In order to better understand and interpret marine fossil pollen records, studies on modern pollen and spore transportation and deposition in the ocean are needed. Sedimentary pollen records can provide crucial information on vegetation, human impact and climate change as well as on past changes of ocean circulation. In particular, these studies can help in understanding seasonal variations of modern pollen distribution patterns related to plant-specific factors such as source vegetation distribution and flowering periods as well as transport specific factors, e.g. winds and ocean currents. Valuable data can be obtained from the sediment trap studies.

Several papers have been published on the palaeovegetation and palaeoecology of the Java region including terrestrial (e.g. Polhaupessy, 1980, 1981; Semah, 1984; Stuijts, 1984, 1993; Stuijts et al., 1988; van der Kaars and Dam, 1995, 1997; Wang, et al., 1999; Pudjoarinto and Cushing, 2001; van der Kaars and De Deckker, 2002; Van der Kaars and van den Bergh, 2004; Yulianto et al., 2005) and marine archives (e.g. van der Kaars, 1991, 1998; Van der Kaars et al., 2000; Van der Kaars, 2001; Sun et al., 2002; Kershaw et al., 2011). Studies on modern pollen sedimentation are rare for the Indonesian region (Stuijts, 1993; Beuning, 1996; Buschman et al., 2011). Data on modern pollen distribution in marine sediments are available from the South China Sea (Sun et al., 1999), the Banda Sea and Seram Sea (Van Waveren, 1989; van der Kaars, 1998) and from waters of eastern Indonesia (van der Kaars, 1991). A number of publications on continuous sediment trap series in the Indian Ocean waters are available (e.g. Rixen et al., 2006a, 2006b; Mohtadi et al., 2009; Romero et al., 2009). However, no studies on pollen assemblages in sediment trap recordings have been carried out for Indonesia. For the first time, studies on pollen and spores from a sediment trap off SW Java are presented in this paper.

The main objectives of this study are to compare the abundance and composition of pollen deposited in the deep Indian Ocean margin under different monsoon conditions during an 11 months period, and to identify the factors that can influence temporal changes in pollen assemblage composition. This study also provides knowledge on the seasonal patterns of pollen and spore sources, fluxes and composition.

3.2. Environmental setting

3.2.1. Study region

The site of the sediment trap (8° 17.5′ S, 108° 02.0′ E) is located in the eastern part of the Indian Ocean, 60 km south off SW Java, Indonesia (Fig. 3.1). Bathymetric data suggest that sea bottom morphology of the study area is characterized by many submarine canyons cutting the shelf and extending down into the deeper parts of the basin. The landward flank of the fore arc basin off Java forms a smooth slope. The outer-arc ridge is 2000–3000mdeep,with isolated highs of approximately 1000 m (Moore et al., 1980).

On Java, two large mountain chains are found up to 3200mhigh. The island's main rivers flowing into the Indian Ocean are the Cimandiri, Cibuni, Ciwulan, Citanduy, Serayu, Progo and Opak (Whitten et al., 1996).

3.2.2. Marine currents

The ocean currents in the study area move according to the seasonal wind regime (e.g. Wijffels et al., 1996, 2002). During the NW monsoon season (mid-December–beginning of March, Fig. 3.1A) the South Java Current (SJC), derived from the Indian Ocean Equatorial Countercurrent (ECC), moves towards the southeast to meet the saline waters of the Leeuwin Current (LC), which originates in the eastern part of the Indonesian Archipelago (Tomczak and Godfrey, 1994). The mixing of the SJC and the LC produces the South Equatorial Current (SEC), which then moves further westward. During the SE monsoon season (end of July–mid-November, Fig. 3.1B), the SJC takes an opposite direction, flowing northwestward and feeding the SEC without a significant contribution of the LC. The high precipitation rates during this season lead to an increased run-off from Sumatra and Java. The Indonesian region is “a key area along the return branch of the global conveyor belt and the only low-latitude pathway between two ocean basins”, with major climatic importance on a global scale (e.g. Gordon, 2005).

3.2.3. Climate

According to the Koppen-Geiger classification, the climate in the study region is tropical: hot and humid. The climate is dominated by the monsoon circulation (Whitten et al., 1996). During the austral summer (December-April), the NW winds transport large masses of moist air from the Asian high-pressure belt, which causes heavy rains on the archipelago. The annual precipitation ranges from 1500-2000 mm in the lowland up to 6000 mm on the upper slopes of the central mountains of

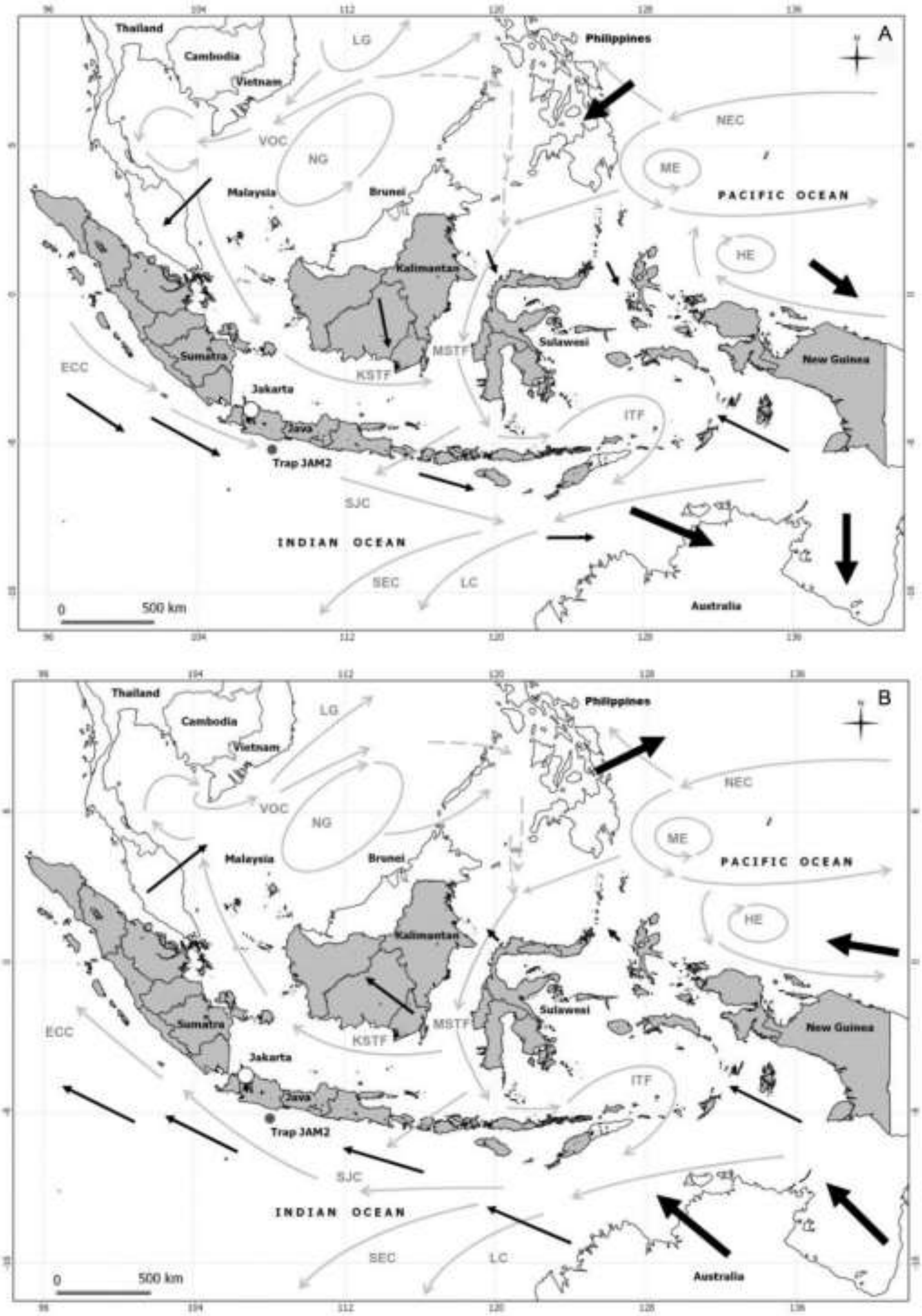

Fig. 3.1. Schematic map showing main oceanic currents and winds in the study area during the (January) southern summer (NW monsoon) and (July) southern winter (SE monsoon) with the position of the sediment trap JAM2 off SW Java (dark-grey dot). Wind patterns according to Wyrtki, 1957; Black (2002) and Wang et al. (2000, 2005); directions of currents are modified after Schott, McCreary (2001); Zheng et al. (2006); Fang et al. (2009). The abbreviations stand for the following: ITF, Indonesian Throughflow; HE, Halmahera Eddy; ECC, Equatorial Counter Current; KSTF, Karimata Strait Throughflow; LC, Leeuwin Current; LG, Luzon Gyre; ME, Mindanao Eddy; MSTF, Makassar Strait Throughflow; NEC, North Equatorial Current; NG, Nansha Gyre; SEC, South Equatorial Current; SJC, Southern Java Current; VOC, Vietnam Offshore Current. Dashed arrows show temporal flows.

West Java (Sijatauw, 1973; Whitten et al., 1996). During the austral winter (June-October) dry and cool winds are predominating. The precipitation during the SE monsoon is relatively low. The rainfall distribution in the western part of Java has a strong south–north gradient, from more than 3000 mm to about 1000–1500 mm per year (Richards, 1952; Sijatauw, 1973; Monk et al., 1997). The rate of precipitation is strongly influenced by the El Niňo Southern Oscillation (ENSO), with its two extreme phases, El Niňo and La Niňa, which respectively lead to low and high precipitation rates over Indonesia (Ropelewski and Halpert, 1987).

3.2.4. Vegetation

The vegetation of Indonesia (Fig. 3.2) includes mangroves, lowland forest and submontane/mountain forest (Burbidge, 1960; Flenley, 1979; Van Steenis, 1984; Collins et al., 1991; Whitten et al., 1996). The natural forests in the lowlands are composed of extensive evergreen and semi-evergreen rainforests as well as moist deciduous and dry deciduous forests. Differences are mostly related to the seasonality of rainfall. There are also small areas of azonal limestone and freshwater swamp forests. The original lowland vegetation has been heavily changed by humans during the last few hundred years. Large areas of the lowlands have been cultivated for rice, palm plantations and have been partly changed to aquaculture ponds. In the areas of secondary forest *Elaeocarpus* (Elaeocarpaceae), Moraceae and a variable number of re-growth taxa occur (Whitten et al., 1996) such as *Acalypha* (Euphorbiaceae), *Ficus* (Moraceae), *Macaranga/Mallotus* (Euphorbiaceae), *Trema* (Cannabaceae), *Pandanus* (Pandanaceae) and others (Van Steenis, 1984; Whitmore, 1984).

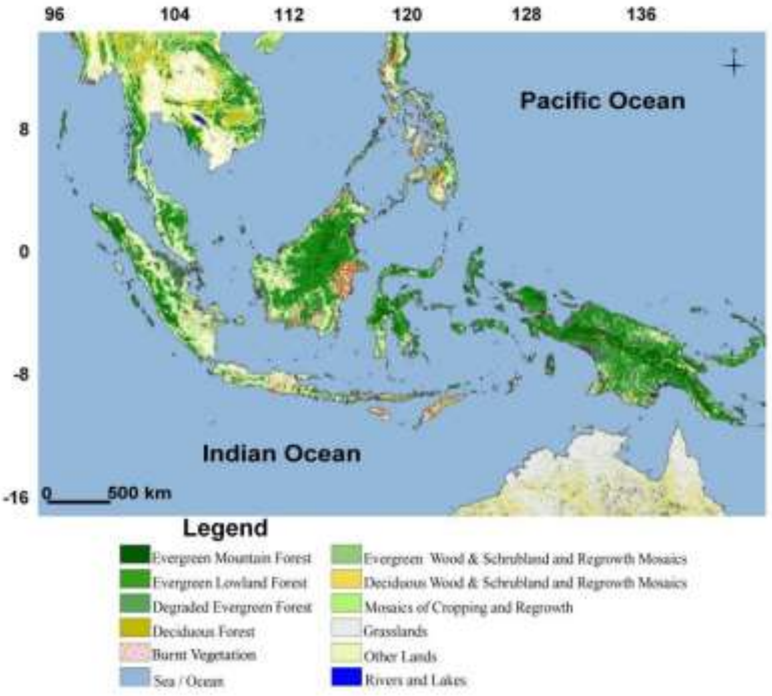

Fig. 3.2. Main vegetation types of Indonesia. Modified after http://bioval.jrc.ec.europa.eu (Continental Southeast Asia - Forest cover map, 1998-2000 and Insular Southeast Asia - Forest Cover Map, 1998-2000; Stibig and Malingreau, 2003; Stibig et al., 2003, 2004).

Starting at 1000–1500 m elevation, submontane forest occurs, which is dominated by *Castanopsis*, *Quercus* (Fagaceae) and Lauraceae. At higher elevations (1500–1800 m) it changes to mountain forest, which is characterized by a distinct vertical zonation rich in ground flora and with an important role of coniferous trees (e.g. *Dacrycarpus* and *Podocarpus*), as well as *Engelhardia* (Juglandaceae), *Myrica* (Myricaceae), *Weinmannia* (Cunoniaceae), Myrsinaceae, Ericaceae and others (e.g. Van Steenis, 1984; Van der Kaars and Dam, 1995). Due to excessive land use, only a few remote spots of natural plant communities have remained in Java and, in general, only the tops of mountains still bear original vegetation (Stuijts, 1993).

The area of mangroves on Java has been highly reduced as well (Collins et al., 1991; Hutomo and Moosa, 2005; Food and Agricultural Organisation, FAO Report, 2007). The remaining pockets of mangroves can be found along the coast of South and Northwest Java (Whitten et al., 1996).

3.3. Material and methods

3.3.1. Sediment trap

Sediment trap JAM2 (ParfluxMark 7G-21, Honjo and Doherty, 1988) was deployed at 2200 m water depth; samples were collected between December 2001 and November 2002. The trap was located about 830m above the seafloor. The sampling interval of the trap was 16 days (Table 3.1). Before installation, sample bottles were filled with seawater from 1800 m water depth. To prevent degradation of trapped material, mercury(II)-chloride (3.3 g/l) was added to the cup water. Recovered samples were stored at 2–4 °C.

Sample No.	Cups open	Cups close	Monsoon conditions
D1	14 Dec 2001	30 Dec 2001	NW
D2	30 Dec 2001	15 Jan 2002	NW
D3	15 Jan 2002	31 Jan 2002	NW
D4	31 Jan 2002	16 Feb 2002	NW
D5	16 Feb 2002	4 Mar 2002	NW
D6	4 Mar 2002	20 Mar 2002	non
D7	20 Mar 2002	5 Apr 2002	non
D8	5 Apr 2002	21 Apr 2002	non
D9	21 Apr 2002	7 May 2002	non
D10	7 May 2002	23 May 2002	non
D11	23 May 2002	8 Jun 2002	non
D12	8 Jun 2002	24 Jun 2002	non
D13	24 Jun 2002	10 Jul 2002	non
D14	10 Jul 2002	26 Jul 2002	non
D15	26 Jul 2002	11 Aug 2002	SE
D16	11 Aug 2002	27 Aug 2002	SE
D17	27 Aug 2002	12 Sep 2002	SE
D18	12 Sep 2002	28 Sep 2002	SE
D19	28 Sep 2002	14 Oct 2002	SE
D20	14 Oct 2002	30 Oct 2002	SE
D21	30 Oct 2002	15 Nov 2002	SE

Table 3.1. Number of samples and sampling periods of trapped material off SW Java in the tropical SE Indian Ocean. The abbreviations indicate the following: NW - northwest monsoon; non (light-grey shading) - intermonsoon period; SE (dark-grey shading), southeast monsoon.

3.3.2. Pollen analysis

Pollen analysis was undertaken on 25% of the collected material. Pollen was concentrated from the settling particle matrix by the method described by Faegri and Iversen (1975). Calcium carbonate was dissolved with hydrochloric acid (HCI 10%). Silicates were dissolved with hydrofluoric acid (HF 72%). The samples were sieved over a nylon filter to remove particles b10 µm. The identification of pollen and spores was done using the department's reference collections including about 300 Indonesian taxa and with the help of palynological literature (e.g. Moore and Webb, 1978; Wang et al., 1995; Fujiki et al., 2005; Mao et al., 2012). Furthermore, the online database "The Australasian Pollen and Spore Atlas" (Weng et al., 2007) was used.

All identified pollen and spore types were photographed with a digital camera through an optical microscope. Photos of identified pollen and spores are available upon request at the Department of Palynology and Climate Dynamics (University of Göttingen, Germany). Samples were counted to a minimum of 100 pollen grains. Pollen and sporepercentages were calculated on the basis of a total pollen sum that excluded indeterminate pollen and Pteridophyta spores. To determine pollen accumulation rates (PAR) a *Lycopodium* tablet (Stockmarr, 1971) with a known number of spores (20,848 ± 1546) was added to each sample before processing. The PAR was calculated for each of the time intervals. The annual PAR was extrapolated and is based on the 11 months record.

Pollen taxa were grouped into the main vegetation types of West Java such as mangrove, lowland trees, montane trees (according to their most common source), herbs and Pteridophyta. Grouping was done according to Whitmore (1990) and Van der Kaars (2001). Pollen taxa that do not belong to the natural vegetation of West Java are summed up as "long distance component" (LDC) and were divided into two subgroups. The "northern" subgroup included pollen types typical for lower latitudes of the northern hemisphere (e.g. *Alnus, Pinus, Picea, Quercus* and *Ulmus*). The "southern" subgroup of pollen represents plants that are more characteristic for the Australian continent (i.e. *Eucalyptus* and *Casuarina*). Some of these pollen types may also originate from exotic taxa planted in West Java (e.g. *Pinus, Alnus* and *Eucalyptus*) or from locally grown taxa (e.g. *Casuarina*).

Relative pollen diagrams (Figs. 3.3 and 3.4) were prepared using TILIA software (Grimm, 1988). Local pollen zones have been established visually by comparing the temporal dynamics of the principal taxa, supported by the results of stratigraphically constrained cluster analysis by sum-of-squares using CONISS for TILIA (Grimm, 1987).

3.4. Results

In total, 21 trap samples were analyzed for pollen and spores. For each sample, the diagram shows the percentages of most common taxa (Fig. 3.3), vegetation groups, mean counts for pollen and spores, as well as the pollen accumulation rate (PAR) for 16 days (Fig. 3.4). Pollen and spore types with a minor contribution are not included in the diagram. In total, 64 pollen types and 17 Pteridophyta spore types were identified (see Appendix A). Trees and shrubs make up around 78% of pollen taxa (50 pollen types) while herbs account for the remaining 22% (14 pollen types). The PAR varies between 30 and 178 grains/cm^2/16 days or between 2 and 11 grains/cm^2/day. Average PAR is about 73.2 grains/cm^2/16 days or about 4.5 grains/cm^2/day. The extrapolated annual PAR is about 1670 grains/cm^2/yr. Based on a cluster analysis, three groups of samples could be recognized, which succeed each other in time and reflect changing monsoon conditions as displayed in Table 3.1. Description of the groups is given below.

3.4.1. Samples D1–D5 (December 14, 2001–March 4, 2002; NW monsoon period)

Mangroves are only represented by *Rhizophora* (~1%, Fig. 3.3). The amount of lowland pollen taxa is high (on average 49% of the pollen sum), with *Macaranga/Mallotus* (~18%) and *Elaeocarpus* (about 13%) being the dominant pollen types. Pollen of *Acalypha* contributes some 2%.

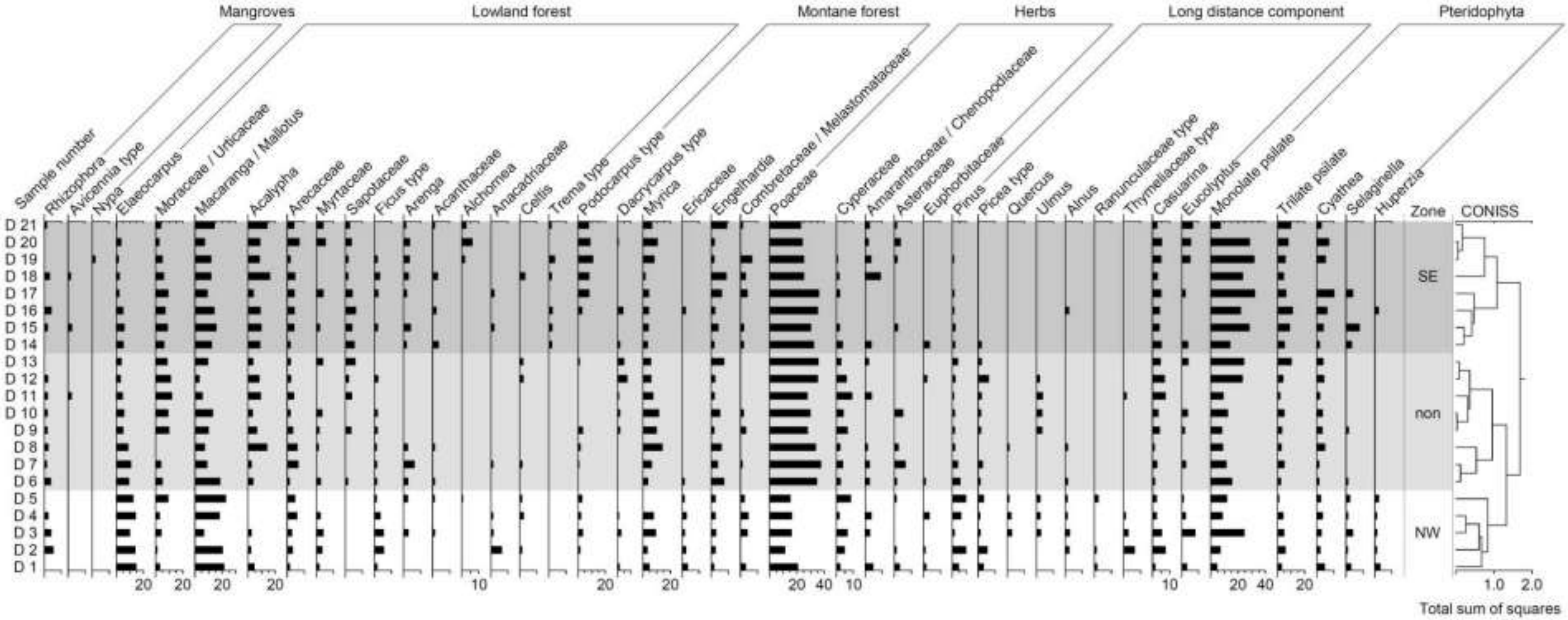

Fig. 3.3. Pollen diagram showing percentage of main pollen and spore types under changing monsoon conditions in the Indian Ocean off SW Java.

Values of Moraceae/Urticaceae slightly increase at the end of the NW monsoon (mid-February–beginning of March). Arecaceae, *Ficus* type and Myrtaceae are constantly present. Montane taxa account for approximately 10%, and are dominated by *Myrica, Podocarpus* type and *Dacrycarpus* type (Fig. 3.3). On average, herb pollen accounts for 23% and is composed of Poaceae (~16%), Cyperaceae (~5%) and Amaranthaceae/Chenopodiaceae (~2%). The long distance component (LDC) amounts to ~17% (from 10% to 24%). The contribution of "northern" pollen types varies from7% to 17% and is composed mainly of *Pinus* and the *Picea* type (~6% and ~2%, respectively) with some grains of *Alnus, Quercus, Ulmus* and Thymelaeaceae type. Pollen of Ranunculaceae type occurs only in this period. The portion of "southern" pollen types is about 3–9% with average values of *Casuarina* of about 3% and values of Eucalyptus of about 2% (Fig. 3.3). Pteridophyta spores are not very frequent in this period, around 20% (except sample D3 where ferns make up about 43%). Mean values of *Cyathea* show minimum values (~2%), while *Huperzia* spores with the same percentages have maximum values during this period. PAR is relatively low, between 45 and 98 grains/cm^2/16 days with an average of 65 grains/cm^2/16 days.

3.4.2. Samples D6–D14 (March 4–July 10, 2002, intermonsoon period)

Values of mangrove pollen remain at the same level. The pollen contribution of lowland trees decreases to about 37% (Fig. 3.4) and the composition of taxa changes. Values of *Elaeocarpus* and *Macaranga/Mallotus* decrease to ~6% and ~9%, respectively, while percentages of Moraceae/Urticaceae (~7%) and *Acalypha* (~6%) increase (Fig. 3.3). Arecaceae and Ficus type are common. Sapotaceae pollen occurs for the first time. Among the montane taxa (increase to ~13%), *Myrica* (~8%) dominates, *Engelhardia* and *Dacrycarpus* type are common and Ericaceae are absent. Herb pollen accounts for about 40%, which is more than in the previous period. LDC stays at about 9% (from 4% to 13%). The portion of "northern" pollen types amounts to ~3–7%. *Pinus, Picea* type and *Ulmus* pollen are common whereas *Alnus, Quercus* and the Thymelaeaceae type are represented by single grains. Ranunculaceae are not found. The contribution of "southern" pollen types is about 1–7% (*Casuarina* mainly). Average Pteridophyta spore values are slightly higher (~28%, Fig. 3.3) than during the NW monsoon while *Selaginella* spores decrease markedly and *Huperzia* is absent. The PAR varies between 47 and 178 grains/cm^2/16 days with an average of about 107 grains/cm^2/16 days, which is much more than in the previous period.

3.4.3. Samples D15–D21 (July 10–November 15, 2002, SE monsoon period)

Mangrove pollen remains at same low values, about 1% of the pollen sum (Fig. 3.4). The value of lowland tree pollen is around 45%. The group is composed mainly of *Macaranga/Mallotus* (~12%) and *Acalypha* (~10%) pollen (Fig. 3.3). Pollen percentages of *Elaeocarpus* (~3%) and Moraceae/Urticaceae (~6%) are lower. Arecaceae are frequent. Pollen of the *Alchornea* type occurs in the samples D19–D21 (Fig. 3.3). Values of montane taxa are about 14%. Percentages of the *Podocarpus* type strongly increase (~6%), while those of *Myrica* decrease (~5%). Percentages of almost all herb taxa decrease, except for Poaceae, which remain stable, while Amaranthaceae/Chenopodiaceae increase. The mean value for herb pollen is about 33%. LDC occurs at slightly lower amounts (from 3% to 10% with the average of about 7%), and only 5 out of 9 taxa are found. The portion of "northern" pollen types amounts to about 1% (Fig. 3.3). *Pinus* is frequent at the beginning of the period (samples D14–D17) but is not found at the end of the SE monsoon (samples D20-D21). The *Picea* type and *Alnus* are represented by single grains only. The contribution of “southern” pollen types is about 3–8%. Values of *Casuarina* pollen are ~4%, and *Eucalyptus* accounts to ~2%. Pteridophyta spores reach their maximum value of about 42%. PAR decreases to an average of 43 grains/cm^2/16 days and varies between 30 and 69 grains/cm^2/16 days.

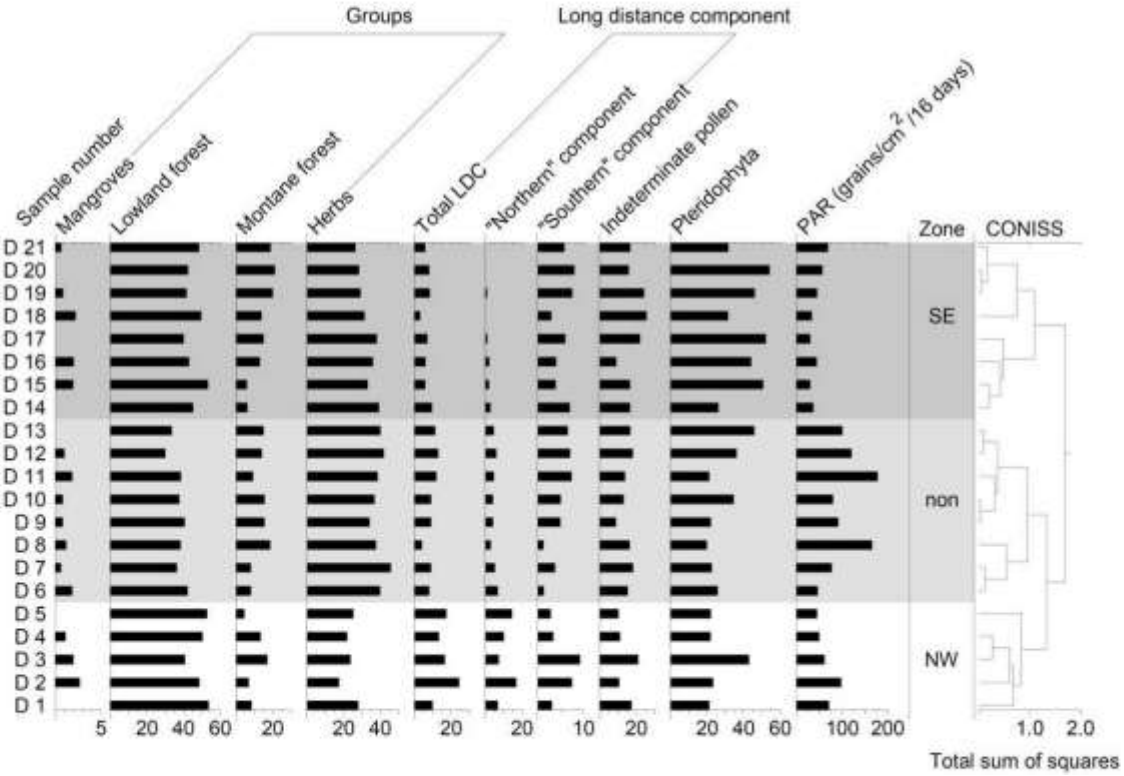

Fig. 3.4. Diagram showing pollen percentages of mangroves, lowland and montane trees, herbs, long distance component (LDC), indeterminate pollen sum as well as Pteridophyta sum and pollen accumulation rate (PAR) under changing monsoon conditions in the Indian Ocean off SW Java. The abbreviations indicate the following: NW-northwest monsoon; non (light-gray shading) - intermonsoon period; SE (dark-gray shading) - southeast monsoon.

3.5. Interpretation and discussion

3.5.1. Factors controlling pollen dispersal in the ocean

Several factors need to be considered for interpreting the pollen and spore assemblages deposited in the sediment trap off SW Java, such as the pollen source area, flowering periods, distance to the pollen producing vegetation, river discharge, wind fields, marine currents and the time for pollen and spore transportation. Throughout the whole recorded period, the pollen and spore spectra generally reflect the vegetation of SW Java well. The lowland forest is represented by pollen of *Elaeocarpus*, Moraceae/Urticaceae, Sapotaceae, Myrtaceae, *Alchornea* and others. High values of re-growth taxa (e.g. *Macaranga/Mallotus, Acalypha, Ficus* and *Trema*) point to the wide occurrence of secondary forest. Montane forest is represented by *Podocarpus, Dacrycarpus, Myrica, Engelhardia* and Ericaceae.

Relatively frequent Arecaceae pollen and *Arenga* occur in the trap samples, reflecting the imprint of palm plantations, which have increased markedly in Java during the last few decades (e.g. Whitten et al., 1996). This signal evidence for the forest disturbance as it has been shown for Rawa Danau (West Java) where land clearance and cultivation of crops from around AD 1770 ± 80 was indicated by a markedly higher abundance of *Arenga* and *Cocos nucifera* pollen and an increased charcoal to pollen ratio (Van der Kaars and van den Bergh, 2004). For Danau Padang (West Java), Stuijts (1993) referred to the marked decline in pollen of forest taxa (e.g. *Altingia, Castanopsis, Nauclea*) that occurred after ca. 2500 BP. During approximately the same time she pointed to the findings of *Arenga* pollen as a possible indicator of the sugar palm cultivation.

High values of Poaceae pollen are probably also related to land use and to the formation of open grasslands in SW Java. It is conceivable that both winds from the land to the ocean and the discharge by several rivers of SW Java (in particular, the Ciwulan, Citanduy and Serayu) contribute to pollen and spore deposition in the trap. The same assumption was made by Sun et al. (2002), who suggested that herbaceous pollen taxa may extend their distribution patterns into the Southern China Sea due to the combined effects of wind, marine currents and rivers.

In our record, mangrove vegetation is reflected mainly by *Rhizophora* pollen. The values of mangroves are low. The same was reported by van der Kaars (2001) for marine surface samples from southern Indonesia which contained less than 5% of mangrove pollen, while mangroves were represented by 2–3 times higher values (about 10 to 15%) in samples obtained close to the coast of New Guinea and to the north of Lombok, Sumbava and Flores. In marine core samples from the late Holocene, Rhizophoraceae contributes about 12 to 20% of the pollen and spore sum on the Sunda Shelf (Sun et al., 2002).

Mangrove taxa often show the highest values within their source area (Muller, 1959; Hooghiemstra et al., 1986; Sun et al., 1999) with decreasing values with distance from shore (van der Kaars, 2001; Sun et al., 2002). The low percentages of mangrove pollen in our data could be the result of the excessive destruction of the mangrove belt in Java during the last few decades. For comparison, in 1981 the area of mangroves on Java was reported to occupy about 500 km^2 (Choong et al., 1990; Sukardjo, 1990), by 2000 it had declined to about 293 km^2 (Food and Agricultural Organisation, FAO Report, 2010).

Fern spores are relatively frequent in the record and are likely linked to river discharge, as Pteridophyta grow mainly under moist conditions. Van Waveren (1989) and Dai and Weng (2011) indicate that it is hardly possible for fern spores to travel by air over long distances, as it is difficult for the wind to take them from the wet soil, while water can easily wash them out.

3.5.2. Seasonal variation in pollen fluxes and composition

3.5.2.1. NW monsoon (December 14, 2001–March 4, 2002)

Pollen from exotic plants such as *Picea, Alnus, Pinus* and *Quercus* contributes up to 17% to the total pollen assemblage and has apparently been transported over a long distance. *Picea* and *Alnus* pollen do not occur naturally south of 20° N in Asia (Muller, 1972; Whitmore, 1984). The closest regions where these trees grow naturally lie within the Malay Peninsula, Thailand, Cambodia and South China (Fig. 3.2). A few trees of *Alnus* have been cultivated in the mountainous regions of West Java as a garden ornamental or in trails by the Forestry Service (Backer and van den Brink, 1965). Only the occasional *Alnus* pollen is known from palaeoecological records in East Java (Beuning, 1996) and from higher elevated sites in West Java (Stuijts, 1993). Therefore, it can be assumed that most of the deposited *Alnus* pollen are transported over a long distance from continental Asia.

Pollen of *Pinus* can originate both from continental Asia highlands and from montane and submontane pine plantations of Sumatra and Java. Plantations of *Pinus* have existed since 1935; pine trees have been used for reforestation and wood production (Backer and van den Brink, 1965; Whitten et al., 1996). Despite the fact that pine trees are not indigenous in Java, both in studies of modern pollen rain and in lake surface sediment samples from West Java and Sumatra, pollen of *Pinus* was regularly found (Stuijts, 1993). In the marine realm they can be observed close to areas where pine trees have never been planted or grow naturally, e.g. in hemipelagic surface sediments north of Borneo, where Sun et al. (1999) reported more than 20% pine pollen of the pollen and spore sum. *Pinus* is known to be a prolific pollen producer. Additionally, its vesiculate pollen grains can easily get translocated by aeolian and fluvial transport (Heusser, 1988; Heusser and Balsam, 1977). It is therefore difficult to interpret the origin of the *Pinus* pollen in the sediment trap, but taking into account all the above mentioned points, we hypothesize that most of it was also transported over a long distance. This is supported by the fact that higher amounts of pine pollen were collected during the NW monsoon compared to the following periods when the winds from the north were almost absent.

Quercus is not indigenous in Java (Whitten et al., 1996). Pollen of the oak tree may come, in particular, from the mountains of Sumatra, where *Quercus* is native. Some pollen grains may also be transported from continental Asia, but this amount can be expected to be low as the distance between the sediment trap and its pollen source area is relatively large. *Ulmus* is considered in the literature (Backer and van den Brink, 1965) as not indigenous in Java as well. Nevertheless, the pollen of *Ulmus* was found in studies of the modern pollen rain in West Java (Stuijts, 1993) and from Sumatra (Maloney, 1985).

We assume that pollen of exotic plants is mainly transported from continental Asia by trade winds and/or to some extent by marine currents such as the Equatorial Counter Current and Southern Java Current (Fig. 3.1).

Apart from information about transport ways, comparing the occurrence of pollen of region specific plants in the traps with their flowering time can provide information about the transport duration. We found high values of *Elaeocarpus* pollen during the NW monsoon period that can be related to its flowering season (from October to December, Table 3.2). The calculated delay between the maximum tree bloom and the maximum accumulation of *Elaeocarpus* pollen in the trap suggests a transportation time of about one month.

3.5.2.2. Intermonsoon period (March 4–July 10, 2002)

During the intermonsoon period, pollen assemblages are mainly composed of regionally produced pollen. Wind masses and marine currents from NW influence the region much less at this time. This is reflected by a lower amount of pollen of the “northern” taxa such as *Alnus, Pinus* and *Picea* in the trap samples. The pollen percentage of Pinus in this period is two times lower (3%) compared to the NW monsoon season (6%) and is considered to be mostly of regional origin, probably from the highlands of SW Java. Maxima of *Myrica* pollen in April-beginning of June and maxima of *Dacrycarpus* in June-July correlate with the flowering periods of these trees in Java (Table 3.2). About 1 to 2 months delay is noticed between flowering time and pollen accumulation in the sediment trap. PAR increases in April (sample D8) and at the end of May-beginning of June (sample D11). The increased amount of fern spores at the end of June-beginning of July (sample D13) could be a consequence of the increased rainfall and associated high river discharges during the late NW monsoon season (Milliman et al., 1999; Rixen et al., 2006a, 2006b).

According to the wind regime, the intermonsoon period lasts until the end of July and the next sample (D14, July 10–26) should be included in this period, as it has been done by Mohtadi et al. (2009). However, the composition of the pollen assemblages and the results of constrained cluster analysis suggest that it belongs to the next pollen zone.

Table 3.2. Flowering periods of selected taxa in Southeast Asia and Australia.

Taxa	Flowering period	Reference
Casuarina	In Australia April - June, *Casuarina equisetifolia* February - April and September - October	Morton (1980)
Dacrycarpus	In Thailand January - May	Lemmens et al. (1995)
Elaeocarpus	2-3 times a year, often after dry season, November - January, in Malaysia August - October and March - May	Sosef et al.(1998); Boomsma(1972)
Eucalyptus	In Indonesia all months, *Eucalyptus urophylla* during the rainy season. In Australia most species March - April (often till June)	Soerianegara and Lemmens (1993)
Myrica	In Java March - May, in Sulawesi and in Australia May - June and October - November	Lemmens et al. (1995)
Podocarpus	In Java October - December	Lemmens et al. (1995)

3.5.2.3. SE monsoon (July 10–November 15, 2002)

Samples collected during the SE monsoon are relatively enriched in *Casuarina* pollen, that are on average 5% higher than in the previous period. *Casuarina* is a characteristic tree of the Australian vegetation (Beadle, 1981; Johns, 1982; van der Kaars, 1991). However, it has to be considered that one species, *Casuarina junghuhniana*, is native on Java and occurs in littoral areas and in highlands, e.g. mountain forests to the east of Mt. Lawu on the border between Central and East Java, as well as on Krakatoa (Whitmore, 1990). These sites might form additional source areas of the trapped *Casuarina* pollen. During the NW monsoon, when pollen transport from the South is almost absent, the portion of *Casuarina* pollen is about 3% on average. Therefore, we conclude that some of the trapped pollen of *Casuarina* (up to about 7%) originate from the South, in particular from northern Australia, and may be transported to the area by marine currents (e.g. the South Equatorial Current, Southern Java Current and partly by the Leeuwin Current, Fig. 3.1).

Eucalyptus has been planted on Java since 1800, especially in the mountainous areas of Central Java such as the Dieng plateau, Mount Sumbing and Mount Sundoro (Pramono and Pudjiharta, 1996), at Pasuruan (East Java) and at a number of experimental stations (Food Agricultural Organisation, FAO Report, 1979; Webb et al., 1984). Another source area for Eucalyptus pollen may be northern Australia, where this tree is very common (Specht, 1970; Pryor, 1976; Soerianegara and Lemmens, 1993). However, during the NW monsoon, when input from the south is likely to be absent, Eucalyptus accounted for up to 4% (sample D3) of the total pollen. Values of Eucalyptus pollen during the SE monsoon period are of the same rate (up to 3–4%). This suggests that only small amounts of Eucalyptus pollen are transported into the area during the SE monsoon (some 2%). Most Eucalyptus pollen during that period are considered to reflect regional production.

In Australia, the maximum flowering period for both Eucalyptus and *Casuarina* occurs from April to June (Table 3.2). The calculated delay between flowering time in Australia and the accumulation of *Casuarina* pollen in the trap suggests a transportation time of roughly 1 to 2 months. In the case of *Eucalyptus*, the assumption is difficult to make as in Indonesia it can have flowers throughout the year (Soerianegara and Lemmens, 1993). The maximum pollen percentages of *Podocarpus*, which is a characteristic tree in the mountain forest of West Java, correspond with the flowering period (Table 3.2).

3.5.3. Pollen accumulation rate in comparison to the accumulation rates of other proxies in the sediment trap studies off SW Java

The extrapolated PAR of 1670 grains/cm^2/yr for the recorded period is rather high compared to the data obtained from the eastern Indonesian marine sediment cores (van der Kaars, 1991), in which pollen and spore fluxes varied during the Holocene from1.6 grains/cm^2/yr and 2.9 spores/cm^2/yr in the Lombok Ridge core to 55 grains/cm^2/yr and 183 spores/cm2/yr in the Weber Deep core. In the Malluca Sea before the Late Glacial Maximum, pollen influx rates show comparable values, of less than 100 grains/cm^2/yr (Barmawidjaja et al., 1993). Approximately the same low pollen influx values are reported for the Sunda Shelf (Wang et al., 2007).

Other proxies from the same trap, such as diatoms, showed the highest fluxes during the SE monsoon in September 2001, during the NW monsoon in February/March 2003 and during early SE monsoon in 2003 (Romero et al., 2009). In the case of foraminifera (the sediment trap JAM1–JAM3 series including our trap JAM2), both total and species specific fluxes, as well as measured opal and organic carbon, were highest during the late SE monsoon (Rixen et al., 2006a,2006b; Mohtadi et al., 2009).

In our study, the reason for the increasing PAR during the intermonsoon period compared to the monsoon periods is yet unclear, but may be a late consequence of the increased rainfall and the high discharge of the associated rivers during the late NW monsoon season (February–April). It might also be related to the rainout of the wind transported component. The latter scenario is however more unlikely as it would induce an increase in “northern” pollen concentrations in the association which we do not observe. Another reason for the increased PAR during the intermonsoon period might be related to the generally high local pollen input from Java and the absence of monsoon influence, transporting low concentrations of pollen from the long distance to the trap and blowing/washing away the high concentrations of regionally produced pollen.

3.6. Conclusions

Marine sediment trap samples, collected from December 2001–November 2002 (at 16 days intervals), at a water-depth of about 2200 m, 60 km off SW Java in the Indian Ocean in Indonesia, have been investigated for pollen abundance and composition. We draw the following conclusions:

(1) Accumulated pollen and spores reflect the present-day vegetation of SW Java well. Both fluvial and aeolian fluxes, as well as transport by ocean currents, play a role in transportation of pollen and spores to the trap site.
(2) The abundance of pioneer taxa pollen, such as *Macaranga/Mallotus, Acalypha, Ficus* and *Trema,* as well as high values of Poaceae, indicates the occurrence of secondary forest and isrelated to the intensification of land use.

(3) Mangroves are represented by only a few pollen grains. We assume that this is a result of the widespread destruction of the mangrove belt on Java during the last decades.

(4) During the NW monsoon (mid-December–beginning of March) the pollen assemblages are strongly influenced by transport of pollen from continental Asia and Sumatra, whereas pollen from northern Australia arrives at the trap site during the SE monsoon (end of July–November).

(5) Pollen assemblages collected during the intermonsoon period (beginning of March–end of July) originate mainly from SW Java.

(6) Long distance transport plays a marked role for pollen accumulation during the monsoon seasons (10–24% during NW monsoon and 3–10% during the SE monsoon).

(7) The pollen record suggests that maxima of *Elaeocarpus, Myrica, Dacrycarpus, Casuarina* and *Podocarpus* in the sediment trap may be related to their flowering periods. In the case of *Elaeocarpus*, a one month difference between flowering time and pollen accumulation in the sediment trap has been recorded. For *Myrica, Dacrycarpus* and *Casuarina* the offset time is about 1–2 months.

(8) Pollen and spore accumulation rates increase during the intermonsoon period compared to the monsoon periods. The reason might be related to a stronger input of pollen from SW Java as a late consequence of the increased rainfall and associated high river discharges at the end of the NW monsoon season (February-April) and\or to the absence of the monsoon influence blowing/washing the local pollen away.

3.7. Acknowledgments

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Appendix A. List of identified pollen and spore types from marinesediment trap JAM2

Mangrove	*Avicennia*
	Nypa
	Rhizophora
Lowland trees	*Acalypha*
	Acanthaceae
	Alchornea
	Anacardiaceae
	Arecaceae
	Arenga
	Bignoniaceae type
	Caryota type
	Celtis
	Clethra
	Cunoniaceae
	Elaeocarpus
	Euphorbiaceae
	Ficus type
	Lamiaceae
	Loranthaceae
	Macaranga / Mallotus
	Mimosaceae
	Moraceae / Urticaceae
	Myrtaceae
	Oleaceae
	Oleaceae 4-porate
	Oncosperma
	Pometia
	Rosaceae type
	Rubiaceae
	Rutaceae type
	Sapindaceae / Meliaceae
	Sapotaceae
	Trema type
Montane trees	*Allophylus*
	Combretaceae / Melastomataceae
	Dacrycarpus type
	Engelhardia
	Ericaceae
	Ilex
	Lithocarpus / Castanopsis
	Myrica
	Myrsinaceae
	Podocarpus type
Herbs	Amaranthaceae / Chenopodiaceae
	Asteraceae
	Caryophyllaceae
	Cichorium

	Cucurbitaceae type
	Cyperaceae
	Iridaceae / Liliaceae
	Malvaceae
	Oryza type
	Plantago
	Poaceae
	Zea mais type
Long distance component (northern subgroup)	*Alnus*
	Picea type
	Pinus
	Quercus
	Ranunculaceae type
	Thymeliaceae type
	Ulmus
Long distance component (southern subgroup)	*Casuarina*
	Eucalyptus
Pteridophyta	*Cyathea*
	Davallia type
	Huperzia type
	Lycopodium
	Ophioglossum type
	Osmunda type
	Selaginella
	Polypodiaceae monolete baculate type
	Polypodiaceae monolete echinate type
	Polypodiaceae monolete psilate type
	Polypodiaceae monolete reticulate type
	Polypodiaceae monolete verrucate type
	Polypodiaceae trilete echinate type
	Polypodiaceae trilete reticulate type
	Polypodiaceae trilete psilate type
	Polypodiaceae trilete scabrate type
	Polypodiaceae trilete verrucate type

Appendix B. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.marmicro.2014.06.006. These data include Google maps of the most important areas described in this article.

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CHAPTER 4

Marine environment, vegetation, and land use changes related to the human impact during the late Holocene in South Kalimantan and East Java based on pollen and dinoflagellate cysts

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Abstract

The pollen, spore and organic walled dinoflagellete cyst associations of two marine sediment cores from the Java Sea off the mouths of Jelai River (S Kalimantan) and Solo River (E Java) reflect environment and vegetation changes for the last ca 3500 years. A decline in primary forest taxa (e.g. *Agathis*, *Allophylus, Dacrycarpus, Dacrydium,* Dipterocarpaceae*, Phyllocladus* and *Podocarpus*) suggest that the major change in vegetation is caused by forest canopy disturbance possibly as a consequence of human activity. The successive increase in pollen of pioneer tress/shrubs and herb taxa (e.g. *Acalypha, Ficus, Macaranga/Mallotus, Trema, Pandanus*) indicate the development of secondary vegetation. In Java these changes started much earlier (ca at 2950 cal yr BP) than in Kalimantan (ca at 910 cal yr BP) and seem to be more severe. Changes in the marine realm, reflected by the dinoflagellate cyst association, correspond to the changes in vegetation on land. They reflect a gradual change from relatively well ventilated to more hypoxic bottom/pore water conditions in a more eutrophic environment. Near the coast of Java, the shift of the water trophic status took place between ca 820 and 500 cal yr BP, while near the coast of Kalimantan it occurred as late as at the beginning of the 20th century. We observe an increasing amount of the cysts of *Polykrikos schwartzii*, *P. kofoidii, Lingulodinium machaerophorum, Nematosphaeropsis labyrinthus* and *Selenopemphix nephroides* at times of secondary vegetation development on land, suggesting that human induced terrestrial changes possibly affected the marine environment as well, most likely through increased eutrophication and pollution.

4.1. Introduction

The concern about the effects of human activities on environment and climate has increased considerably during the last decades. It is essential to know to what extent environments are affected not only by human activity, but also by natural e.g. climatic and ecosystem’s variability. Such information can be achieved by studying natural archives that cover time intervals previous to and during major anthropogenic influences. Marine sediment archives from high deposition areas have the potential to provide this information as they contain continuous sequences with high temporal resolution. Pollen and spores are valuable proxies for reconstructing vegetation change on the continent because of their good preservation, abundant presence in most terrestrial and marine sediments (Dupont, 1999; Anshari et al., 2001; Donders et al., 2005; Willard et al., 2007). Their content in marine sediments can reflect both natural and anthropogenic induced vegetation changes as well variations in runoff rates (Donders et al., 2008). The sedimentary charcoal content can be used to provide information about the fire history of an area or region (Higuera et al., 2010). The fire-ecology can be studied when this is compared to palynological based vegetation reconstructions (e.g. Colombaroli et al., 2007, Conedera et al., 2009, Daniau et al., 2010, Kaltenrieder et al., 2010).

Associations of organic walled dinoflagellate cysts (dinocysts) reflect changes in upper water conditions in detail. Therefore they are suitable to reconstruct marine environmental conditions such as sea surface temperature (SST), sea surface salinity (SSS) trophic state and the redox state of bottom/sediment-pore water environments (e.g. De Vernal et al., 1997; Marret et al., 2001; Dale et al., 2002; Sangiorgi et al., 2002; Zonneveld, 2003; Pospelova et al., 2006; Van der Meer et al., 2008; Chen et al., 2011). Furthermore, they are very useful to distinguish anthropogenic disturbances in marine ecosystems (e.g. Pospelova et al., 2002, Shin et al., 2010, Zonneveld et al., 2012).

Tropical regions are very sensitive to climate fluctuations and to spatial gradients in SST. Minor changes in the sea level or in SST may largely modify tropical climate (Chiang and Koutavas, 2004). This has a direct effect on the vegetation on the continent. Apart from natural factors influencing vegetation composition, the forest ecosystems in Indonesia have experienced a long history of the anthropogenic impact which is increasing annually (FAO, 2010; 2012).

Nowadays a large amount of information is available from late Holocene terrestrial deposits on Java (Semah, 1982, 1984, 2004; Stuijts, 1984, 1993; Stuijts et al., 1988; Grindrod et al., 2002) and Kalimantan (e.g. Anderson and Muller, 1975; Morley, 1981; Caratini and Tissot, 1988; Anshari et al., 2001; Gusti et al., 2001; Weiss, 2002; Anshari et al., 2004; Yulianto et al., 2005) as well as in the southern Indonesia (e.g. Dubois et al., 2014). A number of publications on the late Holocene marine environment are available from the Banda Sea (Van der Kaars, 1991, 1997; Van der Kaars et al., 2000; Ahmad et al., 1995; Van der Kaars, 2000; Van Waveren, 1989; Spooner et al., 2005), Celebes Sea (van der Kaars, 1991), Sulu Sea (Beaufort et al., 2003), Molucca Sea (Barmawidjaja et al., 1993), Mahakam Delta, Kalimantan (Caratini and Tissot, 1988), the Makassar Strait (Yulianto, 2004; Visser et al., 2004), for the western (e.g. Kuhnert et al., 2014; Niedermeyer et al., 2014) and eastern Indian Ocean (Wang, et al., 1999, Baumgart et al., 2010; Mohtadi et al., 2010, 2011; Hessler at al., 2013; Chen et al., 2014) and off Sumatra (van der Kaars et al., 2010, 2012). Information of the Java Sea is almost missing (Emery, 1972; Boely et al., 1991; Suryantini et al., 2011) and palynological studies from the Java Sea are absent. Little attention is paid to the relationship between sea and land, although they are crucial for such areas with monsoon climate as in Indonesia . With this paper, we would like to contribute in filling this gap. We use marine palynology to obtain better understanding of the relations between climatic vs. the human activity related changes on land and in the marine realm during the last 3500 years. To obtain insight into the relationship between natural and anthropogenic processes affecting both the marine and terrestrial environment, we establish detailed reconstructions of environmental changes that contemporaneously took place on the continent as well as in the adjacent marine environment. This is achieved by comparing information data inferred from pollen/spore and dinocyst associations in marine sediments off S Kalimantan and E Java.

4.2. Regional settings

The Java Sea is a large (310,000 km^2) shallow sea (in general between 40 - 100 m water depth) on the Sunda Shelf which lies between the islands of Kalimantan (Borneo) to the north, Java to the south; Sumatra to the west and Sulawesi to the east (Fig.4.1). In the west it is in open to the Indian Ocean, the Andaman Sea and S China Sea by the Sunda Strait, the Malacca Strait and the Karimata Strait, respectively. In the east it has an open connection to the Flores Sea and to the Celebes Sea through the Makassar Strait (Durand and Petit, 1995; Genia et al., 2007).

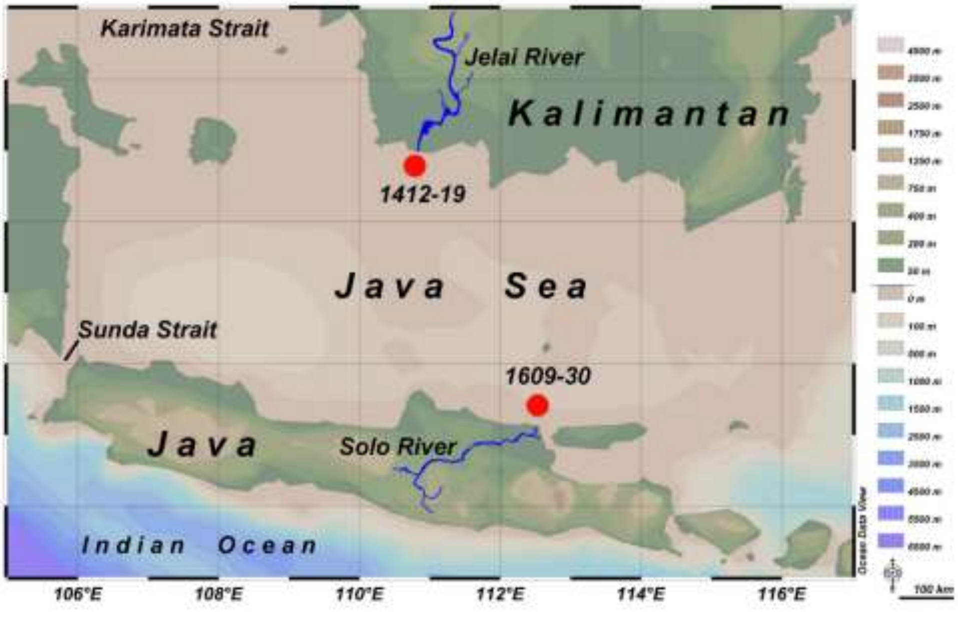

Fig.4.1. Schematic map of the study area. Position of cores 1412-19 and 1609-30 is shown with red circles. The map has been created using the Ocean Data View software (Schlitzer, 2014).

4.2.1. Modern climate

The region has a typical monsoon climate marked by a reversal of the wind regimes (Fig. 4.2) (Durand and Petit, 1995). During the Northwest (NW) monsoon (December to February; Fig. 4.2, left picture) strong western winds bring frequently heavy rainfall (precipitation of up to 300 mm/month; Writky, 1961). During the Southeast (SE) monsoon (June to August; Fig. 4.2, right picture) the winds are reversed and blow from east to west, resulting in drier weather conditions (precipitation can be as little as 50 mm/month; Durand and Petit, 1995). The average annual rate of precipitation is about 1880 mm. During the transitional months precipitation rates increase (decrease) gradually. Usually during the NW monsoon the highest temperatures are found in the eastern part of the sea (e.g. Durand and Petit, 1995) and the lowest ones in the west part of the region along the coasts of Sumatra. During the SE monsoon this gradient is reversed and highest temperatures are then found in the west (Potier et al., 1989; Genia et al., 2007). The rate of precipitation is strongly connected to the climate anomaly known as ENSO (El Niňo Southern Oscillation), with its two extreme phases, El Niňo and La Niňa, reflecting decreases and increases in precipitation rates over Indonesia (Ropelewski and Halpert, 1987; Aldrian and Susanto, 2006).

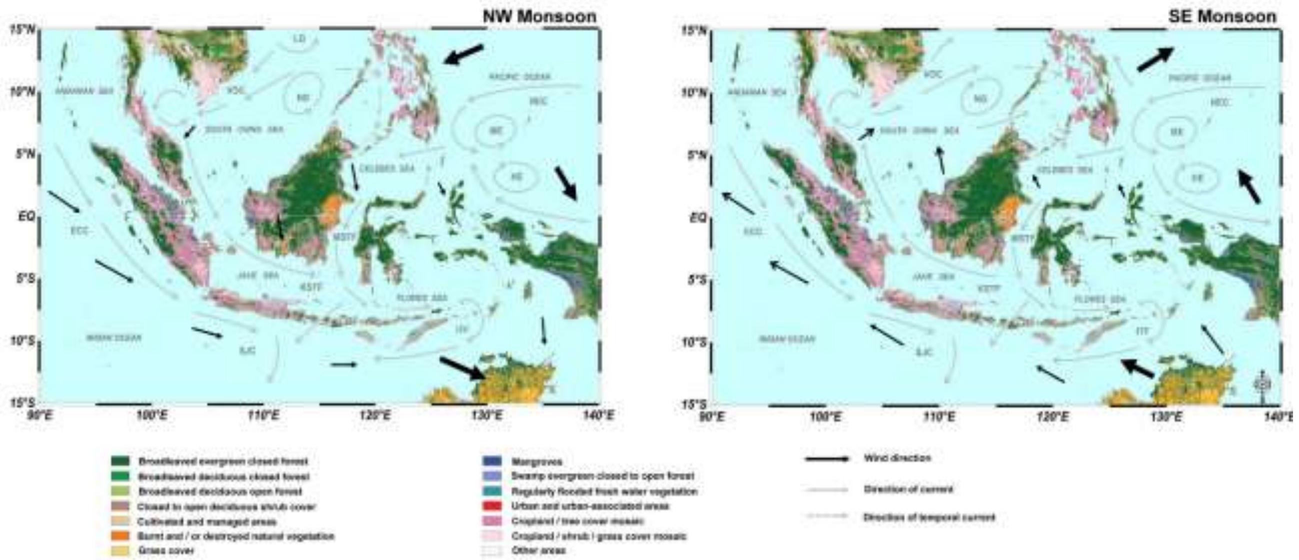

Fig.4.2.Main types of modern vegetation in Indonesia (after Stibig, et al., 2002), principal oceanic currents and winds in the source area during the NW (left picture) and SE monsoon (right picture) with the position of the sediment cores 1412-19 and 1609-30 (red dots). Patterns of winds are drawn following Black (2002) and P. Wang. et al. (2000, 2005); directions of currents are modified after Schott and McCreary (2001), Zheng et al. (2006), Andruleit (2007), Fang et al. (2009). The abbreviations stand for the following: ITF, Indonesian Throughflow; ECC, Equatorial Counter Current; KSTF, Karimata Strait Throughflow; LG, Luzon Gyre; MSTF, Makassar Strait Throughflow; NG, Nansha Gyre; VOC, Vietnam Offshore Current.

4.2.2. System of marine currents

As a result of the shallowness of the basin, the water column of the Java Sea is well mixed. The main driving force of the water current direction is the prevailing wind (Writky, 1961). During the time period covering the NW monsoon (Fig. 4.2) the main currents have an eastern direction. Waters of the Java Sea are appended by the Karimata Strait Throughflow (KSTF) which has its origin in the S China Sea. In the most eastern part of the Java Sea, additional inflow comes from the north by the Makassar Strait Throughflow (MTSF). These waters mix with the KMST and leave the basin through the Flores Sea. During the period of SE monsoon (May-September) its direction changes and waters flow in the western direction (Fig. 4.2). Waters of the Java Sea are then formed by MTSF waters which leave the Sea through the Karimata Strait. During the intermediate months (April and October), the current direction changes and numerous eddies are formed. In these months the currents off the coast of Java generally flow in easterly direction, whereas at the same time a western current is present off the coast of Kalimantan (Genia et al., 2007). The Indonesian Throughflow (ITF) flows through the Lombok Strait and neutralizes lower sea surface temperatures off Java during the upwelling season (Romero et al., 2009).

4.2.3. Vegetation

The vegetation of Java and Kalimantan is represented by mangrove, lowland rainforests, including peat swamp and freshwater swamp forests, submontane (1000 - 1500 m), lower montane (1500 - 2400 m) and upper montane (2400 - 3000 m) forest (Fig. 4.2) (Backer and van den Brink, 1965; Van Steens, 1984; Whitten et al., 1996; Burbidge, 1960; Collins et al., 1991; MacKinnon et al., 1997). Mangroves are composed mainly of *Avicennia* (Acanthaceae), *Nypa* (Arecaceae), Rhizophoraceae and Sonneratiaceae. Lowland vegetation is represented by a high-stemmed mesophyll forest with closed canopy and incredible floristic diversity with *Alchornea* (Euphorbiaceae), *Elaeocarpus* (Elaeocarpaceae), Moraceae and Urticaceae (Backer and van den Brink, 1965; Van Steenis, 1984). At the forest edges and in canopy openings light-demanding *Acalypha* (Euphorbiaceae), *Ficus* (Moraceae), *Macaranga, Mallotus* (Euphorbiaceae), *Trema* (Cannabaceae), *Pandanus* (Pandanaceae) and other pioneer taxa can be found (Van Steens, 1984; Whitmore, 1984). Submontane forest is dominated by Fagaceae: *Castanopsis, Lithocarpus* and *Quercus* with some Myrtaceae and *Myrica* (Myricaceae). Montane forest is characterised by relatively strong vertical zonation and represented by *Engelhardia* (Juglandaceae), Podocarpaceae (*Dacrycarpus*, *Podocarpus*), Ericaceae, *Myrica* (Myricaceae), Myrinaceae and *Weinmannia* (Cunoniaceae) (Van Steenis, 1984; Kaars and Dam, 1995).

Most of Kalimantan is still covered by species-rich closed-canopy forests with high endemism and very high productivity (e.g. Ashton, 1982). The natural forests in the lowlands of Kalimantan are grouped by MacKinnon et al. (1997) mixed *Dipterocarpus* forest, semi-evergreen rainforest, moist deciduous and dry deciduous forests. The differences are mostly related to the seasonality of rainfall. The peat swamp vegetation association is generally similar to lowland dipterocarp forest, which has a bit lower plant diversity (Barber et al., 2002). These forests are dominated by *Gonystylus* (Thymelaeaceae), *Dactylocladus* (Crypteroniaceae), *Shorea* (Dipterocarpaceae), diverse Anacardiaceae, Euphorbiaceae and *Engelhardia* with some *Ilex* and opportunistic taxa like *Trema, Terminalia* (Combretaceae), *Pandanus* (Pandanaceae) (MacKinnon et al. (1997). There are also small areas of extrazonal forests on limestone and some communities in littoral areas, where *Casuarina* (Casuarinaceae) occurs (Whitmore, 1990). Extensive mangroves occur along the coasts lines, in deltas of big rivers and estuaries (Collins et al., 1991; MacKinnon et al., 1997).

Unlike in Kalimantan, the original vegetation of Java has been strongly changed by human activity during the last few hundred years. Only a few remote spots and tops of mountains still bear the original vegetation on Java (Stuijts, 1993); small areas of secondary forests occur in the lowlands (Whitten et al., 1996). Periodical droughts and connected with them fires together with excessive logging, agriculture (e.g. rice and maize cultivation, oil palm plantations) and aquaculture cause a problem of deforestation. The area covered by mangroves on Java has been strongly reduced as well.

4.3. Material and methods

This study is based on the analysis of two sediment cores obtained from the Java Sea. Core 1412-19 (3.258° S; 110.649833° E, water depth 9.7 m; length 91.5 cm) has been retrieved about 25 km off the distal end of the Jelai River plume (S coast of Kalimantan, Fig. 4.1). The length of the river is ca 100 km and the drainage area is about 300 km^2 (http://wetlands.or.id/). Sediments of the core consist of homogeneous pale-brown clayish silt with numerous black particles. By visual observation no clear stratification or lamination can be observed. The sample resolution in the upper 30 cm and lower 11 cm of the core is one sample per every 2 cm. In the intermediate part (30-80 cm) it is one sample per every 5 cm.

The core 1609-30 (6.497147° S; 112.475369° E, water depth 56.3 m; length 96 cm) has been collected about 50 km off the Solo River mouth (E coast of Java, Fig. 4.1). The length of the river is ca 600 km and the drainage area is 15,400 km^2 (Whitten, 1996). The core consists of dark grey to pale-grey silt sediments containing fragments of shells and coarse siliceous material. The lower part between 70 and 96 cm of the core is more compact than the upper part. Sampling resolution is one sample per every 5 cm along the core. The upper 20 cm and the lower 5 cm where sampled every 1 cm.

4.3.1. Age control

The age control for both investigated sediment cores is based on accelerator mass spectrometry (AMS) radiocarbon dating that has been conducted at the Keck Carbon Cycle Accelerator Mass Spectrometry Facility at the University of California in Irvine, USA. The results have been corrected for isotopic fractionation with δ^{13}C values according to the method described by Stuiver and Polach (1977) and calibrated to calendar years with the online version of CALIB 7, marine 13 (Stuiver and Reimer, 1993) considering a reservoir age of 90 yr (Southon et al., 2002). Only the two youngest ages in core 1412-19, being outside the range of the CALIB 7 calibration, have been calibrated using the CALPAL2007-Hulu calibration (Weninger et al., 2007). For each core five radiocarbon dates obtained from bivalve shells or from mixed benthic foraminifera are available (Table 4.1). The ages of the record are discussed in this work as time-windows in order to minimize the error due to the uncertainty of the age-depth model.

Table 4.1. Radiocarbon dates obtained from the two sediment cores 1412-19 and 1609-30 retrieved from the Java Sea. * The shell dated is considered to be reworked and, therefore, the date was omitted.

Core	Depth, cm	UCIAMS lab no.	14C age, yr BP	± error	calendar age, cal yr BP (P=1950)	2σ range, -95%	dated material
1412-19	0-1	145981	515	25	-23	-23	bivalve shell
1412-19	16-17	123477	530	20	-18	-18	bivalve shell
1412-19	41-42	145980	730	25	288	172-411	bivalve shell
1412-19	71-72*	145982	1890	25	1344	1260-1470	bivalve shell
1412-19	79-80	123478	1520	20	979	888 -1098	bivalve shell
1609-30	1-2	133823	790	20	351	266-444	bivalve shell
1609-30	7-8	123491	1365	20	821	717-916	benthic foraminifera
1609-30	41-42	133824	2120	20	1598	1484-1721	benthic foraminifera
1609-30	77-78	133825	2815	25	2436	2315-2613	benthic foraminifera
1609-30	90-91	123492	3500	20	3279	3153-3388	benthic foraminifera

4.3.2. Pollen and dinocyst analysis

For pollen, spore and dinoflagellate cyst analysis 3 g of dry sediment was taken. Samples were prepared following the standard palynological technique as is described by Faegri and Iversen (1975) and Zonneveld et al. (2009). Cold hydrochloric acid (HCl 10%) was added for the removal of carbonate in amounts depending on the intensity of the reaction. Siliceous component of the samples was removed by adding of hydrofluoric acid (HF 72%). To remove all macro-remains, sieving at 150 µm sieve was applied. To remove small organic particles the samples were sieved over a 10 µm nylon filter. In order to avoid damage to the dinocysts, no acetolysis and other oxidation treatments were applied. The samples were mounted in glycerine gelatine and examined under the light microscope at a magnification of 400 and 1000 times.

Per sample, 200 pollen grains and 100 dinocysts were counted. Relative abundances of taxa were calculated on the basis of the total sum of pollen grains and sum of dinocysts respectively, excluding indeterminable grains/cysts, fern spores, and green algae. To determine pollen/spores/dinocyst concentration (in grains/spores/cells per ml) one *Lycopodium clavatum* tablet (Stockmarr, 1971) with known number of spores (20,848 ± 1546) was added to each sample before processing. All identified pollen and cyst types were photographed with a digital camera. Photos of identified pollen and spores are available on request at the Department of Palynology and Climate Dynamics (University of Göttingen, Germany).

4.3.3. Pollen taxonomy and groups

Taxonomy of pollen and spores is based on Moore and Webb (1978), Wang et al. (1995), Kodela (2006), Fujiki et al. (2005), Stevenson (1998) and Mao et al., (2012), online database "The Australasian Pollen and Spore Atlas" (Weng et al., 2007) as well as on our own pollen reference collection including about 300 Indonesian taxa. Determination of large Poaceae (i.e. *Oryza* and *Zea mays*) was based on Chaturvedi et al. (1998), Maloney (1990), Tweddle et al. (2005) and Atahan et al. (2008).

Pollen taxa are divided into 6 groups according to the main vegetation types of Java and Kalimantan, i.e. mangrove, lowland rainforest, submontane and montane forest. Additionally, sums of herbaceous taxa and sum of Pteridophyta was calculated.

4.3.4. Dinoflagellate cyst taxonomy and groups

Dinocysts were identified based on Matsuoka (2009), Fensome et al. (1993), Zonneveld (1997), Zonneveld et al. (2013), Zonneveld and Pospelova (2015, Fensome and Williams (2004), Kawamura (2004). *Echinidinium* spp. includes all spiny brown cysts that could not be identified on species level. *Brigantedinium* spp. includes all smooth-walled spherical brown cysts (RBC).

Dinoflagellate cysts are grouped according to their ecological characteristics based on the global geographic distribution (Marret and Zonneveld, 2013). The post-depositional degradation of dinoflagellate cysts is estimated using the dinoflagellate degradation index "kt" according to Versteegh and Zonneveld (2002) and Liang et al. (2011). Separation between phototrophic (PT), heterotrophic (HT), oxidation-sensitive (OST) and oxidation resistant (ORT) dinocyst types is based on Zonneveld et al., 2008 and Mertens et al. (2009). Identification of tropical (TT), temperature tolerant (TTT), fully marine (FMT) and low salinity tolerant (LST) dinocyst types is based on Zonneveld et al. (2013).

4.3.5. Pollen and dinocyst diagrams

The percentages diagrams for pollen and spores are based on the total pollen sum which includes all pollen types and excludes indeterminate pollen and fern spores. Relative abundances of ferns are calculated on the base of total pollen sum. The percentage diagrams for dinocysts are based on the total sum of all identified cysts. Pollen, spore and dinocyst types contributing less than 2% on average are not included into the diagrams. The whole lists of pollen/spore and dinocyst types as well as raw counts are available under the name of the corresponding author at the PANGAEA server (www.pangaea.de). Pollen and dinocyst diagrams (Figs. 4.4-4.6) were prepared using TILIA and TILIAGRAPH software (Grimm, 1990). The diagrams are subdivided into local zones, which were established visually by comparing dynamics of the principal taxa and groups, supported by the results of the depth-constrained cluster analysis by sum-of-squares implemented with CONISS for TILIA (Grimm, 1987).

4.3.6. Microchacoal analysis

For microcharcoal analysis all black and completely opaque with sharp edges and a size 10-150 µm were counted. The total of at least 200 items was counted per unit of volume, as it was recommended by Finsinger and Tinner (2005). Microcharcoal concentrations were plotted against depth and accompany the pollen diagrams of the respective marine core.

4.3.7. Multivariate data analysis

To study the ecological structure of the datasets of both pollen and dinocysts, two multivariate ordination analyses based on relative abundance of pollen and dinocysts have been carried out, using the CANOCO 5 and CanoDraw software package (ter Braak and Šmilauer, 1997; Lepš and Šmilauer, 2003, Šmilauer and Lepš, 2014). After a detrended correspondence analysis (DCA; Hill and Gauch, 1980) which had revealed a gradient length of 1.3 (core 1412-19) and 2.0 (core 1609-30) for the first axis, principle component analysis (PCA) was applied as recommended by Lepš and Šmilauer (2003) for data sets with short environmental gradients. All taxonomic data were standardized and logarithmic transformed.

To obtain insight into the similarity/dissimilarity of the pollen and dinocyst datasets and to estimate how well the two datasets match to each other in terms of compositional gradients, Procrustes analysis (PA, Jackson, 1995) has been applied using the CANOCO 5 software package (Gower, 1975; Peres-Neto and Jackson, 2001; Šmilauer and Lepš, 2014). The similar ordination methods for both data-sets were used to overcome the problem that differences detected by PA may result from using different ordination methods. The PA errors reflecting the difference in sample ordination scores are depicted with arrows. The length of the arrows indicate the magnitude of similarity between paired ordination diagrams, i.e. sample scores of the pollen and dinocyst analyses with short arrows suggesting high similarity between the outcome of both PCA and long arrows suggesting low similarity.

4.4. Results

4.4.1. Cores stratigraphy

The age models for both cores are based on five radiocarbon dates each (Table 4.1). For core 1412-19 the uppermost three dates show a coherent sequence of increasing age with depth. However, the two ages obtained further downcore (71-72 cm and 79-80 cm, respectively) are reversed. Both ages are obtained on single bivalve shells. However, as reworking can put older material in a younger sequence but not *vice versa*, we consider the shell dated taken from 71-72 cm core depth to be reworked and, thus, omitted it from the further interpretation. The age difference of eight years between the two uppermost dates (0-1 cm and 16-17 cm core depth) places this entire uppermost section of the core into the late 20th century. Consequently, the final age model for this core is based on the three dates in 16-17 cm, 41-42 cm and 79-80 cm core depth giving it a stratigraphic range covering the last ~1200 yr with sedimentation rates varying between 5 to 8 cm

Table 4.2. Core 1412-19: Results of pollen, dinocyst and microcharcoal analysis.

Palynological zone, age (cal yr BP), core depth (cm)	**Pollen zone characteristics**	**Dinocyst zone, age (cal yr BP), core depth (cm)**	**Dinocyst zone characteristics**	**Micro-charcoal concentrations, ~particles/g**
KP-1, 1200 – 910, 91-75	Mangrove pollen form about 34% of the total pollen sum with ~29% of *Rhizophora* and ~4% of *Avicennia*. Lowland rainforest (up to 29%) is the most diverse group (17 pollen types) and is dominated by pollen of *Macaranga/Mallotus* (~11%), *Acalypha* (~7%), Moraceae/Urticaceae (~4%). Dipterocarpaceae form up to 5%) which is their max. Submontane forest contributes ~18%; it is represented by 11 taxa and strongly dominated by *Lithocarpus/Castanopsis* (~11%). Montane taxa add ~5% being represented mainly by *Podocarpus* and *Dacrycarpus* (about 4% together). Herbs are ~14% with Poaceae (~9%) contributing the most. The values of Pteridophyta are ~39%.Pollen concentration is about 1053 grains/g; spore concentration is about 893 spores/g.	KD-1, 1200-980, 91-80	Almost equal contribution of PT (~45% of total dinocyst sum) and HT (~55%). Low values of RBC (~25%), very low values of *Lingulodinium machaerophorum* (~1.5%) and *Nematosphaeropsis labyrinthus* (~1.3%). The group of PT is mainly represented by *Operculodinium israelianum* (~9%), *Spiniferites* spp. (~8%), *Spiniferites ramosus* (~6%) and *Spiniferites mirabilis* (~6%). Among HT spiny brown cysts, *Echinidinium granulatum* (~9%), *Echinidinium delicatum* (~7%) and *Echinidinium zonneveldiae* (~6%) are the most abundant. Relative abundance of cysts of *Polykrikos kofoidii* is about 4%. Contribution of TT is about 23%, while TTT form up to 15%. Percentages of FMT are about 30% and percentages of LST ~9%. OST (~55%) dominate over ORT (~3%). Average dinocyst concentration is ~1030 cysts/g.	78
KP-2, 910 – -20, 75-15	Average values of mangrove declined to about 21%. Lowland rainforest taxa increase both their sum (~38%) and diversity (28 taxa). Values of *Macaranga/Mallotus* increase from about 14% at the beginning of the zone (75-60 cm) to ~31% at the end (20-15 cm). Percentages of Moraceae/Urticaceae stay at about 3%. Submontane forest contributes ~24% and is still dominated by *Lithocarpus/Castanopsis* (~16%). *Engelhardia* is represented by single grains at the beginning of zone and increase its values up to 10% at the end. Montane taxa reduce their values from ~5% (75-55 cm) to 2% (25-15 cm). Percentages of herbs are ~12%. From about 30-25 cm Caryophyllaceae and Asteraceae are constantly present. At the depth of 16 cm first grain of *Oryza* type is found. Pteridophyta form around 58%. Pollen concentration is about 1150 grains/g, spore concentration is about 670 spores/g. Zone KP-2 has been divided into two subzones. Subzone KP-2a (50-15 cm) is clearly separated from subzone KP-2b (75-50 cm) by the decrease of Dipterocarpaceae, *Agathis*, *Allophyllus* and *Dacrycarpus* pollen, by more frequent findings of Quercus and by increasing values of *Acalypha* (up to ~7%) and *Trema* (up to ~4%).	KD-2, 980 – 10, 80-20	Between zones KD-1 and KD-2 a characteristic decrease in PT (~34%) occurs. By contrast, values of *Brigantedinium spp*. reached their highest amount (~50%). *Lingulodinium machaerophorum* with reduced processes and *Votadinium calvum* are registered. The group of PT is dominated by *Spiniferites* spp. (~6%) with some contribution of *S. ramosus* and *S. pachydermus* (both ~5%). Values of *Operculodinium israelianum* decreased to ~4%, values of *O. centrocarpum* fluctuate between 1% and 3%. Percentages of *L. machaerophorum* are about 3%, while concentrations of *Nematosphaeropsis labyrinthus* are similar compared to the previous zone. Contribution of HT is about 66%. Percentages of all *Echinidinium* species decrease markedly. Relative abundances of cysts of *Polykrikos kofoidii* are a bit higher than in the previous zone (~5%). Values of TT are about 15%; TT contribute ~8%. Percentages of FMT are about ~18%. Rate of OST increased up to ~66%, while the rate of ORT stays about the same (~3%). Dinocyst concentration is about 1170 cysts/g.	240
KP-3, -20 – -23, 15-0	The values of mangrove decrease to about 10% with up to ~9% of *Rhizophora*. Lowland rainforest taxa remains the highest contributing (~55%) and most diverse group (21 pollen types) dominated by *Macaranga/Mallotus* (~30%). *Acalypha* forms ~10% and Moraceae/Urticaceae ~6%. *Trema* reaches its max. (~5%). Submontane forest is dominated by *Engelhardia* (~7%). Herbs are at their maximum (~19%) and composed by 11 taxa with Poaceae making up to 12%. Single grains of *Oryza* type, *Zea mays* and *Pinus* are found. Montane taxa contribute ~3% only. The values of Pteridophyta have their lowest rate (~46%).Pollen concentration is about 1230 grains/g; spore concentration is ~560 spores/g.	KD-3, 10 – -23, 20-0	High percentages of *Lingulodinium machaerophorum* (~8%), *Nematosphaeropsis labyrinthus* (~5%), cysts of *Polykrikos kofoidii* (~4%) and increased relative abundances of *Selenopemphix nephroides* (~4%) and cysts of *Polykrikos schwartztii* (~2%). Cysts of the *Impagidinium* group occur regularly in this zone unlike in the two previous zones. Rates of PT and HT are almost equal (both about 50%). PT are mainly represented by *Spiniferites* spp. (~9%) and *Operculodinium israelianum* (~7%). Among HT, *Brigantedinium* spp. contributing ~28% and *Echinidinium transparantum* makes up ~6%. TT and TTT contribute ~19% and 10%, respectively. Percentages of FMT are about 19%. Abundances of OST (~48%) decrease in contrast to ORT cysts which increase (~9%). Dinocyst concentration is the highest for the entire record (~1300 cysts/g).	605

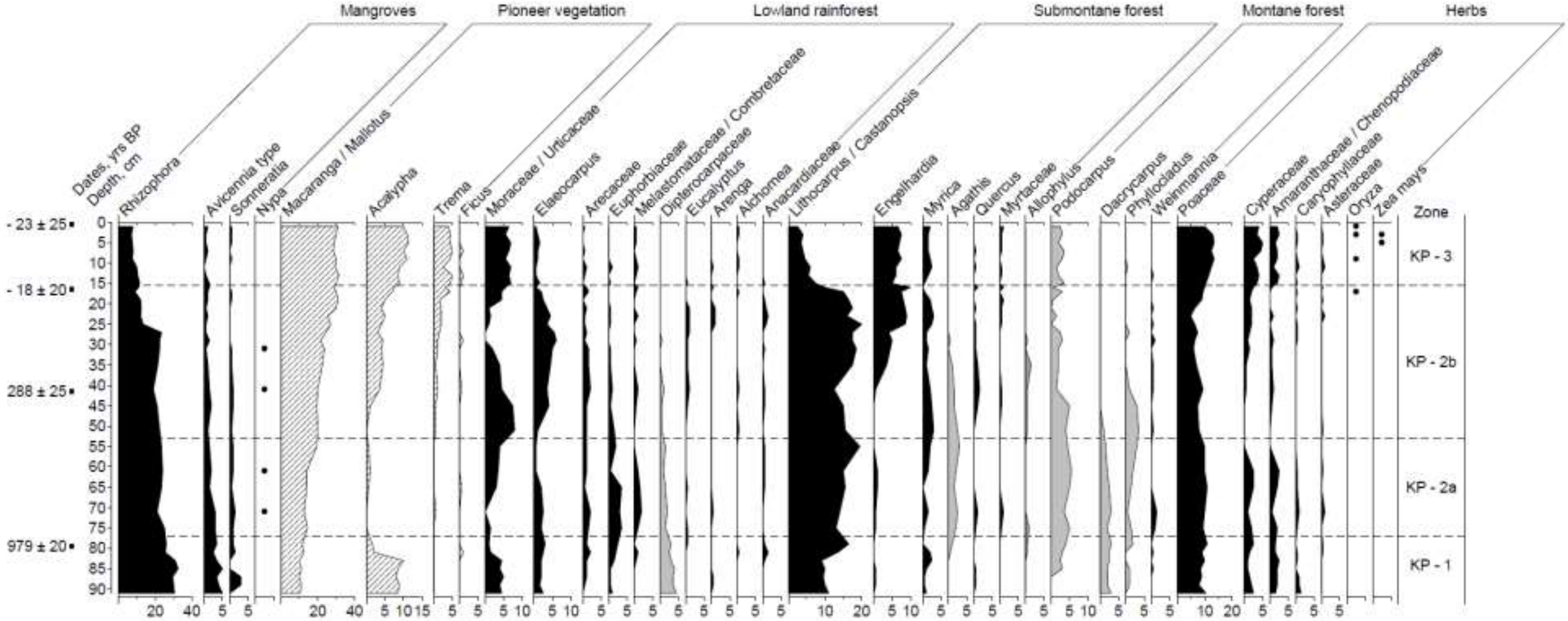

Fig. 4.3. Pollen diagram for the core 1412-19 showing relative frequencies of selected pollen and spore types, main vegetation groups and concentration. Pollen types of pioneer taxa have striped profiles; pollen types of timber tree taxa have grey profiles (beginning).

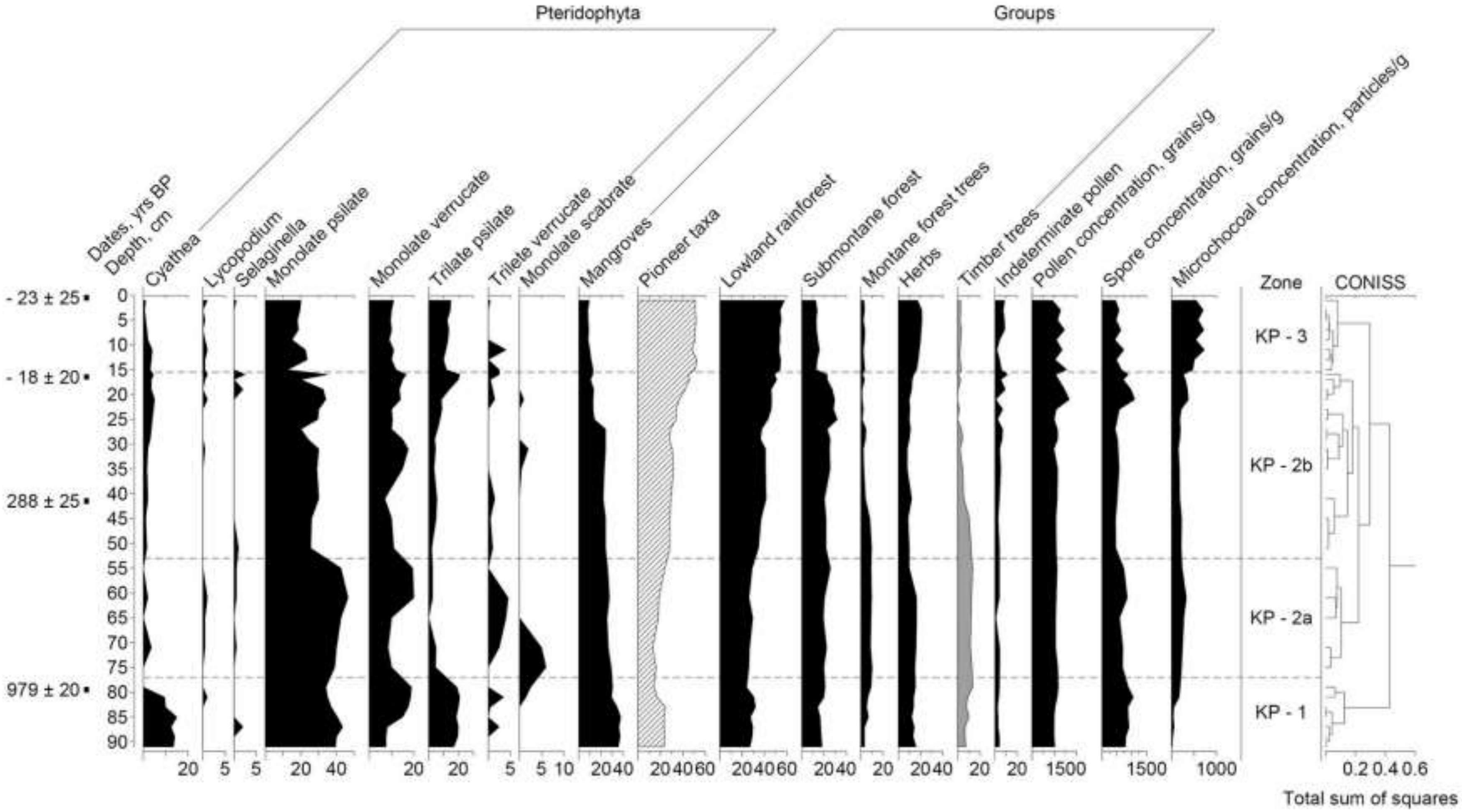

Fig. 4.3. Pollen diagram for the core 1412-19 showing relative frequencies of selected pollen and spore types, main vegetation groups and concentration. Pollen types of pioneer taxa have striped profiles; pollen types of timber tree taxa have grey profiles (end).

per century. For core 1609-30 the age/depth relationship shows a coherent sequence of increasing age with the depth (Table 4.1). This core covers stratigraphically the last ~3500 yr with sedimentation rates varying between 1 and 4 cm per century. For both cores, age assignments between the considered dates are based on linear interpolation, with extrapolation beneath the oldest obtained ages.

4.4.2. Pollen stratigraphy

Pollen diagrams for the cores 1412-19 and 1609-30 are presented in Fig. 4.3 and 4.4, respectively. In samples from S Kalimantan (core 1412-19), 71 pollen types of pollen, 8 types of fern spores were identified. Descriptions of 4 local pollen zones established based on the results of the constrained cluster analysis as well as dynamics of the key pollen/spore types are presented in the Table 4.2.

In samples from E Java (core 1609-30), 73 pollen types, 7 types of fern spores and 29 types of dinoflagellate cysts were recorded. Additionally, 12 indeterminate pollen types and 10 indeterminate spore types were distinguished. The descriptions of 3 local pollen zones are given in the Table 4.3.

The pollen and spore preservation is sufficient and relatively stable throughout both records. Percentages of fern spores in both records prevail over percentages of pollen, while the arboreal sum prevails over the sum of herbs. The most abundant pollen types in both records relate to lowland rainforest. Signals from upper montane forest were generally weak.

4.4.3. Dinocyst stratigraphy

For both cores, dinocyst stratigraphy almost repeats a pollen-based one. Dinocyst diagrams for the cores 1412-19 and 1609-30 are presented in Fig. 4.5 and 4.6 respectively. The preservation state of the pollen/spores and dinocysts in both cores is good, although the proportions of damaged and broken cysts increase with depth. For the core 1412-19 kt varied from 1.0 to 2.9, for the core 1609-30 from 0.1 to 2.7. HT prevailed in both records, RBC mainly. As for PT, *Spiniferitus* ssp. and *Echinidinium* ssp. are common for the core 1412-19, while for the core 1609-30 *Echinidinium granulatum* and *Operculodinium israelianum* are frequent. The descriptions of dinocyst zones are provided given in the tables 4.2 (core 1412-19) and 4.3 (core 1609-30).

4.4.4. Results of multivariate data analysis

The PCA revealed the relationships between samples and taxa (Fig. 4.7). Only taxa with the highest explanatory values are displayed. For both cores, the PCA diagrams (Fig. 4.8) show a clear division of the samples into two groups: left and right parts of the plot. Samples that are characterized by high relative abundances of primary forest pollen types (i.e. *Agathis, Allophylus, Dacrycarpus, Dacrydium,* Dipterocarpaceae, *Phyllocladus* and *Podocarpus*) occupy the left sector. In contrast, the right sector comprises samples that are positively correlated with high the percentages of pioneer taxa, such as *Acalypha, Ficus, Macaranga/Mallotus, Trema* and *Pandanus*. In core 1412-19, these samples belong to the depths below 25 cm (upper part of pollen subzone KP-2b and zone KP-3). In case of core 1609-30, samples positively correlated with secondary taxa belong to pollen zone JP-4, which is the uppermost one.

Results of the PCA of the dinocyst data are depicted in Fig. 4.9. Cosmopolitan dinocyst species that are characteristically present in eutrophic waters (i.e. cysts of *Polykrikos schwartzii*, *P. kofoidii, Lingulodinium machaerophorum, Nematosphaeropsis labyrinthus*, *Selenopemphix nephroides*) are ordinated for both cores in the right sector of the diagram comparable to the ordination scores of the pioneer vegetation pollen types (Fig. 4.9).

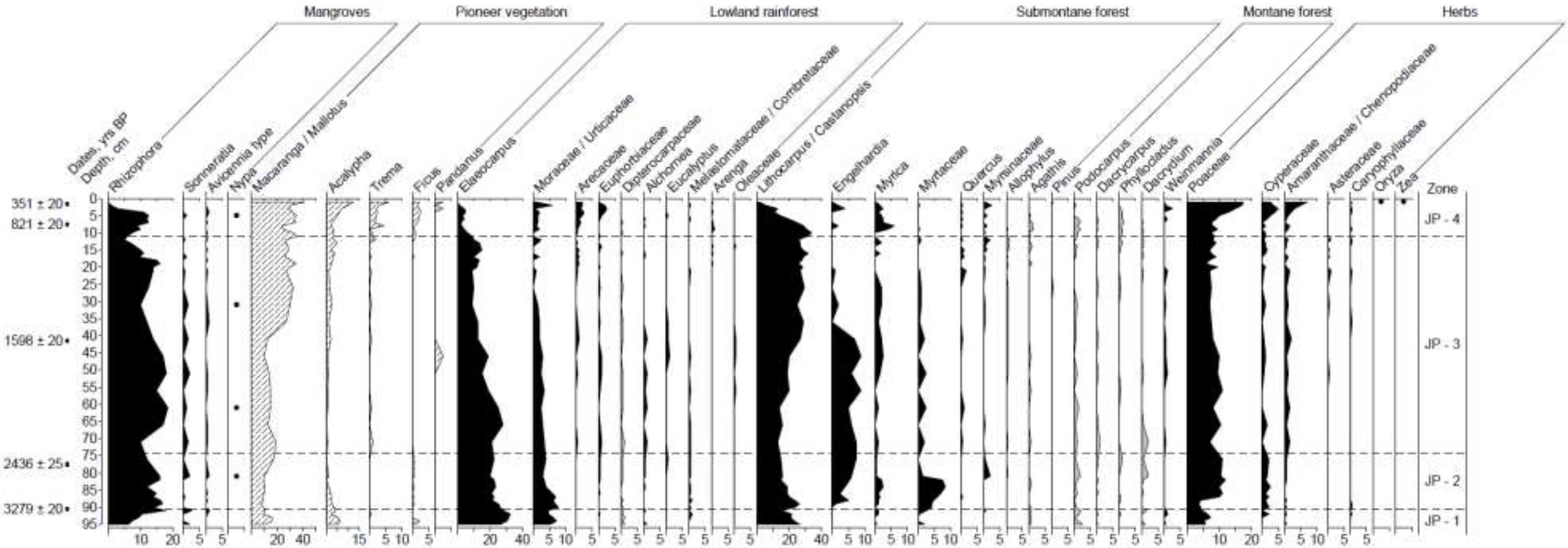

Fig. 4.4. Pollen diagram for the core 1609-30 showing relative frequencies of selected pollen and spore types, main vegetation groups and concentration. Pollen types of pioneer taxa have striped profiles; pollen types of timber tree taxa have grey profiles (beginning).

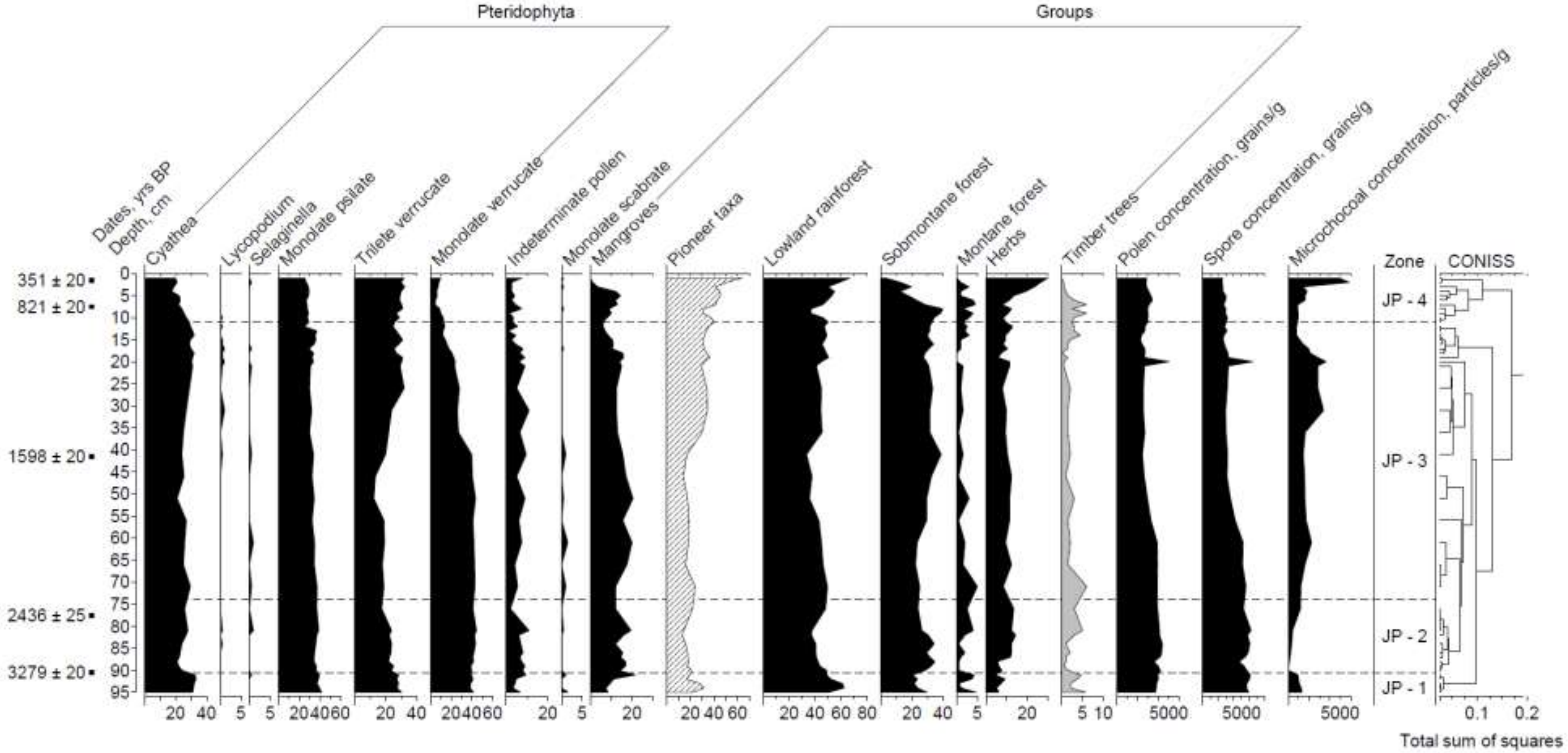

Fig. 4.4. Pollen diagram for the core 1609-30 showing relative frequencies of selected pollen and spore types, main vegetation groups and concentration. Pollen types of pioneer taxa have striped profiles; pollen types of timber tree taxa have grey profiles (end).

The PA comparison of the sample ordination scores of both PCAs reveals a high similarity between both datasets with similar samples ordinated on highly similar positions in both PCA spaces (Fig. 4.9). Sample scores of both PCAs show a very strong correlation of about 0.98 and disagreement measure value of about 0.004. The small PA errors reflected by the length of the short arrows indicate a high magnitude of similarity between paired diagrams. Based on PA, the differences between the results of PCA for pollen and dinocyst datasets collected off Kalimantan as well as off Java can be described as minimal.

4.5. Interpretation and discussion

The combination of pollen, spore and dinocyst data allows the reconstruction of changes on land and in the marine realm during the last 3500 years. For both core sites, the PCA applied to pollen data (Fig. 4.8) shows clear stratification: the lowermost samples contain predominantly pollen of timber tree taxa, whereas the uppermost samples contain greater amounts of pollen of the pioneer trees. The high similarity of the PCA outcomes for the pollen and dinocyst records (Fig. 4.8-4.9) from both locations suggest that changes in the terrestrial and marine assemblages are influenced by similar driving mechanisms. This is also reflected in the relatively uniform separation of samples in the zones as a result of the depth-constrained cluster analyses CONISS. These driving mechanisms may include both climatic and anthropogenic induced factors.

4.5.1. Pollen spectra and their relations with the source vegetation

Pollen assemblages from core 1412-19, S Kalimantan, show more diverse arboreal flora (29 woody taxa) with higher values for lowland trees and lower values for herbs than those from core 1609-30, E Java (22 woody taxa). Pollen can be transported to these locations by either aeolian or fluvial transport. Long distance aeolian transport may contribute, for instance, to the values of vesiculate pollen of montane coniferous taxa in marine sediments, e.g. *Dacrycarpus, Dacrydium, Podocarpus* and *Phyllocladus* (Heusser and Balsam, 1977; Heusser, 1988; Sun, 1999). For both sites, wind patterns are controlled by the monsoonal system and are very similar as wind directions are synchronous at both locations. Consequently, differences in wind directions cannot account for the different pollen assemblages in the two core sites.

The main river systems that discharge in the vicinity of the core sites are the River Jelai in Kalimantan and the River Solo with its tributary the Dengkeng in Java. The River Jelai originates in the Schwaner Mountains that are situated on the border between West Kalimantan and Central Kalimantan and have altitudes from 150 m up to 2278 m above sea level. The River Solo also has its sources in the high mountains, namely the volcano of Mount Lawu (3265 m) and Mount Kidul (700 m in average). The Dengkeng River starts in Mount Merapi (2800 m, Whitten et al., 1996, http://wetlands.or.id/). These settings allow to expect to some extend high values of montane taxa in the pollen assemblages. However, the montane vegetation in E Java, where annual droughts take place (Stuijts, 1993) is regularly affected by fire, both natural and anthropogenic induced, and forest gives way to secondary vegetation and to grasslands (Stuijts, 1993). As a result, montane pollen percentages are lower in the Solo River discharge compared to that of the Jelai River.

For core 1412-19, the pollen associations observed in the upper core samples reflect the modern vegetation in the drainage areas of the Jelai River quite well. Core 1609-30, where the uppermost sample is dated at about 270 cal yr BP, the pollen assemblages are composed of high amounts of pioneer and submontane arboreal taxa as well as of diverse and highly abundant herbs. In Kalimantan where the River Jelai is going through some open areas with shrubs and wide grasslands, particularly on the Central Kalimantan side (http://wetlands.or.id/), sediments are also characterised by relatively high values of herb pollen. Along the eastern bank of the River Jelai, a broad and more or less uninterrupted belt of riparian forest is present. On the western bank, a mosaic of forest and clearings is found. The main water catchment area for this river, however, is the peat swamp forest of Gambut and Mendawai, which is ‘the only remaining peat swamp

Table 4.3. Core 1609-30: Results of pollen, dinocyst and microcharcoal analysis.

Palynological zone, age (cal yr BP), core depth (cm)	**Pollen zone characteristics**	**Dinocyst zone, age (cal yr BP), core depth (cm)**	**Dinocyst zone characteristics**	**Micro-charcoal concentrations, ~particles/g**
JP-1, 3600 – 3215, 95-89	Mangrove pollen forms ~12% of pollen sum and is dominated by *Rhizophora* (~11%). Lowland rainforest taxa contribute ~54% and are composed of 15 taxa, mainly of *Elaeocarpus* (~29%) and *Macaranga/Mallotus* (~12%). Values of *Acalypha* are ~4%. Single grains of Dipterocarpaceae occur. Submontane forest (~25%) is represented mostly by *Lithocarpus/Castanopsis* (~22%). Montane taxa contribute only 2%. Percentages of herbaceous taxa are at their minimal values, ~7%. This group is represented by 5 taxa with Poaceae (~6%) contributing most. Sum of Pteridophyta spores exceeds pollen sum (~150%). Pollen concentration is ~3910 grains/g, spore concentration is ~5860 spores/g.	JD-1, 3600 – 3215, 95-89	High values of *Echinidinium* species (~25% of total dinocyst sum), max.contribution of Echinidinium zonneveldiae (~6%) and low values of *Spiniferites ramosus* (~2%). Values of PT (~29%) are much lower than those of HT (~71%) and composed mainly of *Operculodinium israelianum* and *Spiniferites pachydermus* (both ~6%). HT are dominated by Brigantedinium spp. (~45%) and *Echinidinium transparantum* (~12%). The amounts of ORT is very low (~4%), while those of OST is ~71%. TT and TTT contribute ~23% and ~77%, respectively. Percentages of FMT are ~20%; values of LST are only ~1%. Dinocyst concentration is at its highest value, ~2500 cysts/g.	930
JP-2, 3215 – 2390, 89-75	Values of mangrove slightly increase compared to the previous zone (~15%) while the lowland rainforest taxa decrease values (~41%). The diversity of pollen types increase (21 taxa) at the same time. Amounts of *Macaranga/Mallotus* decrease (~10%) as well as the values of *Elaeocarpus* (~22%). Pollen of Moraceae/Urticaceae contributes ~5% and *Acalypha* almost vanish at the end of this zone (80 cm). Single grains of Dipterocarpaceae occur sporadically. Contribution of submontane forest taxa is ~30% with *Lithocarpus/Castanopsis* forming ~19% and Myrtaceae up to ~8%. Montane taxa are represented mainly by *Podocarpus* and *Dacrydium*. Values of herbs are higher (~11%) due to the higher contribution of Poaceae (~9%). Values of Pteridophyta are ~137%. Pollen concentration is ~4060 grains/g; spore concentration is ~5590 spores/g.	JD-2, 3215 – 2275, 89-70	Higher values of *Brigantedinium* spp. (~49% of the dinocyst sum) and *Spiniferites ramosus* (~5%). *Tuberculodinium vancampoae* and *Stelladinium stellatum* occur regularly. Relative abundances of *Echinidinium zonneveldiae* (~2%) decrease. Abundances of PT form ~32% of the association. Relative abundances of *Operculodinium israelianum* (~5%) are slightly lower than in the previous zone and almost equal to the values of *Operculodinium centrocarpum*. Amounts of *Spiniferites pachydermus* remain stable. HT contribute ~68% to the association. The brown spiny cyst group is dominated by *Echinidinium transparantum* (~10%). Values of ORT/OST as well as those of FMT (~18%)/LST (~2%) remain stable. Percentages of TT and TTT are ~21% and ~79%, respectively. Dinocyst concentration is a bit lower, ~2310 cysts/g.	350
JP-3, 2390 – 870, 75-9	Pollen of mangrove contributes ~13%. Percentages of lowland rainforest are slightly higher (~45%), taxa diversity increases as well (26 taxa). Values of *Macaranga/Mallotus* are notably higher than before (from 20% to 25%). Amounts of *Elaeocarpus* decline to ~14%. *Acalypha* is absent at the beginning of zone, but from 20 to 10 cm it reaches a mean value of ~2%. Submontane taxa contribute ~30% to the pollen sum. Values of *Lithocarpus/Castanopsis* markedly increase (~25%). Montane taxa are represented by only ~2%. Values of herbs are ~10%; values of Poaceae decrease to ~8%, other 10 taxa are of minor contribution. Amounts of Pteridophyta reduce to ~120%. Pollen concentration is ~2960 grains/g; spore concentration is between ~3580 spores/g.	JD -3, 2275 – 910, 70-11	Contribution of *Brigantedinium* spp. (~46%) and *Echinidinium transparantum* (~8%) decreased, while *Spiniferites ramosus* and *Echinidinium zonneveldiae* increase their values (both up to ~6%). This zone is characterized by the first occurrence of *Bitectatodinium spongium, Lingulodinium machaerophorum, Nematosphaeropsis labyrinthus,* the cysts of *Polykrikos kofoidii* and *Stelladinium robustum* type. PT form ~34%. *Operculodinium israelianum* and *Operculodinium centrocarpum* stay unchanged. Values of HT are ~66%. Amounts of ORT are ~65% and amounts of OST are ~5%. Percentages of TT slightly decreased (~19%), while those of TTT increased slightly (~81%). FMT and LST taxa make up ~15% and ~2% respectively. Dinocyst concentration decreases further (~170 cysts/g).	1800
JP-4, 870 – 270, 9-0	Values of mangrove pollen strongly decrease (~8%), while the amounts of lowland rainforest taxa are much higher (~50%). Percentages of *Macaranga/Mallotus* and *Acalypha* increase up to ~31% and ~6%, respectively, while values of *Elaeocarpus* dramatically decrease in comparison to the previous zone (~3%). Pollen of the *Ficus* type and Arecaceae are constantly represented. The portion of submontane taxa gets reduced (~22%). Values of *Lithocarpus/Castanopsis* are ~17%. Montane taxa form only ~2%. Percentages of herbs are at the highest (~18%) with Poaceae ~12%, Cyperaceae ~2% and Amaranthaceae/Chenopodiaceae (~2%). The sum of Pteridophyta spores is the lowest for the entire record, ~91%. Pollen concentration is ~3040 grains/g; spore concentration is ~2770 spores /g.	JD-4, 910 – 270, 11-0	Being very low at the beginning of zone, values of *Nematosphaeropsis labyrinthus* and *Lingulodinium machaerophorum* – (both less than ~1%), reach ~7% and ~18% at the top of the core, respectively. PT decreased to ~30%; the curve of *Operculodinium israelianum* rises (~8%). Amounts of HT are ~70% with *Brigantedinium* spp. Up to ~44% and *Echinidinium transparantum* ~7%. Cysts of *Polykrikos kofoidii* are regularly present with the highest values of ~4%. Cysts of *Polykrikos schwartzii* are registered for the upper most part of this zone. ORT fluctuate around 70% and OST reach their max. value of ~7%. Values of TT are ~20%. Amounts of TTT stay without changes (~80%). FMT form their min. (~4%), while LST reach their max. (~96%). Dinocyst concentration is ~1730 cysts/g.	2240

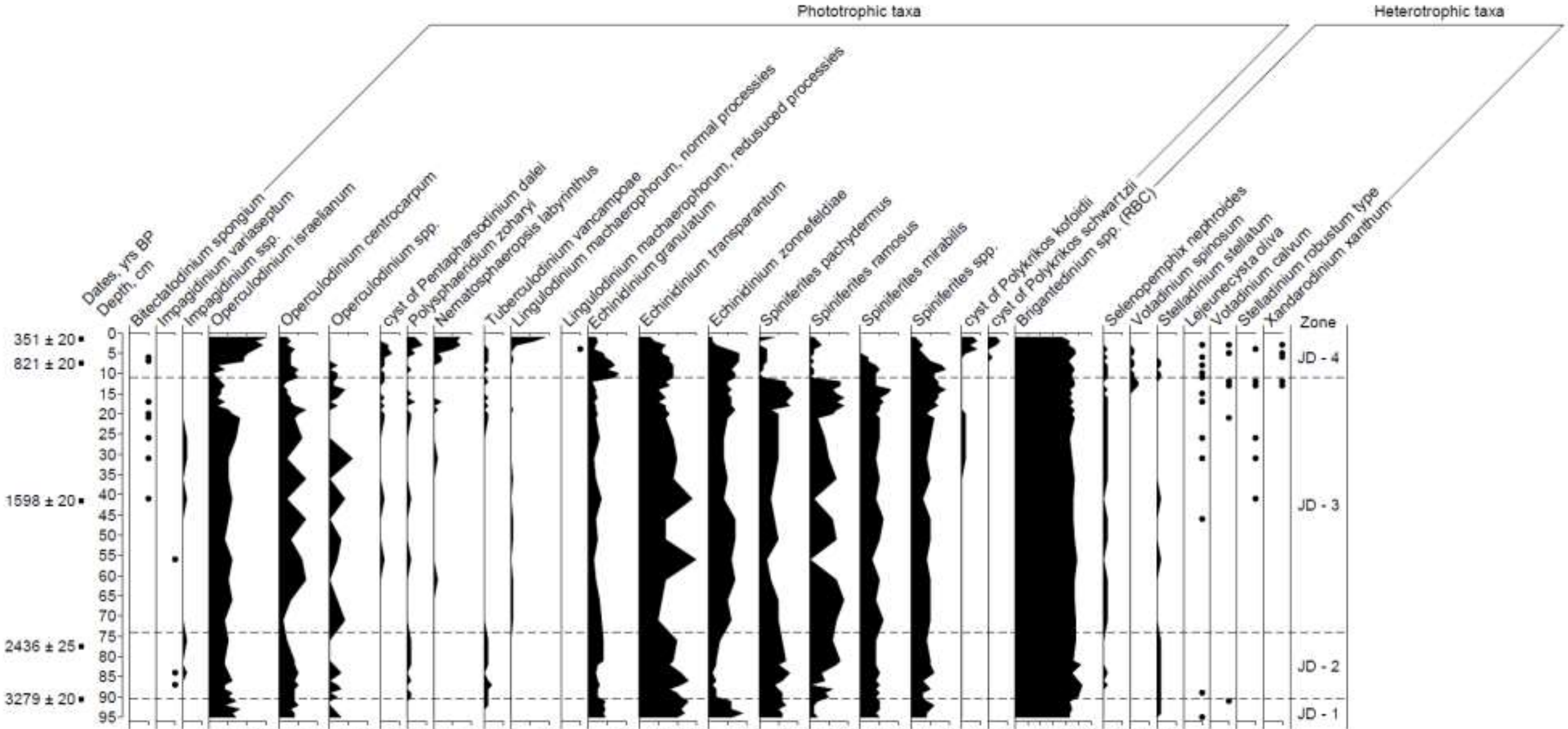

Fig. 4.5. Dinocyst diagram for the core 1412-19 showing relative frequencies of individual taxa, main groups and cyst concentration (beginning).

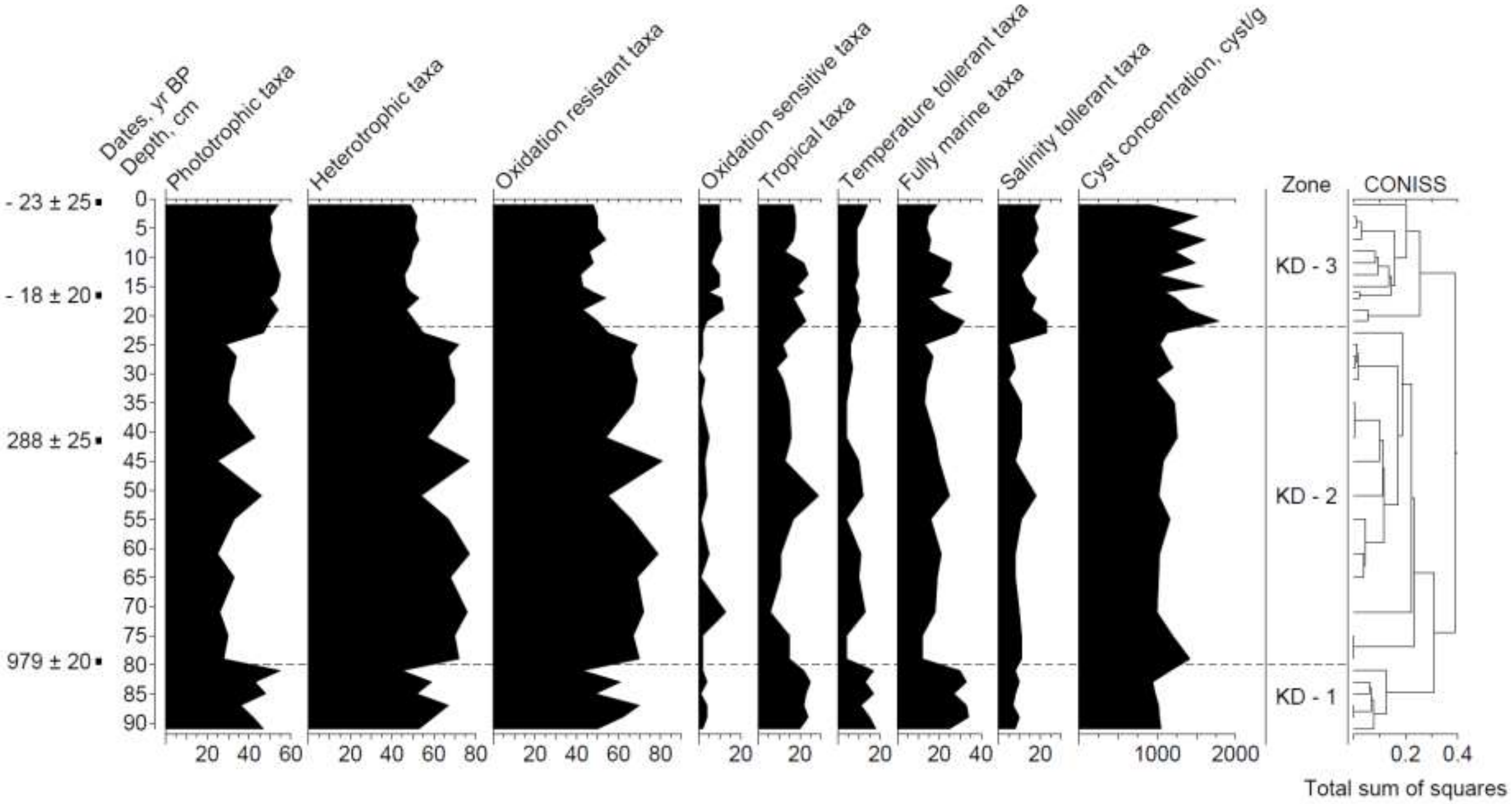

Fig. 4.5. Dinocyst diagram for the core 1412-19 showing relative frequencies of individual taxa, main groups and cyst concentration (end).

forest at the south part of West Kalimantan' (http://wetlands.or.id/). The riparian vegetation and vegetation of peat swamp forest in the sediments of core 1412-19 were represented by 12 pollen types of woody taxa, e.g. Anacardiaceae, Dipterocarpaceae, *Elaeocarpus, Engelhardia*, Euphorbiaceae, *Macaranga/Mallotus*), although, most of these taxa could also originate from other vegetation types: pioneer growths (*Macaranga/Mallotus),* lowland rainforest (Anacardiaceae, Dipterocarpaceae, *Elaeocarpus,* Euphorbiaceae) and submontane forest (*Engelhardia)*. Other taxa observed in the pollen association that might originate from peatland forests are *Celtis, Myrsine* and *Ilex*. However, all these taxa represented less than ~3% of the total pollen sum and were therefore not specifically depicted in the pollen diagram. We assume not to have observed unequivocal evidence of a peatland and/or riparian forest in core 1412-19.

To date, the estuary of the river Jelai is reported to have an approximately 10 m wide *Nypa* belt only (http://wetlands.or.id/) and almost no mangrove vegetation. Nonetheless, pollen of *Nypa* was surprisingly absent in the most recent pollen zone of the sequence 1412-19, while observed values of other types of mangrove pollen (i.e. *Avicennia, Sonneratia* and *Rhizophora*) off S Kalimantan were higher compared to E Java, where mangrove contribute to the total pollen sum not more than 13-14% through the record with exception of the last zone where its contribution drops to ~8%. The reason could be connected to the extensive destruction of the mangroves belt on Java during the recent time as it was shown by e.g. Sukardjo (1980, 1993), Whitten et al. (1996), Reeves et al. (2013) as well as in our recent work on the modern pollen in the Indian Ocean (Poliakova et al., 2014). Moreover, mangrove pollen often show the highest values within their source area (e.g. Hooghiemstra et al., 1986; Sun et al., 1999) with decreasing values with distance from shore (van der Kaars, 2001; Sun et al., 2002; Poliakova et. al., 2014).

4.5.2. Dinocyst assemblages: preservation and translocation

Dinocyst assemblages found in the sediment sequence 1412-19 are characterized by relatively low values of the degradation index (kt) that does not exceed 2.9. This suggests that cyst degradation or differential preservation for this core is negligible and the palaeoenvironmental signal of the OST (round brown and spiny brown cysts especially) was not altered by oxygen-induced degradation (Versteegh and Zonneveld, 2002). Another factor that can alter the fossil dinocyst association is the relocation of the settling material (Dale, 1992; Zonneveld, 2001). Core site 1412-19 is not affected by any significant currents. For the core site 1609-30 the most relevant current that might have caused relocation of cyst material is the Karimata Strait Throughflow (KSTF) which flows along the S coast of Kalimantan (Fig. 4.2). At present, KSTF has a flow speed of about 12-25 cm/sec (10 - 22 km/day) with a strength being strongly depended on the monsoon strength (Wyrtky, 1957). However, taking into account the relatively high sinking rates of dinocysts of about 274 m/day (Zonneveld and Brummer, 2000; Zonneveld et al., 2010a) and a water depth at the core site (56.3 m), we suppose that the influence of lateral drift in the study area is minor. This assumption is supported by the presence of the coastal taxa *Tuberculodinium vancampoae* (Marret and Zonneveld, 2003). This species is rarely observed in open marine environments and it is a typical species for coastal shallow water environments (Rochon et al., 1999; Marret and Zonneveld, 2003). This suggests that for both studied cores dinocysts associations reflect conditions of local marine environment without significant input of the material from other areas or washing away locally produced cysts.

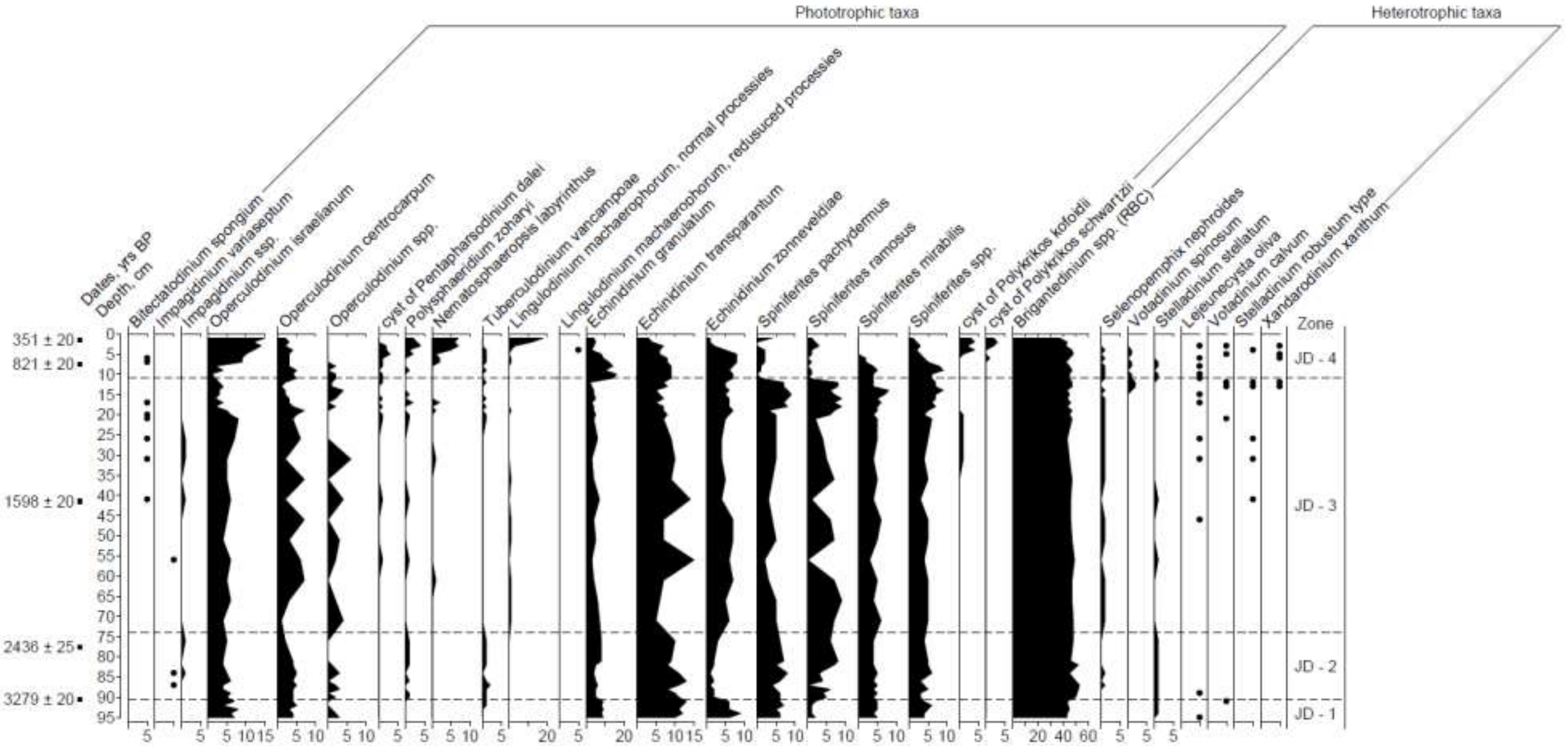

Fig. 4.6. Dinocyst diagram for the core 1609-30 showing relative frequencies of individual taxa, main groups and cyst concentration (beginning).

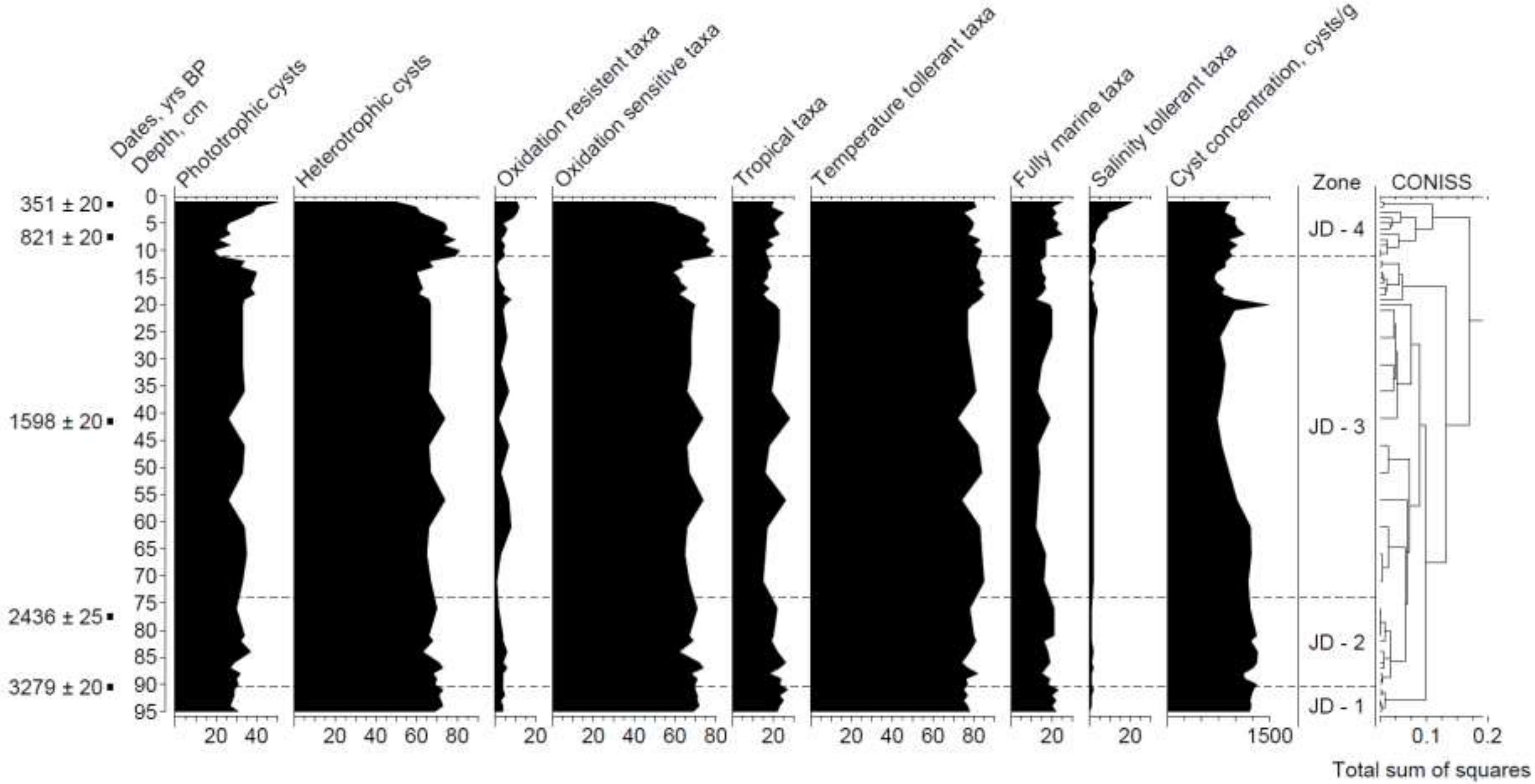

Fig. 4.6. Dinocyst diagram for the core 1609-30 showing relative frequencies of individual taxa, main groups and cyst concentration (end).

4.5.3. Environmental reconstructions

4.5.3.1. East Java

Late Holocene from ca 3600 to 3215 cal yr BP (pollen zone JP-1) and from ca 3600 to 3215 cal yr BP (dincyst zone JD-1)

Mangrove vegetation flourishes along the coast of E Java off the river Solo mouth during this period. Increasing *Rhizophora* may be linked to a slight sea level drop between 6000 and 1000 BP after the Holocene maximum as it is proposed by Yulianto et al. (2005) for Batulicin (S Kalimantan). Alternatively, mangroves expansion can be the consequence of a somewhat higher offshore sediment accumulation, e.g. an increased input of sediments due to the enchased discharge of the river Solo which in turn, may be related to increased precipitation in the drainage area. Wet conditions are also suggested by very high relative abundances of the *Cyathea* and various other types of Polypodiaceae spores. Lowland rainforest with an important role of *Elaeocarpus, Macaranga/Mallotus* and a certain distribution of opportunistic taxa like *Acalypha* and Moraceae/Urticaceae at the forest border and in canopy openings was probably the dominant vegetation type developing behind mangroves at that time. Other pioneer as well as herbaceous taxa show very low values, so, despite human activity most likely was involved in the vegetation change from ca 3000-3800 yr BP in the highlands of West Java (Stuijts, 1993) and in Rava Danau (Kaars et al., 2001), in our study area anthropogenic impact had a limited or at least a constant moderate influence at the regional vegetation before 2950 yr BP (85-75 cm). The most important trees in submontane areas along the river Solo at that time were Fagaceae (*Lithocarpus/Castanopsis*) with a more prominent role of *Quercus* and Myrtaceae in the canopy. Montane taxa palynologically are represented by coniferous, *Podocarpus* mainly.

In zone JD-1 that is fully corresponded to the pollen zone JP-1, the dinocyst associations are characterised by a high abundance of TT and/or FMT (e.g. *Bitectatodinium spongium, Spiniferites pachydermis, Spiniferites mirabilis*) that may point to stable environmental conditions with no abrupt events and high SST and SSS.

Late Holocene from ca 3215 to 2390 cal yr BP (pollen zone JP-2) and from ca 3215 to 2275 cal yr BP (dincyst zone JD-2)

Zone JP-2 is characterised by a reduced role of *Acalypha* and *Ficus* in the lowlands as well as by the declining of Moraceae/Urticaceae that might point to a more closed canopy forest. A marked role of *Engelhardia* (till ca 1480 cal yr BP) and Myrtaceae in submontane forest suggests relatively stable conditions in the river Solo coachmen at this time, whereas an increasing persentages of herb pollen suggests the presence of openings in the canopy. Dinocyst associations from zone JD-2, which well corresponds with the related pollen zone having approximated time difference of 115±20 yr, suggests unchanged marine environmental conditions similar to the previously described.

Late Holocene from ca 2390 to 870 cal yr BP (pollen zone JP-3) and from ca 2275 to 910 cal yr BP (dincyst zone JD-3)

Not much changes in vegetation and environmental conditions could be inferred before about ca 1590 cal yr BP (middle part of pollen zone JP-3, Fig. 4.6), where the clear evidences of the forest disturbance are observed. The reduction in *Elaeocarpus* corresponds with an increase of *Macaranga/Mallotus* which suggest a change to a much more open forest canopy. This is supported by increasing abundance of herbs (10% to 6% in the previous zone). In submontane forest, excessive logging is likely to have taken place as an abrupt reduction of *Engelhardia* is observed which finds no support in natural environmental dynamic (e.g. climate fluctuation) in the study area. The reduced abundances of ferns might suggest a change to somewhat drier conditions compared to the previous period. Alternatively and more likely, it could be a result of the general reduction in the environment suitable for fern growth, i.e. additional evidence for reduction in afforested land. The constant occurrence of *Arecaceae* and *Arenga* after ca 1000 cal yr BP may be coupled with cultivation of sugar palm and coconut plantations on Java as Stuijts (1993) and Van der Kaars, van den Bergh (2004) supposed.

In the corresponding dinocyst zone JD-3, which is shifted from pollen zone JP-3 at 40±20 yr, cyst associations show increased role of the ORT and occurrence of such dynotypes as *Lingulodinium machaerophorum, Nematosphaeropsis labyrinthus,* cyst of *Polykrikos kofoidii* and *Selenopemphix nephroides* those suggest a change to more eutrophic conditions in the marine environment of the Java Sea compared to the previous time period.

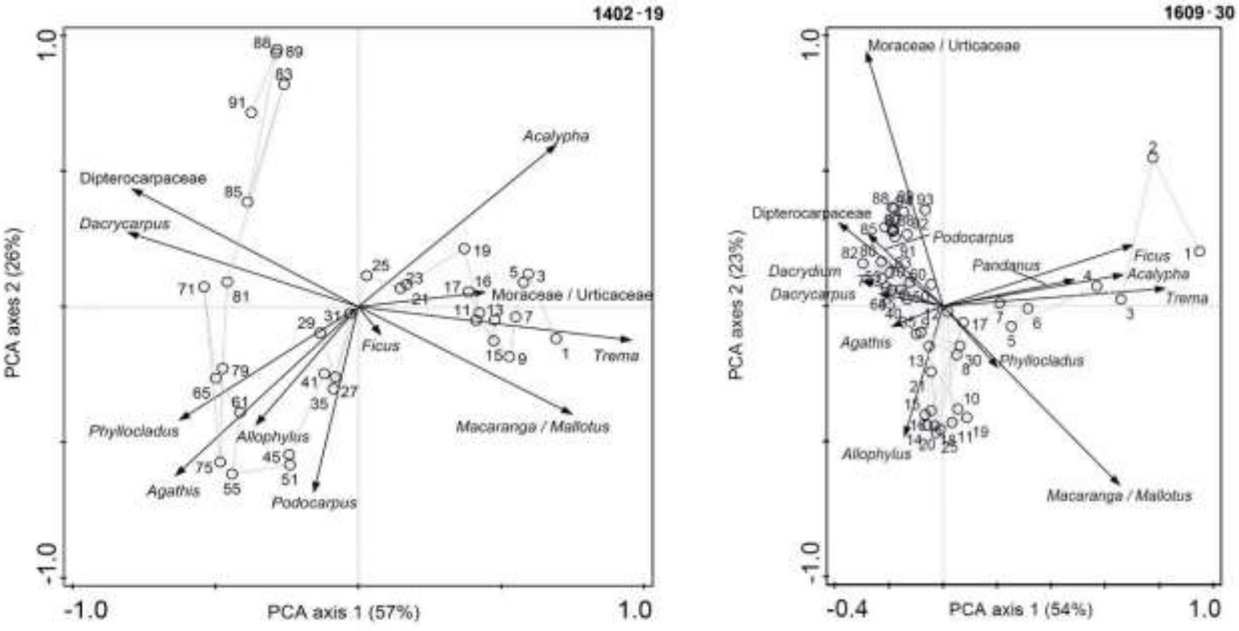

Fig. 4.7. Extraction from the ordination diagram of the principle component analysis (PCA) for pollen types from (A) core 1412-19 and (B) core 1609-30 (B). Only scores for timber trees pollen and pollen of the pioneer taxa are shown. The percentage values on the axes indicate the explained variation.

Late Holocene from ca 870 to 270 cal yr BP (pollen zone JP-4) and from ca 910 to 270 cal yr BP (dincyst zone JD-4)

Since ca 870 cal yr BP (zone PJ-4, Fig. 4.6), the character of vegetation in E Java has changed dramatically. Pioneer taxa (e.g. *Macaranga/Mallotus, Trema, Ficus, Acalypha* and, from ca 500 cal yr BP, *Pandanus*) dominate in the forest which is of secondary origin as the primary close-canopy forest has been gradually replaced by more open and less diverse communities. The same is suggested by the reduction of ferns and the strong increase of herbs (especially by Poaceae, Cyperaceae and Amaranthaceae/Chenopodiaceae). The upper three samples in pollen zone PJ-4 (430 - 270 cal yr BP) are characterised by the least abundant arboreal pollen (e.g. pollen of *Elaeocarpus* and *Lithocarpus/Castanopsis*) and evidence a strong decline in timber trees accomplished by increasing role of herbs and pioneer taxa. For the top sample (ca 270 cal yr BP) crop cultivation is evidenced (pollen of *Zea mays* and *Oryza* type are found) and, apparently, pine plantation establishment as it can be concluded from occurrence of *Pinus* pollen.

Main change in the taxonomical composition of dinocysts took place after ca 820 cal yr BP (middle part of zone JD-4) and is coupled with the increasing in abundances of the taxa indicating river discharge (e.g. *Echinidinium transparantum* and *Lingulodinium machaerophorum*). This shift is also indicated by the increasing values of species indicating both high phosphate (cysts of *Pentapharsodinium dalei*) and high nitrate concentration (*Nematosphaeropsis labyrinthus*, cysts of *Polykrikos kofoidii and P. schwartzii*) as well as by high values of the ORT. In contrast, percentages of salt water species (e.g. species of *Spiniferitus*) slightly decrease between ca 600 and 350 cal yr BP. About the same time *S. mirabilis,* which is restricted to salty waters, eliminates. This could reflect an increase of the fresh water input from the river Solo that changes both the salinity budget and the trophic state of the surface waters at the core 1609-30 site. Alternatively, this change might be related to the construction of a canal from the port of Surakarta to the Java Sea that has been executed by the Dutch during this time (Dick, 2003). Thus, independently of the source of the nutrient rich waters (the river Solo or the canal), the consequences can be described as the same: logging is accompanied with increased soil wash-off and enhanced coastal water pollution that changes its trophic state and leads to development of pollution-resistant and tolerant to fresh water dinocyst types.

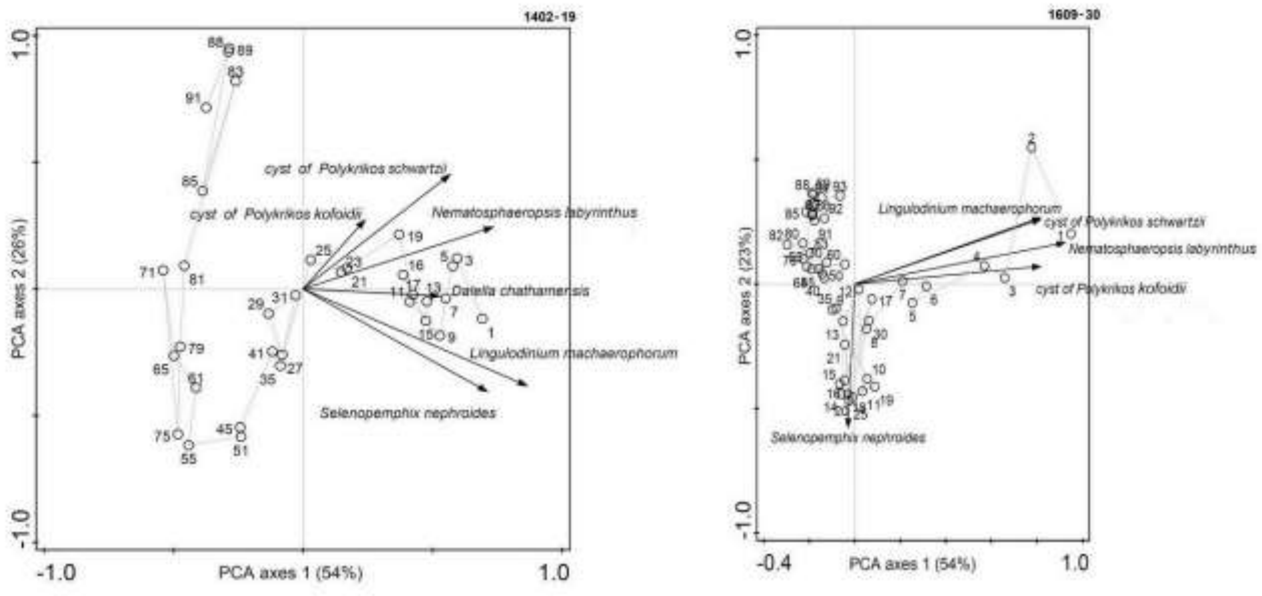

Fig. 4.8. Extractions from the ordination diagram of the principle component analysis (PCA) for dinocyst types from (A) core 1412-19 and (B) core 1609-30. Only scores for P- and N-sensitive dinoflagellate cysts are shown. The percentage values on the axes indicate the explained variation.

4.5.3.2. South Kalimantan

Late Holocene from 1200-910 cal yr BP (pollen zone KP-1) and from ca 1200-980 cal yr BP (dinocyst zone KD-1)

Pollen deposited in this period indicates a marked role of mangrove in the coastal area off the river Jelai in S Kalimantan. The same was suggested by Yulianto et al. (2005) who studied a coastal swamp forest at Batulicin (S Kalimantan) and found that extensive mangroves have been continuously present there since the early Holocene. Behind the mangrove stands, typical for the study area fern-rich mixed lowland rainforest developed that, according to the high portion and high diversity of related pollen taxa in our record, was a species-rich Dipterocarpaceae rainforest, the main type of vegetation which presently occurs in S Kalimantan (MacKinnon et al., 1997). As our age-depth model suggests, it was established at least 1200 years ago. The high values of *Macaranga/Mallotus, Elaeocarpus*, Moraceae/Urticaceae and *Acalypha* however, may indicate some opening in the forest canopy already at that time. The high frequency of Pteridophyta may point to stable wet conditions and a high level of effective precipitation during this period (e.g. Yulianto et al., 2005).
The pollen composition of submontane and montane taxa suggests that at higher elevations upstream along the Jelai River, mixed lowland forest seems to be followed by Fagaceae forest dominated by *Lithocarpus/Castanopsis*. Palynologically, *Quercus* and *Myrica* were less important taxa in submontane forest during this period. As for montane forest, it is reflected poorly, mostly by the coniferous taxa that have vesiculate pollen and are widely dispersed (i.e. *Podocarpus, Dacrycarpus* and *Phyllocladus*). Their pollen can easily become a subject of aeolian transport that suggests some contribution of a long distance aeolian component to the amount of montane pollen.
Dinoflagellate cyst assamblages between 1200 and 980 cal yr BP (dinocyst zone KD-1) is formed by typically warm water and FMT (e.g. *Bitectatodinium spongium*, *Echinidinium transparantum, Operculodinium israelianum, Polysphaeridium zoharyi, Spiniferites mirabilis* and *S. pachydermus*) that suggests rather stable tropical marine environment within the Java Sea which does not contradict to pollen-based reconstruction. Relatively high abundance of *Lingulodinium machaerophorum* in this zone suggests continuous and high discharge of fresh water reaching the deposition site.

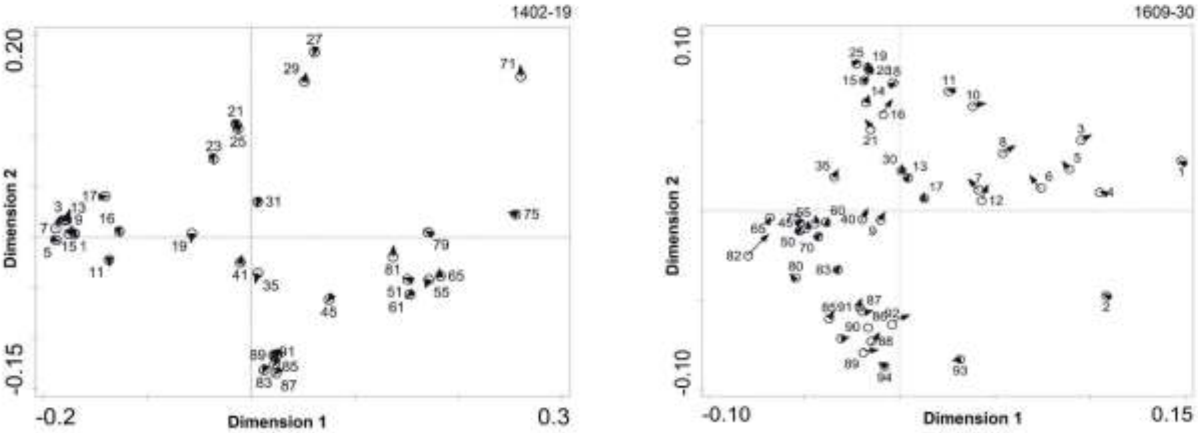

Fig. 4.9. Procrustes analysis errors in two-dimensional ordination space between pollen and dinocysts for the comparison of PCA ordinations of (A) core 1412-19 and (B) core 1609-30. The length of the

arrows indicate the magnitude of similarity between paired sites with short arrows suggesting high similarity and long arrows suggesting low similarity.

Late Holocene from ca 910 – -20 cal yr BP (pollen zone KP-2) and from ca 980 – 10 cal yr BP (dincyst zone KD-2)

During this period pollen data indicate in the lowland rainforest an increase of *Macaranga/Mallotus, Acalypha, Trema* and *Arenga* and a decrease of important timber trees such as Dipterocarpaceae and submontane *Agathis* and *Allophyllus*. This reflects an expansion of the secondary forest and pioneer taxa in the lowland rainforest that can be typically subscribed as evidence of logging (e.g. Stuijts, 1993; Yulianto et al., 2005). This assumption is supported by the observation of the increasing abundances of herbaceous taxa and the significant decrease or disappearance of pollen of such important timber trees such as *Dacrycarpus* (becoming absent at around 530 cal yr BP) and *Phyllocladus* (becoming much less frequently present after 380 cal yr BP). *Engelhardia* trees may possibly increase their abundance due to the further development of peatland forest in the S Kalimantan as it has been stated by Anshari et al. (2001) and Yulianto et al. (2005). Another possible reason for higher occurrence of *Engelhardia* at this time could be the occupation of canopy gaps by *Engelhardia* in the submontane forest due to logging. We do not connect these changes with climatic fluctuations as neither any additional indicators for these fluctuations in any other vegetation groups are evident. Marked reduction in mangroves (most clearly reflected by the *Rhizophora* record), in *Lithocarpus/Castanopsis* as well as in *Elaeocarpus* pollen that are typical for canopy openings where a lot of light is available (Whitten et al., 1996), suggests intensification of the land use and forest disturbance since ca 500 cal yr BP. Changes on land at this time correspond to a small alteration in the dinocyst taxonomic composition. At about ca 360-275 cal yr BP (zone KD-2, 41-45 cm) a slight increase in ORT occurred that may point to somewhat less ventilation in the marine environment.

Late Holocene from ca -20 – -23 (pollen zone KP-3) and from ca 10 – -23 cal yr BP (dincyst zone KD-3)

Further reduction in mangroves accompanied by a marked decline in montane taxa and in pollen of timber trees was followed by an increasing diversity and abundance of herbs, e.g. Poaceae, Cyperaceae and Amarantaceae/Chenopodiaceae especially. This suggests the reduction of closed-canopy forests along the river Jelai and high occurrence of open fields during the last decades. All this corresponds in time with the increase of human population in the area and establishing of permanent settlements. Small reduction in the tree fern *Cyathea* and the increasing occurrence of *Lycopodium*, if it is not an additional evidence of the disturbance, may be explained by some drier conditions or at least to some more pronounced difference in rainy and dry periods of the year as it is suggested by Anshari et al. (2001). Reeves et al. (2013a; 2013b) in their discussion also referred to an increasing variability of the environment and enhanced drier overall conditions of the Australasian subregion during this time. The authors connect this variability to the intensification of ENSO in the El Niño mode. First findings of pollen grains of *Oryza* type and *Zea mays* in this zone are related to the beginning of 20th century and evidence a crop breeding. Additionally to the change in vegetation, the dinocyst composition has altered by an increase in relative abundance of HT (in particular, *Selenopemphix nephroides*, cyst of *Polykrikos kofoidii* and *P. schwartzii*). This may suggest changes in marine environment to more nutrient-rich conditions that could have stimulated development of prey organisms and, as a result, increasing in abundance of their predators (e.g. Harland et al., 2006; Dale, 2009, Zonneveld et al., 2013 and references therein). Furthermore, at this time enhanced abundance of *L. machaerophorum* occurs, which can be explained either again by the increased nutrient supply, or by the intensification of the river input (e.g. as the result of the increased precipitation) because this dinocyst type is common both in river plume areas and in nitrogen-rich waters (e.g. Zonneveld et al., 2012 and references therein). Until now there is no evidence from literature of increased precipitation in the area that could have resulted in enhanced river discharge. On the contrary, some drier conditions have been suggested during this time (e.g. Anshari et al., 2001). This stays in agreement with our conclusions done for the previous time period and most likely suggests that enhanced fresh water input at this time is not the cause of the increased presence of *L. machaerophorum*. Moreover, the sum of FMT slightly increased at this time pointing to an increase of SSS rather than to a decrease. We, therefore, assume that the increase in *L. machaerophorum* is the result of the eutrophication and connect is to the intensification of the human activity.

4.6. General comparison of the study sites and conclusion

Pollen, spore and dinocyst assemblages from two marine cores, retrieved off S Kalimantan and off E Java have been used to reconstruct the terrestrial and marine environmental changes during the last 3500 years. Pollen and dinocyst content were sufficient to produce reliable results. This first palynological study from the Java Sea inferred that environmental and vegetation changes in the region during the late Holocene were mostly related to human activity. This was clearly reflected by both studied sequences and, despite they are overlapped only minimally (see Table 4.2), general trends observed at each site are similar although occured at different time periods: forest canopy opening, decline in primary forest taxa, development of secondary vegetation with an increasing role of pioneer taxa and herbs. These shifts in both sequences are associated with an increase in the concentration of micro-charcoal (Fig. 4.5 and 4.6) suggesting that the occurrence of fires corresponds to the changes in forest canopy and can possibly be accounted as additional indicator of human activity, especially because of a traditional slash-and-burn technique.

In Java, with its long history of agriculture and human settlements, changes took place much earlier starting at ca 2950 cal yr BP than in Kalimantan staring at ca 910 cal yr BP and were much more intensive. A strong decline in timber trees, associated with an increase in herbs and pioneer taxa, is dated for Java (1609-30 core) back to at least 870 yr BP, while for Kalimantan (core 1412-19) such processes are evidenced only in modern times since about 1940 AD when increased population and intensification of human activity started in Kalimantan. A similar early, opening and disturbance of the forest in Java started at about 3500 cal yr BP in the highlands of Central Sulawesi according to Kirleis et al. (2011).

Changes in the marine costal realm of the Java Sea evidenced from the dinocyst analysis are highly corresponded to those on land (correlation is about 0.90 with disagreement measure value of ~0.004). They could be described as a gradual change from relatively well ventilated to more hypoxic and somewhat eutrophic conditions. Dinoflagellate associations off both the river Jelai at ca 1200 – ca 910 cal yr BP and river Solo before 2275 yr BP are composed of warm water and fully marine taxa. Near the coast of Java, the shift in the trophic status of water took place between ca 820 and 500 cal yr BP, while near the coast of Kalimantan it occurred as late as at the beginning of the 20th century.

The occurrence of certain types of dinocysts (i.e. cyst of *Polykrikos schwartzii* and *P. kofoidii*, *Lingulodinium machaerophorum, Nematosphaeropsis labyrinthus* and *Selenopemphix nephroides*) were strongly positively correlated with the increase in pioneer taxa and negatively correlated with the increase in pollen taxa related to the primary forest (e.g. to *Agathis*, *Allophylus, Dacrycarpus, Dacrydium, Dipterocarpaceae, Phyllocladus* and *Podocarpus*) which are excessively logged for timber. This suggests that those dinocyst types react strongly on human induced changes in the marine environment and may potentially be used as palaeoecological indicators of anthropogenic activity.

Statistical correlation of the dinocyst and pollen data was very high. The comparison of pollen and dinocyst data and their CONISS-based clustering (Fig. 4.3-4.6) provided interesting insights on environmental changes in terrestrial and marine realm. For Java, between 3600 and 3215 cal yr BP changes on land occurred at the same time as the changes in coastal waters of the Java Sea (beginning of pollen zone JP-2 and dinocyst zone JD-2) or were earlier (pollen zone JP-3 started about 115±20 years before than the dinocyst zone JD-3, Fig. 4.4 and Fig. 4.6). The uppermost pollen zone (JP-4, Fig. 4.4) started at ca 870 cal yr BP which is about 40±20 years later than the related dinocyst zone JD-4 which started at ca 910 cal yr BP (Fig. 4.6). For Kalimantan, time differences between pollen and dinocyst zones were 70±25 yr for KP-2 and KD-2 and 40±20 yr for KP-3 and KD-3 (Fig. 4.3 and Fig. 4.5). To explain this time difference between pollen and dinocyst zones one needs to consider that the secondary vegetation requires some time to develop, while the dinoflagellates being unicellular organisms may respond much faster. The observed 40-70 year difference between the beginning of dinocyst and pollen zones is about the time required for establishing a pioneer community in a disturbed area and a complete re-organization of the vegetation (Whitmore, 1975; Stuijts, 1993).

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CHAPTER 5

High-resolution multi-proxy reconstruction of environmental changes in coastal waters of the Java Sea, Indonesia, during the late Holocene

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Abstract

To obtain insight into the natural variability of the coastal ecosystems off southern Kalimantan, late Holocene environmental conditions between ca. 2850 and 990 cal yr BP in the Java Sea were investigated. A 134-cm-long sediment core collected ~50 km off the Pembuang River mouth was analysed for organic-walled dinoflagellate cysts, pollen/spores and biogeochemical parameters, e.g. organic carbon (Corg), total nitrogen (N) and calcium carbonate (CaCO3) as well as carbon and nitrogen stable isotope composition (d13C, d15N). Sediments consist of mixed terrestrial as well as marine organic matter, are characterised by low nutrient uptake and suggest generally low river discharge that is supported by very low pollen and spore concentrations (256 pollen grains cm^{-3} and 20 spores cm^{-3} at maximum, respectively). Foraminifera and coccolithophores dominated the plankton over cyst-producing dinoflagellates and diatoms. Dinoflagellate cyst assemblages are composed mainly of oxidation-resistant species of the genera *Operculodinium* and *Spiniferites* with a minor contribution of *Impagidinium* (mainly *I. strialatum*). The percentages of round brown and peridinioid cysts are low and decrease from the bottom of the core to the top. Palynological and biogeochemical data appear well correlated and synchronously reflect changes in the marine environment. It is reconstructed that after ca. 2480 cal yr BP, bottom waters became increasingly ventilated. A typical open-water dinoflagellate cyst association is gradually replaced by a more coastal association between ca. 2480 and 1530 cal yr BP that is most likely attributed to El Niňo-induced seasonal differences between dry and wet periods of the year. After 1530 cal yr BP, a more pronounced influence of the Pembuang River is indicated by an increase in d15N and decreased d13C which is supported by the occurrence of nutrient-sensitive *Lingulodinium machaerophorum* and *Nematosphaeropsis labyrinthus*. The overall results indicate short-scale local environment fluctuations attributed to abiotic factors.

5.1. Introduction

Over the last decades, coastal regions in the tropics have become increasingly influenced by anthropogenic activities. Since these regions are of major economic and environmental importance, it is essential to maintain their sustainability. One of the regions where anthropogenic pressure has increased strongly during the last decades is the Java Sea, Indonesia. However, apart from anthropogenic forcing, obviously also natural factors influence the coastal ecosystems in this region. For adequate planning of maintenance measurements, it is essential to have insight into the natural forcing as well. This can be achieved by studying ecosystem variability at times of relatively pristine conditions, hence prior to the major industrial/agricultural revolution. This requires detailed high-temporal-resolution information about environmental change in the last few millennia as well as the relations between land and ocean. Coastal sediments are well-known archives that can preserve signatures of high temporal resolution environmental change. By studying the sediments with a multi-proxy approach combining marine palynological (study of marine dinoflagellate cysts and pollen/spores) and biogeochemical techniques, information about past changes in the marine system as well as its relations with changes on the surrounding land can be obtained. Here we use this approach to gain insight into the natural variability of a coastal ecosystem of the Java Sea off southern Kalimantan.

Several palaeoenvironmental studies have been conducted in the Java Sea and in the surrounding islands since the end of the last century. Probably the first scientific paper dedicated to the marine environment of the region was published by Emery et al. (1972). These authors studied the physical water characteristics of the Java Sea and adjacent continental shelf. Detailed descriptions of the climate, marine currents, bottom sediments and biota of the Java Sea are given by Boely et al. (1991) and Durand & Petit (1995). Since then, several studies have focused on the history of ocean current systems, sea level change, and sediment composition (e.g. Gingele et al. 2002; Hanebuth et al. 2000; Horton et al. 2007; Suryantini et al. 2011). Others focused on palaeoenvironmental changes on the surrounding land such as the reconstruction of the palaeoenvironment of Kalimantan (e.g. Anderson & Muller 1975; Morley 1981; Caratini & Tissot 1988; Anshari et al. 2001; Weiss 2002; Anshari et al. 2004; Griffiths et al. 2009; Dommain et al. 2014 and Poliakova et al., 2014, 2015). Until now no comprehensive high temporal resolution land-sea correlation of the region is available. For the Indonesian region, a few studies on the modern organic-walled dinoflagellate cyst associations have been published (Lirdwitayaprasit 1997, 1998; Azanza et al. 2004). Most of these studies focus on toxic algal blooms (Gonzales 1989; Wiadnyana et al. 1994; Bajarias 1995; Matsuoka et al. 1999; Mizushima et al. 2007; Reotita et al. 2008; Furio 2006, 2012 and references therein). In addition, dinoflagellate cysts diversity and spatial distribution in relation to modern local environmental conditions in the eastern Indian Ocean off SE Indonesia and N Australia were presented by Hessler et al. (2013). This work documents three environmental and oceanographic regions characterized by differences in annual sea surface temperature (SST) patterns and nitrogen supply.

To date, palaeoecological studies based on dinoflagellate cyst associations from the Indonesian region are not available. Here we present the first comprehensive study of the dinoflagellate cyst succession during the late Holocene for the time interval between 2850 and 990 cal yr BP. By combining these results with biogeochemical information, we establish a detailed land-sea correlation with decadal resolution of the coastal Java Sea ecosystem, off SE Kalimantan during the late Holocene and estimate the natural and human induced impact on this system.

5.2. Study site

The Java Sea is a large (310,000 km^2) shallow sea (in general between 100 - 40 m water depth) on the Sunda Shelf which lies between the islands of Kalimantan (Borneo) to the north, Java to the south; Sumatra to the west and Sulawesi to the east (Figure 1). In the west, it is open to the Indian Ocean, the South China Sea by the Sunda Strait and the Karimata Strait, respectively. In the east, it has an open connection to the Flores Sea and to the Celebes Sea through the Makassar Strait (Durand & Petit 1995; Genia et al. 2007).

The Pembuang (Seruyan) River is one of the peat draining rivers in Indonesia (see map in Couwenberg et al. 2009) and is one of the longest among the rivers of the Indonesian province of Central Kalimantan that flows into the Java Sea. It stretches over 350 km draining a catchment of about 200 km^2 (http://eyeglobe-indonesiaku.blogspot.de/2009/11/central-kalimantan.html).

At the present time, the area has a tropical monsoon climate characterized by a reversal of the wind and marine current regimes (Writky 1961; Durand & Petit 1995) with an eight-month rainy season and four-months of a drier season. The rate of precipitation varies from 2,776 to 3,393 mm with about 145 rainy days per year (http://eyeglobe-indonesiaku.blogspot.de/2009/11/central-kalimantan.html). It is strongly influenced by the climate anomaly known as El Niňo Southern Oscillation (ENSO), with its two extreme faces, El Niňo and La Niňa that can respectively decrease and increase precipitation rates over the Indonesian Archipelago. These phenomena cause heavy rainfall during the NW monsoon between December and March and may cause severe droughts occurring during the SE monsoon season between June and October (e.g. Ropelewski & Halpert 1987; Aldrian & Susanto 2003). The summer monsoon is relatively weak compared to the winter monsoon (Liu & Xie 1999).

The annual average sea surface temperature (SST) in the Java Sea is about 28 °C with some small variation of 2°C (Wrytki 1961). Sea surface salinity (SSS) in the study area varies from relatively low values of 30.6-32.0 in the near-shore areas where the rivers of Kalimantan (e.g. Pembuang, Mendawai, Barito) discharge to about 34 in the more offshore regions.

The Java Sea water dissolved oxygen is about 4.5-4.7 mg l^{-1} near the bottom and about 5 mg l^{-1} at the surface (Boely et al. 1991; Sadhatomo 2006). According to the World Ocean Atlas (2009), the waters off the south-eastern cost of Kalimantan are slightly less well ventilated compared to the waters in more western parts of the sea. However, this difference in the dissolved oxygen does not exceed 0.2-0.5 µmol l^{-1} and is too small to form a distinct environmental gradient. Distribution of the chlorophyll-*a* has a clear pattern within the study area: off Kalimantan it is relatively low (1.5 mg m^{-3}) while in the eastern part of the sea it is comparably high and may reach 3 mg m^{-3}.

5.3. Material and Methods

5.3.1. Sediment core

Sediment material for this study (core 1612-23; S3° 35' 21.84" E112° 44' 13.56", Figure 1) was collected about 50 km off the Pembuang River mouth, from a water depth of 20 m. The core is 134 cm-long and is composed of relatively dry pale-grey silt sandy sediments, slightly brownish towards the upper part and containing many irregular fragments of shells and siliceous material that ranges in size from angular blocky pieces up to 1.5 cm in length to small (1-2 mm) sand-sized particles.

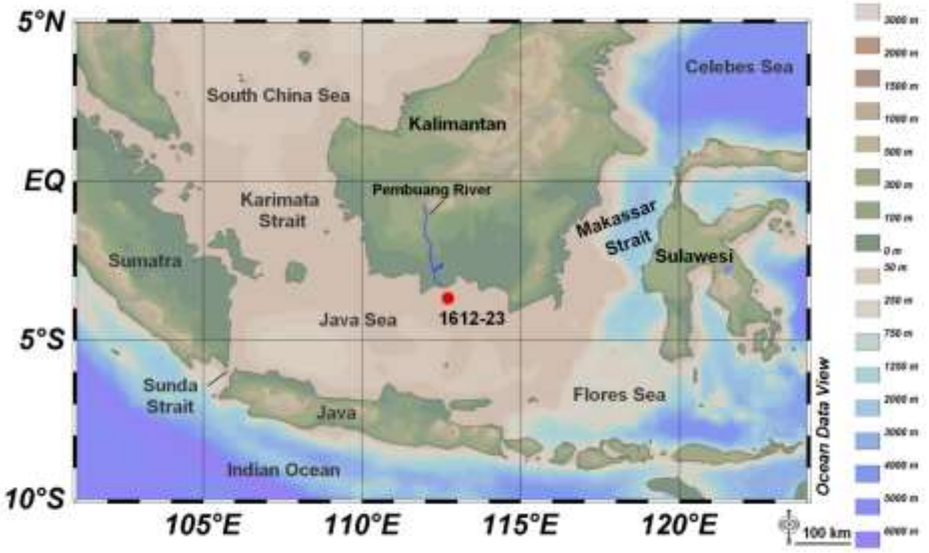

Figure 1. Study area with main water depths, land orography (delivered from the World Ocean Atlas 2009) and a position of the study site (marked with a dot). The map was created using the Ocean Data View software (Schlitzer 2014).

5.3.2. Age control

The age control for the investigated sediment core is based on accelerator mass spectrometry (AMS) radiocarbon dating that has been conducted at the Keck Carbon Cycle Accelerator Mass Spectrometry Facility at the University of California (Irvine, USA). Five radiocarbon dates obtained from mixed benthic foraminifera and are presented in Table 1. The results have been corrected for isotopic fractionation with $\delta^{13}C_{org}$ values according to the method described by Stuiver & Polach (1977) and calibrated to calendar years with the online version of CALIB 7, marine 13 (Stuiver & Reimer 1986, 1993; Stuiver et al. 1998, 2005; nhttp://calib.qub.ac.uk/calib) considering a reservoir age of 90 yr (Southon et al. 2002). To create an age-depth model, a linear extrapolation approach was used.

Table 1. Radiocarbon dates obtained from the sediment core 1612-23.

Depth, cm	UCIAMS lab no.	14C age, yr BP	± error, yr BP	calendar age, cal yr BP (P=1950)	dated material
7-8	123503	1605	20	1071	benthic foraminifera

31-32	133821	1895	20	1357	epibenthic foraminifera
51-52	145985	2025	25	1485	epibenthic foraminifera
81-82	133822	2275	20	1778	epibenthic foraminifera
106-107	145986	2760	25	2379	epibenthic foraminifera
127-128	123483	3060	20	2748	benthic foraminifera

5.3.3. Marine palynological analysis

Samples for marine palynological analysis were collected at 2 cm intervals along the core. Three grams of dry sediment were processed following a slightly modified palynological technique (Erdtman 1960; Faegri & Iversen 1975; Moore et al. 1999; Zonneveld et al. 2009). Samples were dried at 60°C for 24 h and weighed. In order to remove all macro-remains, material was wet sieved over a 150 µm mesh sieve. Prior to chemical treatments, a *Lycopodium clavatum* tablet (Stockmarr 1971) with a known number of spores (20,848 ± 1546) was added to each sample. For the removal of carbonate, cold hydrochloric acid (HCl 10%) was added in amounts depending on the intensity of the reaction. The siliceous component was removed by adding cold hydrofluoric acid (HF 72%). When samples contained high amounts of sand that could not be removed with a single HF treatment, this step was repeated. After chemical treatment, samples were washed with distilled water and centrifuged for 5 min at 3500 rpm. Each residue was sieved over a nylon 10 µm filter in order to remove smaller fractions. No acetolysis or ultrasonic treatment was applied in order to avoid any potential damage of the dinoflagellate cysts and pollen/spores (e.g. Marret et al. 2009). Microscope slides were prepared by embedding the residue in glycerine jelly and isolated from air by a transparent nail polish. Dinoflagellate cysts and pollen/spores were counted using a light microscope (Zeiss Axiostar Plus) at x400 to x1000 magnifications until 150 identified dinoflagellate cysts had been registred.

The taxonomy of dinoflagellate cysts is based on Zonneveld (1997), Fensome & Williams (2004), Kawamura (2004) and Zonneveld & Pospelova (2015). *Echinidinium* spp. includes all spiny brown cysts that could not be identified to species level. *Brigantedinium* spp. includes all smooth-walled spherical brown cysts without processes (RBC). *Spiniferitus hyperacanthus* was grouped with *Spiniferites mirabilis s.l.,* cysts of *Protoperidinium nudum* are grouped with *Selenopemphix quanta*.

A cumulative dinoflagellate cyst diagram (Figure 2) was created using the TILIA/TILIAGRAPH (Grimm 1987) software. It presents relative abundances of individual dinoflagellate cyst types that were calculated on basis of the total sum of dinoflagellate cysts excluding indeterminate cysts. Cyst groups were established based on their common ecological characteristics and modern geographic distribution patterns (Zonneveld et al. 2013): offshore cysts, costal-water cysts and cosmopolitan cysts. Group sums as well as sums of phototrophic (Figures 3-4) and heterotrophic cysts (Figure 5) accompany the relative abundance profiles of single dinoflagellate cyst types. Furthermore, dinoflagellate cysts and pollen/spores concentrations (palynomorphs per gram dry sediment) are given (Figure 2).

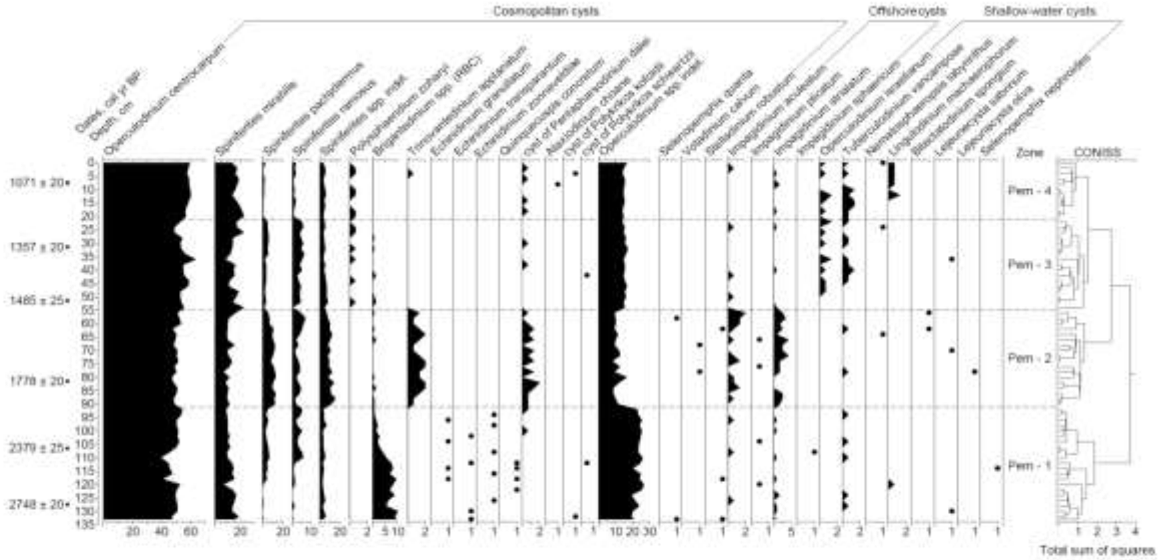

Figure 2. Organic-walled dinoflagellate cyst diagram showing relative abundances of the individual dinoflagellate cysts, sums of cosmopolitan, offshore, coastal-water cysts, phototrophic and heterotrophic species, dry bulk concentrations of dinoflagellate cysts, pollen and fern spores, sedimentation rates and a CONISS cluster-diagram based on total sum of squares. Presence of cysts types contributing to the dinoflagellate cyst total sum less than 2% on average depicted as black dots.

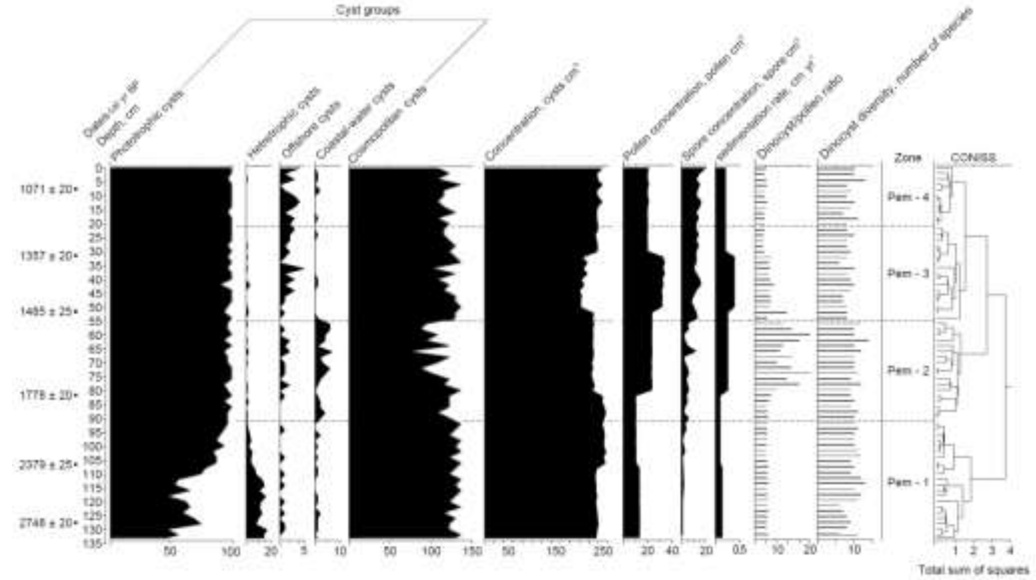

Figure 2. (continuation)

The dinoflagellate cyst record was subdivided into zones that contain successive samples with a common cyst association. Definition of the zones was established by combining empirical observations with the results of constrained cluster analysis by sum-of-squares using CONISS for

TILIA (Grimm 1987). The stability of the classification and the sharpness of the clusters were tested using the bootstrap resembling performed in MULTIV (Pillar & Orlóci 1996; Pillar 1999).

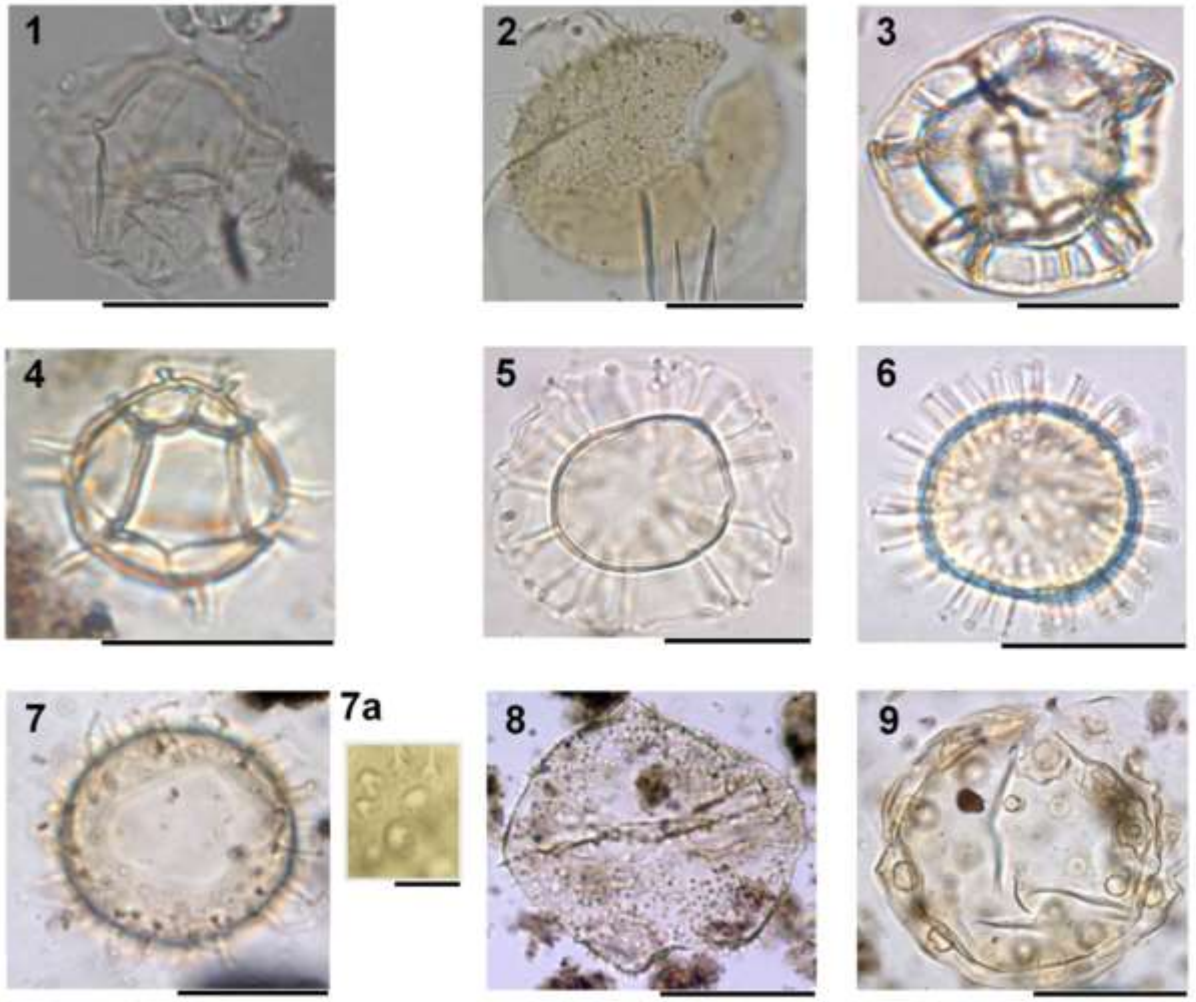

Plate 1. Light microscope photographs of selected phototrophic taxa found in the sediment sequence 1216-23: 1 - *Ataxodinium choane* Reid 1974; 2 - *Bitectatodinium spongium* (Zonneveld 1997) Zonneveld et Jurkschat 1999 ; 3 - *Impagidinium strialatum* (Wall 1967) Stover et Evitt 1978; 4 - *Impagidinium aculeatum* (Wall 1967) Lentin et Williams 1981 ; 5 - *Nematosphaeropsis labyrinthus* (Ostenfeld 1903) Reid 1974; 6 - *Operculodinium centrocarpum* sensu Wall et Dale 1966; 7 - *Operculodinium israelianum* (Rossignol 1962) Wall 1967; 8 - *Trinovantedinium applanatum* (Bradford 1977) Bujak et Davies 1983; 9 - *Tuberculodinium vancampoae* (Rossignol 1962) Wall 1967. Scales bars: 20 µm.

5.3.4. Biogeochemical parameters

For biogeochemical analyses, sediments of a layer in 1-3 cm resolution were dried at 40 °C and ground to a fine homogenous powder in a Retsch planetary ball mill PM 100. Samples were analyzed for total carbon (C_{tot}) and total nitrogen (N_{tot}) by high-temperature combustion in a Euro EA 3000 elemental analyzer. Organic carbon (C_{org}) was determined the same way after removal of carbonate by acidification with 1N HCl and subsequent drying at 40°C. Calcium carbonate contents ($CaCO_3$)

were calculated from inorganic carbon ($C_{inorg} = C_{tot} - C_{org}$). Measurements had a precision of 0.02% for C_{tot}, 0.02% for C_{org} and 0.003% for N_{tot}, based on repeated measurements of a standard. The carbon and nitrogen stable isotope composition ($\delta^{13}C_{org}$, $\delta^{15}N$) was determined with a Thermo Finnigan Delta Plus gas isotope ratio mass spectrometer after high temperature combustion in a Flash 1112 EA elemental analyzer. Carbonates were removed prior to the $\delta^{13}C_{org}$ analysis by adding 1N HCl and subsequent drying at 40 °C. Values of $\delta^{13}C_{org}$ and $\delta^{15}N$ are given as ‰-deviation from the carbon isotope composition of the PDB standard and the nitrogen isotope composition of atmospheric air, respectively. The analytical precisions of the methods determined by repeated measurements of internal standards were 0.07‰ for $\delta^{13}C_{org}$ and 0.09‰ for $\delta^{15}N$. Biogenic silica was extracted from 15 mg ground sediment subsamples by a method modified from Mortlock & Froelich (1989) and detected using a Spectro Ametek Ciros Vision ICP-OES (inductively coupled plasma optical emission spectrometry). Raw data of the dinoflagellate cyst counts and biogeochemical data are stored in the PANGEA database: http://pangaea.de

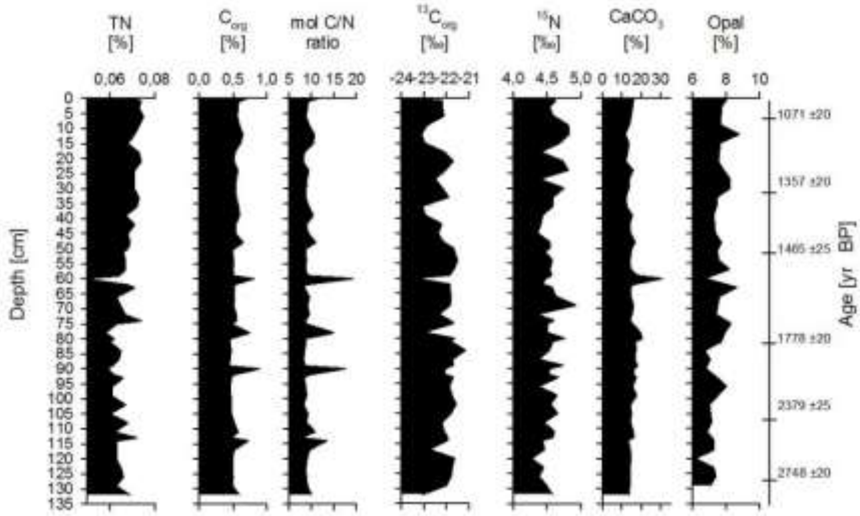

Figure 3. Depth-related changes in total nitrogen content (N_{tot}), organic carbon (C_{org}), stable carbon ($\delta^{13}C_{org}$) and nitrogen ($\delta^{15}N$) isotopes, calcium carbonate ($CaCO_3$) and biogenic opal throughout the core 1612-23.

5.3.5. *Statistical analysis*

To study the relations between the dinoflagellate cyst relative abundances and the biogeochemical parameters, redundancy multivariate analysis (RDA, Rao 1964) was applied using the CANOCO 5 and CanoDraw software package (ter Braak & Šmilauer 2002; Šmilauer & Lepš 2014). All taxonomic data were standardized and logarithmically transformed. The length of the variance gradient was estimated by means of a preliminary detrended correspondence analysis (DCA, Hill and Gauch, 1980). In order to evaluate the significance of the RDA axes, the null hypothesis was tested using the nonparametric Monte Carlo permutation test (Manly 1992). The null hypothesis expects that no relations exist between the variation in relative abundance of the dinoflagellate cyst taxa and biogeochemical sediment parameters. Biogeochemical parameters were tested for linear regressions with depth and correlations with each other using the Spearman test.

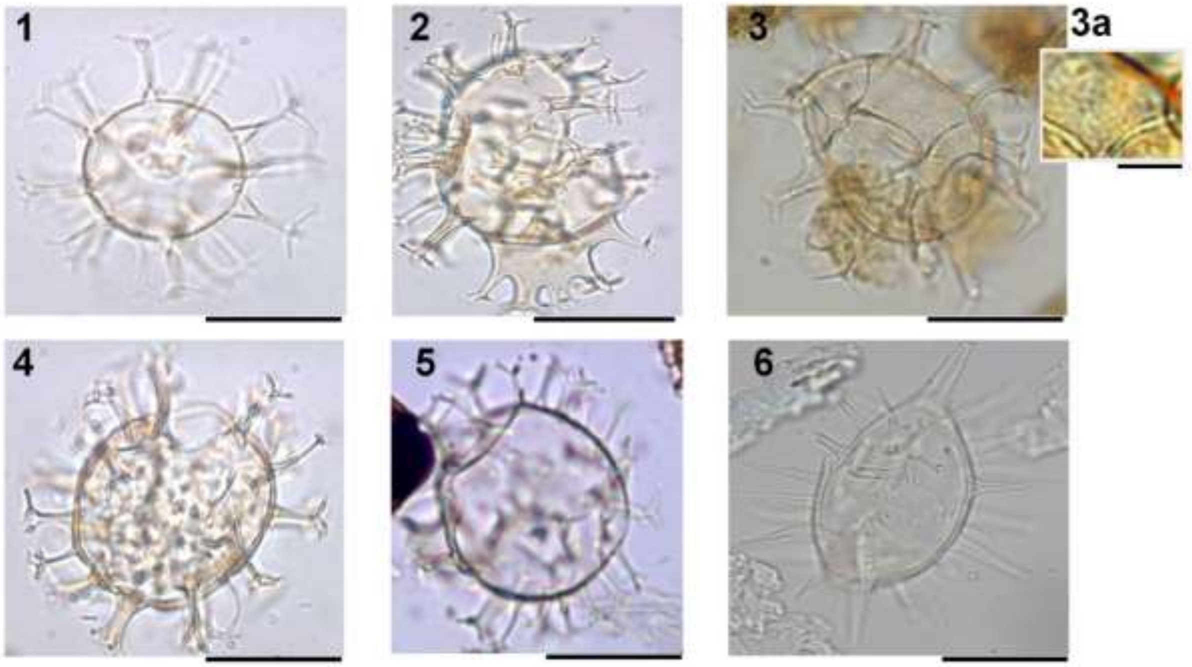

Plate 2. Light microscope photographs of selected phototrophic taxa found in the sediment sequence 1216-23: 1 - *Spiniferites ramosus* (Ehrenberg 1838) Mantell 1854; 2 - *Spiniferites mirabilis* (Rossignol 1964) Sarjeant 1970; 3 - *Spiniferites pachydermus* (Rossignol 1964) Reid 1974; 4, 5 - *Spiniferites* spp.; 6 - *Lingulodinium machaerophorum* (Deflandre & Cookson 1955) Wall 1967. Scales bars: 20 µm.

5.4. Results

5.4.1. Age-depth model and sedimentation rate

Extrapolation of the dates suggests that the base of the core (at 133-134 cm) is as old as about 2850 cal yr BP. The uppermost layer (0-1 cm) dates back to 990 cal yr BP. Estimated sedimentation rates vary along the core from low rates of 0.4 - 0.5 mm yr^{-1} (between 134 and 81 cm) to relatively high rates of ~1 mm yr^{-1} (between 81 and 51 cm) and ~1.6 mm yr^{-1} (between 52 and 32 cm) decreasing to ~0.8 mm yr^{-1} in the upper part of the core (32-0 cm). From 90 to 50 cm, the sand content increases, whilst after 50 cm towards the top it slightly decreases again.

5.4.2. Dinoflagellate cyst stratigraphy

5.4.2.1. General patterns

Based on the taxonomic composition of the dinoflagellate cyst association supported by CONISS analyses, four distinct dinoflagellate zones are described (Pem-1 to Pem-4, Figure 2). Despite being suggested by the cluster analysis, no additional subzones in Pem-1 and Pem-3 are derived as the species composition change of these subzones is not significant ($p>0.05$) and the probability (P; $1 \leq P>0$) for two given sub-clusters was low: $P=0.45$ (Pem-1) and $P=0.3$ (Pem-3; Pillar, 1999). These sub-zones are, therefore, not presented in the diagrams and are not considered for the further analysis.

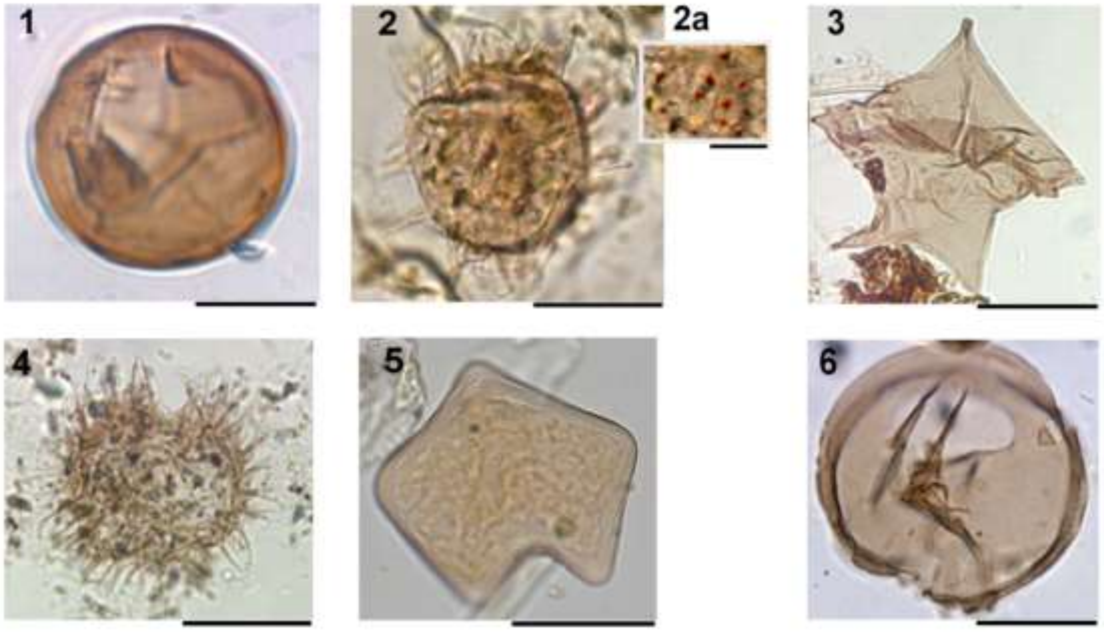

Plate 3. Light microscope photographs of selected heterotrophic taxa found in the sediment sequence 1216-23: 1 - *Brigantedinium* sp. (RBC) Reid 1977 ex Lentin et Williams 1993; 2 - *Echinidinium transparantum* Zonneveld 1997; 3 - *Stelladinium robustum* Zonneveld 1997; 4 - *Selenopemphix quanta* (Bradford 1975) Matsuoka 1985; 5 - *Votadinium calvum* Reid 1977; 6 - *Selenopemphix nephroides* (Benedek 1972) Benedek et Sarjeant 1981. Scales bars: 20 µm.

Most of the dinoflagellate cyst association is composed of warm water and fully marine cysts, predominantly by the transparent oxidation-resistant species of the genera *Operculodinium* and *Spiniferites* with minor contributions of *Impagidinium (*mainly *Impagidinium strialatum*) and brown coloured oxidation-sensitive cysts, both round (i.e. *Brigantedinium* spp.) and spiny (*Echinidinium* spp.) as well as various other but not well preserved peridinoid dinoflagellate cysts. The amount of pollen and fern spores is low, 256 pollen grains g^{-1} and 20 spores g^{-1} at maximum, respectively.

5.4.2.2. Zone description

Zone Pem-1 (134-91 cm; 11 samples)

Sediments of this zone were deposited between ca 2850 and ca 2480 cal yr BP (Figure 2). The dinoflagellate cyst association is dominated by oxidation-resistant species (~70%) with *Operculodinium centrocarpum* contributing almost a half of the total amount (about 50%). *Spiniferites mirabilis* forms about 12% of the association. *Spiniferites pachydermus* and *Spiniferites ramosus* contribute 3% each. *Impagidinium strialatum* and *Tuberculodinium vancampoae* occur regularly but contribute less than 1%. Values of the oxidation-sensitive cysts are generally low but compared to the other zones form the highest for the entire record (~10%) with round brown cysts (*Brigantedinium* spp.) being most dominant (~5%). *Echinidinium* species are restricted to this zone where they are constantly present. At the depth interval between *Quinquecuspis concreta* occurs between 120 and 110 cm. The concentration of dinoflagellate cysts is about 242 cysts g^{-1}; pollen concentration is very low, ~12 pollen g^{-1}.

Zone Pem-2 (91-55 cm; 17 samples)

Sediments were deposited between ca 2480 and ca 1530 cal yr BP. The cyst association displays a slight increase in oxidation-resistant cysts (~75%, Figure 2) due to the increase in the proportions of *S. pachydermus* (~10%) and *Impagidinium* species (~3%). Values of *O. centrocarpum*, *S. mirabilis* and *S. ramosus* stay almost unchanged, being about 50%, ~10% and ~2% of the association respectively. In this zone, occurrences of *T. vancampoae* are rare. *Trinovantedinium applanatum* as well as the cysts of *Pentapharsodinium dalei* contribute together ~2% of the association. Oxidation-sensitive cysts contribute ~3% only and are almost exclusively formed by *Brigantedinium* spp. *(*~2%). Some single specimens of peridinioid cysts are registered sporadically in the samples. The concentration of dinoflagellate cysts is ~235 cysts g^{-1}; pollen concentration increases to about 20 pollen g^{-1}.

Zone Pem-3 (55-21 cm; 11 samples)

Sediments were deposited between ca 1530 and ca 1250 cal yr BP. In this zone, again an increase in oxidation-resistant cysts (~78%) is observed. Values for O*. centrocarpum* (~60%, Figure 2) and *S. mirabilis* (~15%) slightly increase, while the proportions of *S. pachydermus* (~4%) decrease markedly. Above 50-45 cm, *O. israelianum*, *P. zoharyi* and *T. vancampoae* occur regularly as compared to *Impagidinium* species which are seldom observed. The heterotrophic species *T. applanatum* is not seen in this zone. The proportion of oxidation- sensitive cysts decreases to ~1% due to the decrease in *Brigantedinium* spp. The concentration of dinoflagellate cysts decreases to ~218 cysts g^{-1}, whilst pollen concentration slightly increases (~28 pollen g^{-1}).

Zone Pem-4 (21-0 cm; 11 samples)

Sediments were deposited between ca 1250 – 990 cal yr BP. They are characterized by a strong dominance of oxidation-resistant cysts (up to 80%, Figure 2) with a high abundance of *O. centrocarpum* (about 60%) and *S. mirabilis* (~17%). Values for *S. pachydermus* decrease to ~2%; *S. ramosus* and *T. vancampoae* occur regularly unlike *T. applanatum,* which is only sporadically present.

Impagidinium species contribute less than 1% to the association. From a depth of 15 cm upwards, *Lingulodinium machaerophorum* is constantly present. Oxidation-sensitive cysts contribute only ~2% to the association and have a disruptive profile in this zone. The concentration of dinoflagellate cysts is ~240 cysts g^{-1}; pollen concentration is ~20 pollen g^{-1}.

5.4.2.3. *Biogeochemical profiles*

Contents of N_{tot} and C_{org} in the sediments (Figure 6) is overall relatively low (mean ± SD N_{tot}: 0.07±0.02%; C_{org}: 0.55 ± 0.09%). Contents of N_{tot} decrease with depth (r^2=0.34, p<0.0001). At 60 cm, 78 cm, 90 cm and 114 cm, C_{org} contents are elevated and N_{tot} contents decrease. The molar C/N ratios, which are usually around 10, increase to values between 14 and 18 (Figure 6); $\delta^{13}C_{org}$ values are usually around -22‰ and are lower (-23 to -24‰) at the depths mentioned above as well as at 12 cm and 36 cm. There are strong negative correlations of $\delta^{13}C_{org}$ with the C/N ratios (Spearman, r^2=-0.71, p<0.001) and with C_{org} contents (Spearman, r^2=-0.78, p<0.001); $\delta^{15}N$ displays only small variability (mean ± SD: 4.5 ± 0.1‰). Carbonate contents are mostly around 15% with exception of those at 60 cm and 78 cm (Figure 6), where they amounted to 30% and 20%, respectively. Biogenic opal contributes usually 7-8% and displays a slight increase towards the top (linear regression analysis: r^2=0.27, p<0.001). Biogenic opal contents were always lower than $CaCO_3$ contents.

5.4.2.4. *Results of multivariate analysis*

After DCA had revealed a gradient of 1.5 standard deviation (SD), RDA redundancy analysis (RDA) was applied as recommended by Šmilauer & Leps (2014) for data sets with short environmental gradients (i.e. environmental gradients less than 2 SD). The first two dimensions of the RDA (Figure 7) account for 48% and 12% of the total variance of dinoflagellate cyst taxa and biogeochemical data. The ratio λ1+λ2 / total variance, a measure of the goodness of fit equivalent to R^2 (Jongman et al. 1987), is 0.84. The relative distance between samples explains the differences in dinoflagellate cyst composition.

As it is shown (Figure 7A), most of brown-coloured heterotrophic dinoflagellate cysts (e.g. *Brigantedinium* spp., *Echinidinium granulatum, Echinidinium transparantum*, *Echinidinium zonneveldiae*) are positively correlated with $\delta^{13}C_{org}$ and are negatively correlated with opal content and most of the abundant phototrophic cysts. *Operculodinium centrocarpum, Operculodinium israelianum, Polysphaeridium zoharyi, Spiniferites mirabilis* and *Tuberculodinium vancampoae* are correlated with N_{tot} and $\delta^{15}N$. *Impagidinium* species, *Spiniferites pachydermus, Spiniferites* spp., and *Trinovantedinium applanatum* are in accordance with C_{tot}, $CaCo_3$ and C/N ratio that are strongly correlated between each other, whereas *Spiniferites ramosus* turn out to be strongly correlated with

C_{org}. All others (Figure 7A) are weakly correlated to other species and presented low abundances in the dinoflagellate cyst assemblages throughout the sequence.

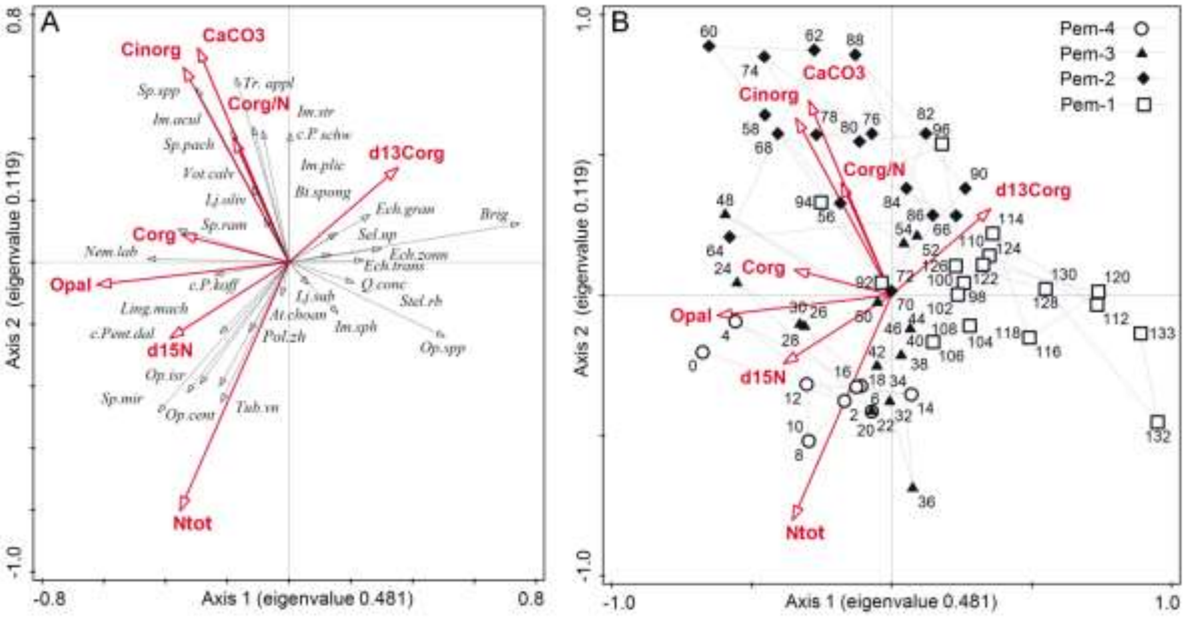

Figure 7. Results of RDA analysis illustrating dinotypes in relation to biogeochemical environmental variables. Biogeochemical parameters are abbreviated as indicated in text. Dinoflagellate cyst types are indicated as following: At.choan - *Ataxodinium choane*, Brig - *Brigantedinium* spp. (RBC), Bt.spong - *Bitectatodinium spongium*, c.P.koff - Cyst of *Polykrikos kofoidii*, c.Pent.dal - cyst of *Pentapharsodinium dalei*, c.P.schw - cyst of *Polykrikos schwartzii*, Ech.gran - *Echinidinium granullatum*, Ech.trans - *Echinidinium transparantum*, Ech.zonn - *Echinidinium zonneveldiae*, Im.str - *Impagidinium strialatum*, Im.acul - *Impagidinium aculeatum*, Im.plc - *Impagidinium plicatum*, In.sph - *Impagidinium sphaericum*, Ling.mach - *Lingulodinium machaerophorum*, Lj.oliv - *Lejeunecysta oliva*, Lj.sab - *Lejeunecysta sabrina*, Nem.lab - *Nematosphaeropsis labyrinthus*, Op.cent - *Operculodinium centrocarpum*, Op.izr - *Operculodinium israelianum*, Op.spp - indeterminate *Operculodinium* spp., Pol.zh - *Polysphaeridium zoharyi*, Q.conc - *Quinquecuspis concretum*, Sel.np - *Selenopemphix nephroides*, Sel.rb - *Stelladinium robustum*, Sp.mir - *Spiniferites mirabilis*, Sp.pach - *Spiniferites pachydermus*, Sp.ram - *Spiniferites ramosus*, Sp.spp - indeterminate *Spiniferites* spp., Tr. appl - *Trinovantedinium applanatum*, Tub.vn - *Tuberculodinium vancampoae*, Vot.calv - *Votadinium calvum*.

Monte Carlo permutations with specific restrictions for time-series analysis were used for both tests concerning only the first RDA axis and a second test including all eigenvalues. Both tests reject the null hypothesis implying that no relation exists between species and the environmental variables at 3.5% level of significance.

Figure 7B shows a positive relations for the most of samples from the lowest dinoflagellate cyst zone (Pem-1, 134-92 cm) to $\delta^{13}C_{org}$ with exception of samples collected from the core depths 116-118 cm and 128 -132 cm. These samples have a high percentage of damaged, broken and therefore undistinguished *Operculodinium* spp., sample from 96 cm because of its high content of C_{org} and samples from the depths 94-92 cm probably due to their increased opal content. Samples from the dinoflagellate cyst zone Pem-2 (90-56 cm) are heterogeneous and show poor correlation with the geochemical parameters. Samples from the dinoflagellate cyst zone Pem-3 (55-21 cm) are correlated with $CaCo_3$ and C/N ratio, and samples from the dinoflagellate cyst zone Pem-4 (20-0 cm) with the opal content, N_{tot} and $\delta^{15}N$. Moreover, samples from the lowest and the highest dinoflagellate cyst zones are correlated negatively with each other.

5.5. Interpretation and Discussion

5.5.1. Taxonomic composition of dinoflagellate cyst assemblages

The organic-walled dinoflagellate cyst assemblages observed in this study are typical for tropical open marine and shallow water environments that are characterized by a relatively low productivity and strong water ventilation (e.g. Marret & Zonneveld 2003; Zonneveld 2013). It is comparable to assemblages observed in other coastal waters in Indonesia, intercontinental shelves and estuaries in other tropical regions of the world such as e.g. the Caribbean Sea, the Yucatan channel, the Bahamas, the Mississippi Sound, Tampa Bay, Gulf of Mexico and a few estuaries in Vietnam (Deflandre & Cookson 1955; Wall & Dale 1977; Head & Westphal 1999; Matsuoka et al. 1999; Edwards & Willard 2001; van Soelen et al. 2010; Limoge 2013).

Our results are mainly in agreement with the “Checklist of dinoflagellate cysts found in the surface sediment samples from the Gulf of Thailand and the East Coast of Peninsular Malaysia” and with species list made for upper Sabah, Sarawak and Brunei Darussalam waters (Lirdwitayaprasit 1997, 1998). It is also in consonance with the dinoflagellate cyst species list compiled for surface sediments of the tropics and Southeast Asian waters by Furio et al. (2012). We observed, however, two to three times lower diversity along the heterotrophic species. Registrations of so-called causative species of paralytic shellfish poisoning or harmful algal blooms in this study are doubtful as the result of the preservation state of cysts in the downcore sediments, with cell content being degraded hampering detailed determination. For instance, for downcore material it is impossible to distinguish between different toxic *Alexandrium* species as the discriminating criteria focus on cell organelles and structures. An exception is the paralytic shellfish poisoning species *Polysphaeridium zoharyi* (theca-based name is *Pyrodinium bahamense* var. *compressum* (Böhm) Steidinger, Tester et Taylor). This species is reported by Matsuoka et al. (1999) in sediment surface samples from Jakarta Bay (Java), Larantuka (Flores) and Ujung Pandang (Sulawesi). In our samples, *P. zoharyi* is observed only in sediments deposited after ca 1485 BP which might suggest the introduction of this species in the research area at this time. Although, abundances of this species never exceed 1-2% of the total dinoflagellate cyst sum (i.e. concentrations of less than 20 cells g^{-1}) which makes it unlikely that this species might have induced water poisoning events in the study area.

In surface sediments along the coast of northwest to Western Australia and Indonesia, the occurrence of relatively high relative abundances of *O. centrocarpum* and *Impagidinium* species is typical for open marine water sites (Hessler et al., 2013). The high relative abundances of these species in the 1612-23 core sediments throughout the studied time interval suggest an open marine environmental setting of the core site.

Hessler et al. (2013) document high relative abundances of *Spiniferites* spp., *S. mirabilis* and *S. ramosus* in surface sediments of western and eastern Indonesia characterized by high surface water temperatures and low nutrient concentrations. A predominant role of *Spiniferites* species from 10 kyr ago was indicated by Murgese et al. (2008) for relatively shallow waters of the Sunda Shelf (Kawamura 2004) and for the coastal waters of Sabah, Malaysia (Furio et al. 2006). These species are among the most abundant species in core 1612-23, suggesting warm upper water-column temperatures at the study site throughout the studied time interval.

5.5.2. Primary production and aerobic decomposition of dinoflagellate cysts

The slight increase in bulk dry concentrations of dinoflagellate cysts and in opal concentrations may point to development of favorable conditions for maintaining high primary production in the Java Sea between ca 2850 and 990 cal yr BP. This would result in a better food base for heterotrophic dinoflagellates and it can therefore be expected that a trend of increase in abundance of cyst of heterotrophic species (e.g. peridinoid cysts, *Echinidinium* species and in *Brigantedinium* spp.) should occur over time. However, we do no observe this. On the contrary, we observe a decreasing diversity trend of heterotrophic dinoflagellate cyst species followed by sharp decrease of their total absolute and relative abundances (Figure 2).

Organic-walled dinoflagellate cysts have a remarkable physical and chemical resistance (Kokinos et al. 1998). However, recent studies have shown that the macromolecular wall composition of the cyst is species-specific with some species being extremely sensitive to aerobic degradations, whereas others are extremely resistant (e.g. Versteegh 2012; Bogus et al. 2012, 2014). It has been shown that that cyst concentrations of many peridinioid species, *Echinidinium* spp., and *Brigantedinium* spp. can vary not only as the result of change in upper water-column primary production, but also from post-depositional selective preservation, which is related to bottom/pore water oxygen concentrations (e.g. Versteegh & Zonneveld 2002; Zonneveld et al. 2007; Zonneveld & Brummer 2000). Hence, the decrease in abundances of *Brigantedinium* spp., *Echinidinium* spp. and peridinioid dinoflagellate cysts in our samples from 2350 cal yr BP (105 cm) onwards, might have been a consequence of aerobic dinoflagellate cyst decomposition rather than changes in upper water bio-productivity.

5.5.3. Reconstruction of changes in the marine environment

Pem-1: ca 2850 - 2480 cal yr BP

This phase is characterized by a dinoflagellate cyst association that is mainly composed of cosmopolitan species (i.e. *Operculodinium centrocarpum, Spiniferites ramosus, S. pachydermus, Spiniferites* spp. and *Operculodinium* spp.). To date, these species are found in regions where surface water has a broad range of SST, SSS and trophic conditions (Zonneveld et al. 2013). High values of *Spiniferites mirabilis* suggest warm water and fully marine conditions at the core site throughout this time interval (Marret & Zonneveld 2003; Zonneveld et al. 2013). The occurrences of the typically open water species *Impagidinium strialatum* suggest that waters from open marine environments reached the core site (e.g. Edwards & Andrle 1992; Zonneveld et al. 2009).

A very low pollen concentration and the almost absence of fern spores in sediments of this zone suggest a limited terrestrial input from the river Pembuang between ca 2850 and 2480 cal yr BP. The C/N ratio is usually around 10, exceeding somewhat that of plankton (6.6) but is lower than that of suspended organic matter carried by peat draining rivers into the Java Sea (16.6) (Baum & Rixen, 2014). This suggests that although the organic material at the sea floor contains of a mixture of terrestrial and marine produced organic matter, the majority of OM found in the sediments has a marine origin. This is corroborated by $\delta^{13}C_{org}$ values that vary around -22‰, which are at the lower end of the range of values typical for tropical marine phytoplankton (-18 to -22‰; e.g. Fischer et al. 1991). Biogenic opal contents are lower than contents of $CaCO_3$ that indicates that the plankton is dominated by foraminifera and coccolithophores, rather than by diatoms and dinoflagellates. This suggests that a quite low productivity regime has existed at the core site during this time interval.

Pem-2: ca 2480 – 1530 cal yr BP

Compared to the previous phase, the composition of the dinoflagellate cyst association has changed notably. The decrease in values of heterotrophic peridinioid, *Echinidinium* and *Brigantedinium* species suggests increased organic matter degradation which can be interpreted as being the result of a better ventilation of the bottom waters. Increased abundance of *Trinovantedinium applanatum* that 'in the region and other parts of the world has its maximal occurrences in upwelling areas and in river plumes regions where large inter-annual variability in the upper water trophic state can occur' (Zonneveld et al. 2009) suggest that more coastal waters reached the core position. This is also in consistence with the somewhat higher pollen concentrations found in this zone.

Sea-level reconstructions by Griffiths et al. (2009; see Figure 2) based on Red Sea benthic foraminifera and Barbados and Tahiti coral reef studies indicate that sea-level fluctuated remarkably in the region after ca 4000 cal yr BP. Particularly between ca 2000 and 3000 cal yr BP, a slight decrease in sea-level is reconstructed that might suggest that the core site might have become more neritic and surface waters became under influence of more coastal water masses. The presence of relatively high abundances of *Impagidinium* species throughout this zone implies that the core site was influenced by open sea waters as well. These waters might have been flowing to the core site through the Karimata Strait Throughflow that is the strongest surface current in the area connecting the South China Sea and the Java Sea (e.g. Wirtki 1961; Fang 2010; He et al. 2015). Contemporaneous with increased relative and absolute abundances of *Trinovantedinium applanatum,* three events of distinctly higher C/N ratios and lower $\delta^{13}C_{org}$ values are observed. This suggests a higher contribution of allochthonous organic matter at these intervals. It is likely that this is caused by enhanced discharge of terrestrial organic matter from the Pembuang River, due to e.g. floods or short wet periods.

Pem-3: ca 1530 - 1250 cal yr BP

In this period an increased contribution of typically lagoon and shallow waters species can be observed in the dinoflagellate cyst association (notably *Operculodinium israelianum, Polysphaeridium zoharyi* and *Tuberculodinium vancampoae,* e.g. Wall & Dale 1969; Limoges 2013). This suggests that coastal waters more pronouncedly influenced the core site. This is in agreement with the decline in abundances of the typical offshore species *Impagidinium* a*culeatum* and *I. strialatum* as well as the somewhat higher concentrations of pollen/spores found in this zone. A stronger influence of coastal water might have enhanced the trophic conditions in the surface waters and as such bio-productivity. This is reflected by higher biogenic opal contents and $\delta^{15}N$ values around 1350 cal yr BP. A stronger influence of coastal waters on the study site might have been the result of either increased river discharge on the nearby island, or a sea level lowering.

Holocene sea-level reconstructions in SE Asia are limited and fragmentary and often controversial (Woodroffe and Horton, 2005). It is suggested that one (e.g. Geyh & Kudrass 1979; Woodroffe and McLean 1990; Scoffin & Le Tissier 1998; Hanebuth et al. 2000) to three (Tija 1996) Holocene high water stands occurred. However, all these events were subscribed for much earlier time intervals (from 8000 to 2700 ^{14}C yr BP the latest) compared to the changes observed here. Griffiths et al. (2009) postulated a slight increase in sea level between ca 2000 and 1500 cal yr BP followed by a small decrease until the modern level was reached. However, all these studies indicate sea level fluctuated during the time frame of this zone only between 0.5 - 1 m, which is not enough to explain the differences in palynological and biogeochemical signals observed at the study site.

For the nearby Banda Sea (core G5-2-56P), Ganssen et al. (1989) reconstructed that productivity in their study area decreased after 1500 cal yr BP and concluded it to be a result of a weakening of the monsoonal regime. Additionally, Reeves et al. (2013a and related references; 2013b) indicated increasing changes in the environment and enhanced drier overall conditions of the Australasian region between 5000 and 0 cal yr BP, indicative of ENSO in El Niño mode with more extreme El Niño events compared with present. We therefore assume that changes in composition of dinoflagellate cyst assemblages in the Java Sea after ca 1530 cal yr BP are likely to be forced by change in precipitation changes, probably related to short-scale seasonal differences between dry and wet periods, rather than by the sea level change.

Pem-4: ca 1250 - 990 cal yr BP

The occurrence of nutrient-sensitive *Lingulodinium machaerophorum* and *Nematosphaeropsis labyrinthus* and the typical coastal species *Tuberculodinium vancampoae* suggest that an increased amount of coastal and/or river plume waters reached the study site. This might be related to an increased Pembuang River discharge. This is corroborated by biogeochemical data. Lower $\delta^{13}C_{org}$ values indicate higher inputs of terrestrial organic matter. This also makes slightly higher nutrient discharge from the Pembuang River likely. Elevated contents of biogenic opal indicate a temporarily enhanced contribution of diatoms in the phytoplankton suggesting higher productivity during this period. Moreover, increased primary productivity also resulted in a slight increase in the dinoflagellate cyst concentrations. Slight increases in $\delta^{15}N$ values point to more efficient nutrient uptake and enhanced productivity, hence less isotopic fractionation.

5.6. Summary and conclusions

This study provides a reconstruction of palaeoenvironmental conditions in the Java Sea between ca 2850 and 990 cal yr BP. Study of marine palynomorphs and biogeochemical analysis as two independent methods were used to study a sediment core 1612-23 obtained off the Pembuang River mouth (SE Kalimantan, Indonesia). A low sedimentation rate throughout the sequence (0.8 – 1.6 mm yr^{-1}) together with a low C_{org} content (0.4-0.9%) and very low pollen and spore concentrations (256 pollen grains g^{-1} and 20 spores g^{-1} at maximum) suggest open marine conditions with relatively low terrestrial input throughout the studied time period (Schulz & Zabel 2000).

The sedimentary sequences reveal four major units corresponding to distinct environmental changes. For the first unit, dinoflagellate cyst assemblages suggest stable warm water conditions between ca 2850 and 2480 cal yr BP, which are similar to the present day environment in the study area. In the second zone, after 2480 cal yr BP, stronger water ventilation was evidenced. The third zone is characterized by the increase in more coastal water masses reaching the core position between 1530 and 1250 cal yr BP. This might have been the result of El Niño-induced seasonal differences between dry and wet periods of the year. In the latest zone between ca 1530 - 990 cal yr BP, a slight increase in primary productivity was reconstructed that is probably related to an increased Pembuang River discharge.

5.7. Acknowledgements

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5.8. Disclosure statement

No potential conflict of interest was reported by the author.

5.9. Supplemental data

Supplemental data for this article can be accessed here: PANGEA database www.pangaea.de under the name of correspondence author.

5.10. References

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CHAPTER 6

Pollen and fern spores recorded in recent and late Holocene marine sediments from the Indian Ocean and Java Sea in Indonesia

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Abstract

Fossil pollen and spore diversity in marine sediment cores from the coasts off SW Kalimantan and NE Java (Java Sea) as well as modern pollen assemblages collected off West Java in the SE Indian Ocean in a marine sediment trap are documented in this paper. In total, photographic images of 138 pollen and 41 spores including 14 pollen and 32 unidentified spore types are presented in morphological order. Illustrated pollen and spore taxa list may help pollen and spore identification of future palynological investigations focused on the reconstruction of past vegetation, climate and environment dynamics in SE Asia.

6.1. Introduction

With the development of palynology as an applied method in micropalaeontology, palaeoecology and palaeoclimatology and an increased interest in the vegetation-pollen deposition relationship, a number of continental and subcontinental pollen atlases (e.g. list from Hooghiemstra and van Geel, 1998) and databases have been established since the late 1970's (Rowe, 2006): the North American Pollen Database (Grimm, 2000), incorporating the datasets from Canada (Gajewski, 2005), Alaska (Anderson and Brubaker, 1986), eastern North America (Webb and McAndrews, 1976) and the southwestern United States (Davis, 1995); the European Pollen Database (Cheddadi, 2002), PalDat – a palynological dataset based in Austria (Buchner and Weber, 2000), Cambridge University Palynological Online Database (QPG, 2008) and a database for the Northwest European Pollen Flora (Punt et. al., 2003); the Africa Pollen Database (Lézine, 2005); the image collections of Latin American Pollen Database (Marchant et al., 2002) and of the Neotropical Pollen Database (Bush and Weng, 2007).

For Southeast (SE) Asia, only a few sources of the information on pollen are available, such as the Australasian Pollen and Spore Atlas (APSA, 2007), an online accessible database that contains a large collection of pollen and spores images (details on about 15,000 species) and morphological descriptions from the Australasian region. The database deals not only with Australia itself, but also provides information on pollen from tropical India, tropical China, New Guinea, New Zealand, the Hawaiian Islands, Oceania and the Southeast Asia (SE), including the continental (Malay Archipelago) and maritime subregions. The last subregion refers to the vast group of islands located between mainland SE Asia and Australia (Rowe, 2006). Collection of Indonesian fossil and modern pollen photos of Department of Palynology and Climate Dynamics is being developed recently and is also available (Albrecht-von-Haller-Institute for Plant Sciences, the University of Göttingen, Germany: http://www.gdvh.uni-goettingen.de/).

Additionally, a specific GIS atlas provides data on the fossil and modern records of *Ficus* and related species of island SE Asia, Australasia, and the Western Pacific (Jago and Boyd, 2003). The pollen atlas of Malaysia (Kiew and Muid, 1991) describes pollen of 95 species in 84 genera and 43 families with regard of beekeeping. For each species a photograph of the whole plant, the flower, and pollen grain is presented, as well as provided information on pollen size/colour, plant habit (crop, weed or forest taxa) and distribution.

Furthermore, a modern palynoflora of the Philippines (Jagudilla-Bulalacao, 1997) is published. The atlas contains light and SEM microphotographs as well as the morphological key and descriptions of 45 species related to 264 genera and 63 families.

Several papers on pollen morphology are available for Taiwan (Huang, 1972, 1981) and tropical Asia in general (Guinet, 1962; Tilak, 1989). For Malaysian Borneo a paper on the pollen diversity of the Kelabit Highlands (Jones, 2014) presenting microphotographs from pollen grains of about 200 species with a morphological key has been recently published in addition to older pollen studies by Anderson and Muller (1975) on a Holocene peat near Marudi (Sarawak) and a Miocene coal near Berakas (Brunei). Additionally, publications on pollen morphology of selected plant families are available, e.g. by Adam and Wilcock (1999) on Bornean Nepenthes, and by Sofiyanti and Yen (2012), who described pollen grains of Malaysian and Indonesian *Rafflesia*.

Specifically on pollen diversity in Indonesia, since the early 1990s are provided only two publications, a study on the Late Pleistocene and Holocene vegetation of West Java (Stuijts, 1993) and a pollen morphology overview of the main taxa from the SE Asian archipelago (Van der Kaars, 1993). Concerning the pollen and spores in marine sediments in the Indonesian Archipelago, available amount of information is still very limited. Marine palynology started to develop in the region only in recent decades. The first work on the marine palynomorphs in the region was the study on the palynological residues from surface sediments in the Banda Sea (Van Waveren, 1989) where ‘a series of 27 palynomorph types are described and informally categorized’, although the paper does not contain any analysis of palaeomorphs. First pollen analytical works for the Indonesian region were published at the beginning of 1990s (Van der Kaars, 1991; Barmawidjaja et al., 1993) and indicated the potential of marine palynology in the reconstruction of the vegetation of this region. A number of papers were published for the Banda Sea (e.g. Van der Kaars et al., 2000; Ahmad et al., 1995; Spooner et al., 2005), Celebes Sea (van der Kaars, 1991), Sulu Sea (Beaufort et al., 2003), Molucca Sea (Barmawidjaja et al., 1993), Mahakam Delta, Kalimantan (Caratini and Tissot, 1988), Makassar Strait (Yulianto, 2004; Visser et al., 2004), eastern Indian Ocean (Wang, et al., 1999) and southern Indian Ocean (Poliakova et al., 2014), off Sumatra (van der Kaars et al., 2010, 2012).

In this paper, we would like to contribute in filling an important knowledge gap with pollen diversity in the region. We summarize our knowledge gained from the work on marine sediments from the Java Sea and SE Indian Ocean with the aims (1) to provide a documentation of modern and fossil pollen and spores recorded in the last ~3500 yr and (2) to compare pollen diversity indicating different vegetation types described for South Kalimantan and East Java. This work will be relevant to research involving pollen and spore identification and/or focused on the fossil pollen diversity, it may also help in future palynological investigations focused on the reconstruction of past vegetation, climate and environment dynamics in Indonesia as well as in SE Asia in general.

6.2. Modern vegetation as a source for pollen and spore in the Java Sea

Most of pollen and spores found in the marine sediment deposits off Jelai, Pembuang and Solo rivers were transported by wind and river systems and have their main source from the vegetation of South Kalimantan and East Java, respectively. Modern vegetation is briefly described below. However, it needs to be considered that a certain amount of pollen and spores can also be transported over longer distance by wind and in particular by the oceanic circulation (for details see Poliakova et al., 2014).

6.2.1. East Java

River Solo is the longest river in Java (ca. 600 km) with the broad catchment area (15,400 km^2, Whitten, 1996) transporting great amount of the sediments to the Java See. The river has two sources in high mountains, the volcano of Mount Lawu (3265 m elevation) and the Kidul Highlands (ca. 500 m), as well as the early tributary Dengkeng River which has its source in Mount Merapi (2800 m, Whitten et al., 1996, http://wetlands.or.id/).

Modern vegetation of the drainage area is mainly represented by the secondary lowland forest, some freshwater swamp forests, submontane (1000-1500 m), lower montane (1800 and 2400 m), and upper montane (2400-3000 m) forest (Fig. 1) (e.g. Whitten et al., 1996; MacKinnon et al., 1997). Mangroves are represented by only small numbers of individual *Sonneratia* and *Rhizophora* trees. Lowland forest along the coasts of the River Solo is virtually absent; most of its area has been turned into agricultural/aquacultural landscapes. Some remains of the secondary lowland vegetation are characterised by presence of *Acalypha* (Euphorbiaceae), *Ficus* (Moraceae), *Macaranga, Mallotus* (Euphorbiaceae), *Trema* (Cannabaceae), *Pandanus* (Pandanaceae) and other pioneer taxa (e.g. Backer et al., 1965; Van Steenis, 1984; Whitmore, 1984).

Submontane forest in the East and Central Java is dominated by *Castanopsis, Lithocarpus* and *Quercus* (Fagaceae). Mountain forest is characterised by relatively strong vertical zonation and represented mainly by *Engelhardia* (Juglandaceae), Podocarpaceae (*Dacrycarpus, Podocarpus*), Ericaceae, *Myrica* (Myricaceae), Myrsinaceae, and *Weinmannia* (Cunoniaceae) (Van Steenis, 1984;

Kaars and Dam, 1995). Mountain vegetation is regularly suffering from fire, and forest gives way to grasslands (Stuijts, 1993).

6.2.2. South Kalimantan

In Borneo, the Jelai River (ca. 100 km long) separates the Indonesian provinces of Central and South Kalimantan and has the source in the SE slopes of the Schwaner Mountain Range (average height – 500 m; the highest point – Mt. Bukit Raya, 2278 m) and is draining mainly through open areas with shrubs and grasslands particularly at the Central Kalimantan side (http://wetlands.or.id/). At this eastern bank of the Jelai River, a broad and more or less uninterrupted belt of riparian forest occurs (Fig. 1). On the western bank, there is a mosaic of forest and clearings. Although, the main water catchment area for the River Jelai is a peat swamp forest on Gambut and Mendawai land systems, 'the only remaining peat swamp forest occur at the south part of West Kalimantan' (http://wetlands.or.id/) with Anacardiaceae, diverse Dipterocarpaceae, *Elaeocarpus, Engelhardia*, Euphorbiaceae, *Macaranga* and *Mallotus.*

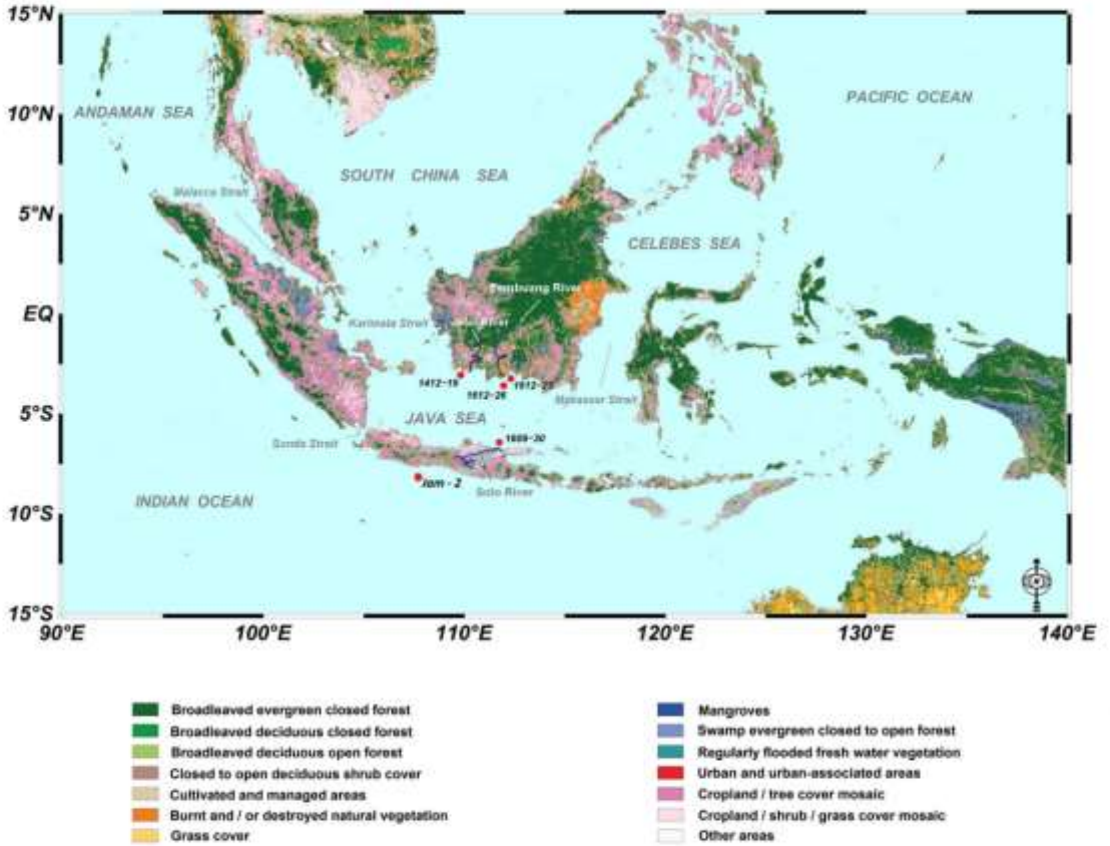


Figure 1. Schematic map of the study area with distribution patterns of main vegetation types. Marine sediment cores and a sediment trap are shown with red dots. Data on the vegetation

distribution are derived from OSGeo website (http://geonetwork-opensource.org) and partly from Stibig et al. (2002).

The River Pembuang (ca. 300 km long) has its source near the Bikit Tikung (1175 m elevation) in the Schwaner Mountain Range. Mangroves in the area of the mouth of River Pembuang are composed of *Avicennia* (Avicenniaceae), *Nypa* (Arecaceae), Rhizophoraceae, Sonneratiaceae, and other taxa. The eastern side of the river contains dense lowland forest down to Sembulu (Belajau) lakes (Rijksen and Meijaard, 1999).

The lowland rainforest of South Kalimantan Borneo has a great diversity (e.g. Whitmore, 1984; Jacobs, 1988; Whitten et al., 1987a, 1987b, Rubeli, 1986; MacKinnon, 1986, 1992; MacKinnon et al., 1997); there are as many as ~240 different species of trees growing within a hectare (Kartawinata et al., 1981; Ashton, 1989). Main types of lowland rainforest of southern Kalimantan are dipterocarp forest, heath forest (in Indonesian: Kerangas), ironwood forests predominating by *Eusideroxylon zageri*, or Belian, a common and commercially valuable species, as well as forests on limestones and ultrabasic rocks. The general characteristics of these forests are canopies 24-36 m high with emergents reaching up to 65 m. Dipterocarpaceae is a dominant family in the emergent stratum. In the richest forests, up to 80% of the emergent trees are dipterocarps: *Dipterocarpus, Dryobalanops, Shorea*. *Hopea* and *Vatica* together with species from Berseraceae and Sapotaceae families are usually found in the main canopy as well.

A third layer occurs below the canopy of shade-tolerant species, adorned with lianas, orchids, and epiphytic ferns. This layer includes many species from the Euphorbiaceae, Rubiaceae, Annonaceae, Lauraceae, and Myristicaceae families. In some cases Euphorbiaceae is more common than dipterocarps, being the second most common family in Kalimantan (MacKinnon et al., 1997).

In submontane and montane areas of Borneo, Whitmore (1984) described five altitudinal floristic zones. These are already described lowland dipterocarp zone (less than 300 m), the hill dipterocarp zone (300-800m), the upper dipterocarp zone (800-1200m), the oak-chestnut zone with Fagaceae and Lauraceae predominant (1200-1500m), and the montane ericaceous zone (higher than 1500m). Upper montane forests share many species and features of the structure and appearance with heath forests (*Eugenia, Rhododendron, Vaccinium*), yet none of the heath forest dipterocarps expends above 1,500m. Only few plants span the complete altitudinal range from lowlands to upper montane forest, e.g. *Dacrydium* (Whitmore, 1984; MacKinnon et al., 1997). The highest altitudes of South Kalimantan bare closed-canopy scrubs.

6.3. Material and methods

6.3.1. Sediment material

This work was based on the modern pollen and spore material collected with the help of an ocean sediment trap, as well as on the fossil material available from the four short marine sediment cores (Fig. 1) that were obtained from four shallow water bore holes drilled in the northern and south-eastern parts of the Java Sea. Core 1412-19 (S3° 15' 28.8"; E110° 38' 59.399"; length 91.5 cm) was taken from the mouth of the Jelai River, SW Kalimantan. Cores 1612-23 (S3° 35' 21.84"; E112° 44' 13.56"; length 134 cm) and 1612-26 (S3° 47' 39.48"; E112° 34' 6.96"; length 100 cm) were retrieved off the Pembuang River plume, South Kalimantan. Core 1609-30 (S6° 29' 49.729"; E112° 28' 31.328"; length 96 cm) was recovered from the mouth of the River Solo, East Java. Age schemes are given in Fig. 2.

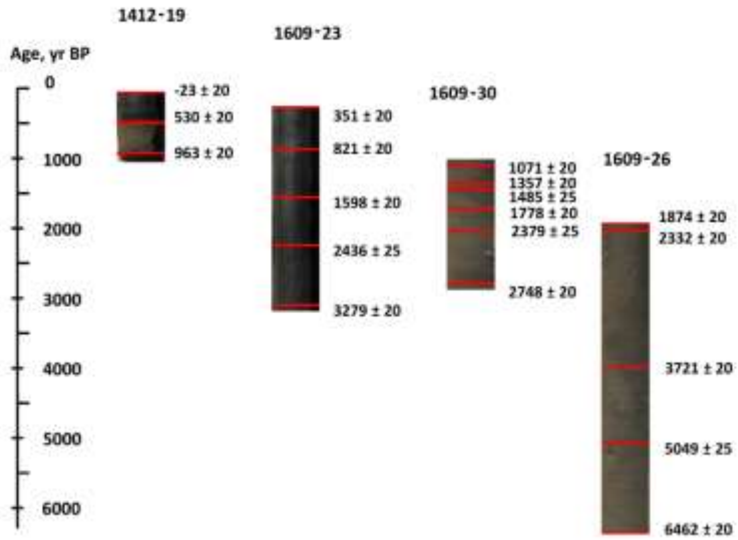


Figure 2. Age schemes of the marine sediment cores used for the present study. Radiocarbon dating (Stuiver and Polach, 1977) and calibration (CALIB 7, marine 13: Stuiver and Reimer, 1993) considered a reservoir age of 90 yrs (Southon et al., 2002).

Additionally, modern pollen and spores from the samples collected with sediment trap JAM-2 (Honjo and Doherty, 1988) (Fig. 1) were studied. Sediment trap had been installed in the SE Indian Ocean (S 08° 17' 30"; E 108° 02' 00") at 2200 m water depth and sampled between December 2001 and November 2002 about 830 m above the seafloor. The sampling interval of the trap was 16 days (Poliakova et al., 2014).

6.3.2. Marine sediments and sample preparation

For pollen and spore analysis, per sample 3 g of sediment was taken from the marine cores. The samples were treated following the standard palynological technique as is described by Faegri and Iversen (1975). First, the samples were filtered using a sieve with a mesh size of 150 µm to remove the larger fraction. Cold hydrochloric acid (HCl 10%) was added for the removal of carbonate in amounts depending on the intensity of the reaction. Siliceous component of the samples was dissolved by adding of hydrofluoric acid (HF 72%). Afterwards, the staining processes known in palynology as the acetolysis (Erdtman, 1952, 1969), was applied. To avoid the dangerous and highly exothermic reaction of the acetolysis mixture with water, dehydration with acetic acid (CH_3COOH) was applied. At the next step, a 9:1 mixture of acetic anhydride [($(CH_3CO)_2O$ 20%] and concentrated sulphuric acid (H_2SO_4 90%) was added and the samples were kept for 10 minutes in the water bath (ca. 90°C). To remove small organic particles (<10 µm), the samples were sieved at a nylon filter at the final stage.

6.3.3. Microscopic photo-documentation

For pollen slides preparation glycerine gelatine was used. The photo documentation was done with the light microscope (Zeiss Axiostar Plus) and ocular magnifications between x200 and x1000 µm dependent on the size of objects. Microphotographs were taken, processed and scaled with the Leica DM 6000 B - CTR 6000B photomicroscope using Leica DFC 320 camera and Leica QWin software adjusted to auto-white-balance, continuous exposure measurement and increased contrast settings. Each pollen and spore type, where it was possible to obtain images, was photographed from both equatorial and polar view, with different focus, from high to low.

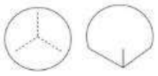
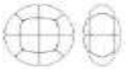
6.3.4. Pollen and spore determination and nomenclature

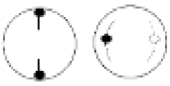
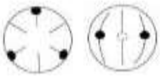
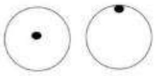
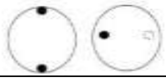
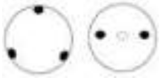
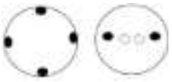
Taxonomy of pollen and spores is based on Moore and Webb (1978), Wang et al. (1995), Jagudilla-Bulalacao (1997), Kodela (2000), Fujiki et al. (2005), Stevenson (2005), APG III (2009) and Mao et al., (2012). In each case, cross-checking with APSA (2007) and with our own reference collection for Indonesia and/or, if applicable, for other tropical areas was applied. Pollen was identified to the genera/species level when possible. In most cases, the family was indicated and if only, “indet.” was added (e.g. Ericaceae indet.). If the definitive specification of the pollen/spore type was some doubtful, the sign “Cf.” was used prior the name. The word “type” was used when including several other taxa, i.e. more than two different genera (e.g. *Dacrycarpus* type). If from the point of view of the morphology two identification possibilities were likely, both taxa was indicated (e.g. Moraceae/Urticaceae). Different morphological types within the same identification were distinguished by different numbers (e.g. Arecaceae indet., type 1 and Arecaceae indet., type 2). In cases when due to the bad preservation of the pollen/spore or because of some other objective reasons, further differentiation was not possible or ambiguous, the name ‘indet. type’ with number was used. *Orhiza type* was distinguished by careful morphological comparison with reference slides from modern Indonesian plants and measuring morphological parameters, i.e. both diameters of a grain, width of annulus and thickness of exine. Furthermore, the literature was used, i.e. Chaturvedi et al. (1998), Maloney (1990), Atahan et al. (2008). Photos of all identified pollen and spores as well as the original slides are available on request at the Department of Palynology and Climate Dynamics (Albrecht-von-Haller-Institute for Plant Sciences, University of Göttingen, Germany). Pollen terminology is followed Lang (1994) and Punt et al. (2007).

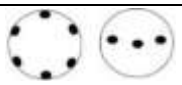
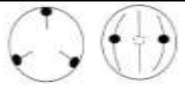
6.4. Results and discussion

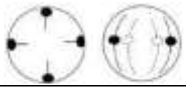
In total, 124 pollen and 9 spore types were identified. Additionally, 14 undetermined pollen and 32 spore types were described. They are presented in 179 plates, following the morphological order (see Table). The analysed samples showed a good preservation of pollen and spores in the sediment material. Most of the pollen types belong to dicotyledonean angiosperms which is equal to 99 (80%, here and further percentage is given based on the total number of identified pollen types, excluding spores and unknown palynomorphs). The number of basal and monocotyledonean angiosperms is 16 (13%). Gymnosperms are represented by 9 types (7%).

Table of spore and pollen types according to their morphology (after Lang, 1994 with additions). Only identified types are included.

Morphological type	Taxa	Plate
Monolete spores 	*Davallia*	1
	Schizaea	2
Trilete spores 	Cf. *Anthocerus*	19
	Cyathea	20
	Dicksonia	21
	Huperzia	22
	Lycopodium	23
	Ophioglossum	24
	Selaginella	25
Vesiculate, saccate grains 	*Dacrycarpus* type	42
	Dacrydium type	43
	Phyllocladus	44
	Picea type	45
	Pinus type 1	46
	Pinus type 2. Cf. *P. sylvestris*	47
	Podocarpus	48
	Tsuga type	49
Polyade grains 	*Acacia*	50
	Albizia	51
Tetrade grains 	*Annona*	52
	Ericaceae indet.	53
	Mimosaceae indet. type	54
Inaperturate grains 	*Agathis*	55

Monosulcate grains 	*Areca*	56
	Arecaceae indet., type 1	57
	Arecaceae indet., type 2	58
	Arecaceae indet., type 3	59
	Arenga	60
	Calamus	61
	Caryota	62
	Chloranthaceae indet.	63
	Iridaceae/Liliaceae indet.	64
	Nypa	65
	Oncosperma	66
	Pinanga	67
Dicolporate grains 	Cunoniaceae indet.	68
Tricolpate grains 	Acanthaceae indet.	69
	Cf. Brassicaceae indet. type	70
	Clematis	71
	Durio	72
	Oleaceae indet., type 1	73
	Plumbaginaceae indet.	74
	Ranunculaceae indet. type	75
Heterocolpate grains 	*Arceuthobium*	76
	Combretaceae/Melastomataceae indet., type 1	77
	Combretaceae/Melastomataceae indet., type 2	78
Monoporate grains 	*Oryza* type	79
	Pandanus	80
	Poaceae indet.	81
	Typha	82
	Zea mais	83
Diporate grains 	*Ficus*	84
	Trema	85
Triporate grains 	*Allophylus*, type 1	86
	Bignoniaceae indet., type 1	87
	Casuarina	88
	Celtis	89
	Cucurbitaceae indet.	90
	Engelhardia	91
	Fabaceae indet., type 1	92
	Myrica	93
	Moraceae/Urticaceae indet.	94
	Onagraceae indet.	95
	Pometia	96
	Sonneratia	97
Tetraporate grains 	*Alnus*, type 1	98
	Allophylus, type 2	99
	Dysoxylum	100
	Garcinia	101

4-6-porate, Stephanoporate grains 	*Alnus*, type 2	102
	Ulmus	103
5-colpate 	*Quintinia*	104
6-colpate grains 	Cf. Bignoniaceae indet., type 2/Cf. Lamiaceae indet.	105
Periporate grains 	*Altingia*	106
	Amaranthaceae indet.	107
	Caryophyllaceae indet.	108
	Cyperaceae indet.	109
	Hibiscus	110
	Juglandaceae indet.	111
	Malvaceae indet., type 1	112
	Malvaceae indet., type 2	113
	Plantago	114
	Thalictrum	115
	Thymeliaceae indet. type	116
Tricolporate grains 	*Acalypha*	117
	Aglaia	118
	Ailanthus	119
	Alchornea	120
	Anacardiaceae indet.	121
	Apiaceae indet.	122
	Artemisia	123
	Asteraceae indet., type 1	124
	Asteraceae indet., type 2	125
	Asteraceae indet., type 3	126
	Avicennia	127
	Barringtonia	128
	Bombacaceae indet.	129
	Bruguiera	130
	Castanopsis/Lithocarpus	131
	Centauria	132
	Clethra type	133
	Dillenia	134
	Dipterocarpaceae indet.	135
	Elaeocarpus	136
	Eucalyptus	137
	Euphorbiaceae indet.	138
	Fabaceae indet., type 2	139
	Hopea	140
	Ilex	141
	Ixora	142
	Loranthaceae indet., type 1	143
	Loranthaceae indet., type 2	144
	Loranthaceae indet., type 3	145
	Lythraceae indet.	146
	Macaranga/Mallotus	147

	Malpighiaceae indet	148
	Myrtaceae indet.	149
	Polygonaceae indet.	150
	Quercus	151
	Rhizophora	152
	Rosaceae indet. type	153
	Rubiaceae indet.	154
	Rutaceae indet.	155
	Salix type	156
	Sapindaceae indet.	157
	Sapotaceae indet.	158
	Symplocos	159
	Verbenaceae indet. type	160
	Vitaceae indet. type	161
	Weinmannia	162
4-colporate grains 	Meliaceae type	163
	Oleaceae indet., type 2	164
Fenestrate grains 	Asteraceae subfamily Cichorideae indet.	165

In terms of the size, the largest of pollen grains (larger than 50 µm) were recorded for Annona (Annonaceae, Appendix, Fig. 54), Malvaceae (Appendix, Fig. 114-115) including *Hibiscus* (Appendix, Fig. 112), Onagraceae (Appendix, Fig. 97), *Picea* type (Appendix, Fig. 47) and *Tsuga* type (Appendix, Fig. 49) (Pinaceae) some of Poaceae, e.g. *Zea mays* (Appendix, Fig. 85), while rather small grains (about 10 µm and less) are represented by, for example, *Aglaia* (Meliaceae, Appendix, Fig. 120), *Elaeocarpus* (Elaeocarpaceae, Appendix, Fig. 137), some of *Ficus* (Moraceae, Appendix, Fig. 86) and *Weinmannia* (Cunnoniaceae, Appendix, Fig. 164).

Pollen diversity reflects regional vegetation sufficiently well; most of vegetation types could be inferred from pollen and spore assemblages both in Kalimantan and in Java. Among pollen, arboreal types estimate 99 (80% of all identified pollen types), while non-arboreal pollen types account 25 (20%). Additionally, two tree ferns, i.e. *Dicksonia* (Appendix, Fig. 23) and *Cyathea* (Appendix,Fig. 22), as well as one spore type of mosses (Cf. *Anthocerus,* Appendix, Fig. 21) were represented. Wet lowland evergreen forest is indicated by 69 pollen types (57% of all identified pollen types), while dry lowland forest is reflected by 4 (3%); 7 pollen types (6%) are related to the submontane and/or lower montane forest and 11 (9%) to the upper montane forest. Some 4-5 of pollen taxa (about 3%) are related to the specifically tropical dipterocarp group, all found in samples off the Jelai and Pembuang rivers flowing through the large peat swamp areas in Kalimantan. Additionally, *Engelhardia* (Appendix, Fig. 93), Myricaceae (Appendix, Fig. 151), *Ilex* (Appendix, Fig. 142), *Pandanus* (Appendix, Fig. 82), and *Durio* (Appendix, Fig. 74) may point to this specific type of the vegetation.

No evidences of dipterocarp forest were obtained for Java as this forest type is virtually absent from most of the island. Mangroves were reflected by 5 pollen types (4 %), all with the sufficient abundance. In the most modern samples, abrupt decrease in mangrove pollen abundance may point to the human activity induced destruction of mangrove belt, on Java especially. Aquatic vegetation was also reflected poorly, by *Typha* (Appendix, Fig. 84) and Cyperaceae indet. (Appendix, Fig. 111) only.

About the half of all pollen types were found both in the sediment core samples and in the samples from a sediment trap. The most abundant pollen types both for pollen trap and for sediment cores were those typical for the lowland rainforest, e.g. *Elaeocarpus* (Appendix, Fig. 137), Moraceae/Urticaceae (Appendix, Fig. 96), Euphorbiaceae (Appendix, Fig. 139) and submontane forest, e.g. *Castanopsis/Lithocarpus* (Appendix, Fig. 144), *Quercus* (Appendix, Fig. 153), *Engelhardia* (Appendix, Fig. 93), *Myrica* (Appendix, Fig. 93). High values (up to 60%) of secondary vegetation taxa, e.g. *Macaranga/Mallotus* (Appendix, Fig. 149), *Acalypha* (Appendix, Fig. 119), *Ficus* (Appendix, Fig. 86), and *Trema* (Fig. 87) point to the wide occurrence of secondary forest and is supported by the modern pattern of lowland vegetation distribution (Appendix, Fig.1).

Montane forest is reflected by *Podocarpus* (Appendix, Fig. 50), *Dacrycarpus* (Appendix, Fig.44), *Phyllocladus* (Appendix, Fig. 46), *Dacridium* (Appendix, Fig. 43), *Myrica, Engelhardia*, and Ericaceae (Appendix, Fig. 55). For all vesiculate pollen long-distance transport cannot be excluded. Relatively frequent are Arecaceae pollen (Appendix, Fig. 58-64 and Fig. 68), particularly *Arenga* (Appendix, Fig. 62), in most of the modern samples. In the samples off Jelai River especially, Arecaceae pollen may indicate palm plantations. Additional indicator for a large formation of plantations in recent times could be the increased abundance of *Eucalyptus* (Appendix, Fig. 138) and occurrence of *Pinus* (Appendix, Fig. 48) pollen in sediment samples taken off East Java. Increased agricultural activity is reflected by a relative increase of large-grained Poaceae, e.g. *Orhiza type* (Appendix, Fig. 81) as well as *Zea mays* (Appendix, Fig. 85).

6.5. Conclusion

This paper provides the first documentation of the pollen and spore diversity in marine sediments from the Java Sea and SE Indian Ocean and presents microphotographic images of 138 pollen/41 spore types, including 124/9 identified and 14/32 unidentified types. We consider this set of digital photographs taken with a light microscope on different focal levels as a base for the further palynological and palaeoecological work. It may help as the comprehensive reference for morphology and taxonomy of fossil pollen and spores recovered from marine sediments in Indonesia and to be the good start for the future detailed studies on such a rich and diverse pollen flora in

Indonesia. However, our knowledge on the pollen and spore flora of the region is still limited, the list of pollen and spores is far from being completed and additional investigations are required.

6.6. Acknowledgements

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CHAPTER 7

Overall discussion and synthesis

7.1. Main research outcomes and discussion

Our studies presented in the previous chapters evidenced that marine sediment material from the Java Sea has a good potential to be used for the palaeoenvironmental reconstruction in Kalimantan and Java. The total of four sequences from the mouth of the River Jelai (core 1412-19, SE Kalimantan), off the River Pembuang (core 1412-23, S Kalimantan) and from the water plume of the River Solo (cores 1609-30, NE Java) contributed to a general picture the of late Holocene environment in Indonesia and SE Asia. In order to obtain possibly more detailed information, a combination of terrestrially-born proxies, such as pollen/spores and microcharcoal were used together with the water-born proxies, i.e. organic-walled dinocysts. This approach helped to enhance our overall knowledge of environment dynamics, history of vegetation and land use in the region, spanning over the last ca 3500 cal years. This novel data can be compared and contrasted with other terrestrial and marine environmental records from the region. In this chapter we derive main outcomes of our work, discuss open questions and give an outlook to the further possible perspectives of marine palynology in Indonesia.

7.1.1. Relations between vegetation and pollen

The issue of relations between vegetation and pollen was addressed in **chapters 3** and **5**. Fossil pollen and spore diversity in the sediment material from the Java Sea reflected neighboring regional vegetation sufficiently; most of vegetation types both from NE Java (the River Solo catchment) and S Kalimantan (basins of the rivers Jelai and Pembuang) are well represented in the pollen assemblages (**chapter 5**). The highest pollen diversity and abundance was detected for Kalimantan and was corresponded to the wet lowland evergreen rainforest. The most abundant pollen group in Java was adjacent to the secondary vegetation and accounted up to 60% of total pollen sum. Pollen from mangroves and submontane/lower montane forest reliably show dynamics of these vegetation types through the time, whilst dry lowland forest and upper montane forest taxa were underrepresented in pollen from all studied cores. Specific and widely distributed in Kalimantan peat swamp forest were evidenced from high abundances of *Engelhardia* pollen as well as from the presence of Myricaceae, *Ilex, Pandanus,* and *Durio* pollen. Dipterocarp forest was represented by *Hopea*, *Shorea,* and indeterminate pollen of Dipterocarpaceae. At present, this forest type is virtually absent from Java, this explains why it was not evidenced for the modern sediments collected with the sediment trap JAM-2 (**chapter 2**), although grains of Dipterocarpaceae were found off the River Solo in sediments dated back to ca 820 cal yr BP and earlier (**chapter 3**).

Aquatic vegetation was reflected poorly, by two pollen types (*Typha* and Cyperaceae indet.) only. Palynologically, herb diversity in Java, where extensive open shrub- and grasslands occur since ca 500-800 cal yr BP (**Chapter 1**, Fig. 1.5. and literature cited), were higher and better reflected than in Kalimantan. Among the land-use indicators, in most of the modern samples were found an increased abundance of Arecaceae pollen, particularly *Arenga* that could have been started to be cultivated for its fiber and as a source of sugar (Stuijts, 1993) since ca 1000 cal yr BP; large-grained Poaceae, e.g. *Orhiza* type and *Zea mays* help to evidence agriculture. For Java, additional indicator of human activity in a form of reforestation could be increased abundance of the *Eucalyptus* and *Pinus* pollen that may point to plantation development as it was suggested by Van der Kaars and van den Bergh (2004).

As the sediment trap study has shown (**chapter 2**), marked amount of accumulated pollen could be related to the long distance transport from continental part of SE Asia and Sumatra (from 7% to 17% of total pollen sum) during NW monsoon season from N Australia (up to 10% of total pollen sum) during the SE monsoon. Vesiculate pollen (e.g. *Pinus* and *Picea*) as well as *Alnus, Quercus* and some herbaceous pollen types like Ranunculaceae indet. and Thymeliaceae indet. could become a subject of aeolian and marine translocation between mid-December and beginning of March, while from beginning of July till November pollen of *Casuarina* and *Eucalyptus* can contribute. Since all of these taxa also naturally grow or are planted in SW Java, it is difficult to make unequivocal conclusions with regard to origin of this pollen in marine sediments.

Maxima of some pollen types (i.e. *Elaeocarpus, Myrica, Dacrycarpus, Casuarina,* and *Podocarpus*) are connected with the flowering periods of related trees. Our work shown that regional patterns of pollen are strongly dependent on the reversal system of winds and marine currents, especially in monsoon-induced climate like one in Indonesia.

7.1.2. Late Holocene vegetation, climate and human impact in Kalimantan and Java inferred from marine and terrestrial proxies

The last ca 3500 years vegetation and land use history of Java (the River Solo catchment) and Kalimantan (basin of the River Jelai) were in a focus of our interest in the **chapter 3**. Main environmental changes indicated for both islands were related to human activity. A decline in primary forest taxa, as it has been reviled for such commercially important timber tree taxa as *Agathis, Allophylus, Dacrycarpus, Dacrydium*, Dipterocarpaceae, *Phyllocladus,* and *Podocarpus*, are a subject of logging in the study area. These changes were correspondent to the increase in pollen of pioneer (e.g. *Acalypha, Ficus, Macaranga/Mallotus,* and *Trema*) and herb taxa indicating openings in the canopy and development of secondary vegetation. In Java, these changes started about ca 2950 cal yr BP that is much earlier than in Kalimantan where the first changes recorded at ca 910 cal yr BP and were less intensive.

7.1.3. Late Holocene environment in the Java Sea

Dinocyst and biogeochemical analysis as two independent methods were applied to a set of the sediment samples obtained off the Pembuang River mouth (SE Kalimantan, **chapter 4**) and show good correlation. The sedimentary sequences revealed four major units, which were corresponded with distinct environmental changes. The first unit (between 2850 and 2480 cal yr BP) indicated tropical fully-marine and shallow water environment that is characterized by a relatively low productivity and is generally similar to recent conditions. Foraminifera and cocolithophores probably dominated the phytoplankton over dinoflagellates and diatoms. After 2480 cal yr BP water ventilation apparently enchased as it was reviled from the elimination of the oxygen-degradable heterotrophic dinocysts. Typically open-water dinocyst association had been gradually changed by neritic one between ca 2040 and 1530 cal yr BP. Afterwards, before ca 990 cal yr BP, more pronounced influence of the Pembuang River was suggested by the increase of $\delta^{15}N$ and decreased $\delta^{13}C_{org}$ values. That is supported by the occurrence of *Lingulodinium machaerophorum* and *Nematosphaeropsis labyrinthus*, good indicators of fresh water input and increased wash-off from land.

A gradual change from relatively well ventilated to more hypoxic bottom/pore water conditions in a more eutrophic environment were also reflected by the dinoflagellate cyst association off the Jelai and the Solo rivers (**chapter 3**), which well corresponds to the changes in vegetation on land. Near the coast of Java, the shift of the water trophic status took place between ca 820 and 500 cal yr BP, while near the coast of Kalimantan it occurred as late as at the beginning of the 20th century. Increasing amount of certain types of dinocysts, e.g. cysts of *Polykrikos schwartzii* and *P. kofoidii*, *Lingulodinium machaerophorum, Nematosphaeropsis labyrinthus, Selenopemphix nephroides* at times of secondary vegetation development on land, pointed to the enhanced input of nitrogen and phosphorus that may be a result of human induced terrestrial changes such as vegetation cover disturbance and soil erosion. Occurrence of these dinocysts were strongly positively correlated with the increase in pioneer taxa and negatively correlated with increase in pollen taxa related to the primary forest vegetation, suggesting that these taxa may potentially be used as palaeoecological indicators of anthropogenic activity.

The signal of intensive logging on land found about 50-70 years later, than the changes in the dinocysts assemblages in the marine realm of the Java Sea. This is in accordance to the time which is required for the vegetation changing, establishing a pioneer community in and a complete re-organization of the vegetation (**chapter 2**; Whitmore, 1975; Stuijts, 1993).

7.2. Open questions

A number of open questions are still left behind this study, mainly, due to the fact that marine palynology in Indonesia is a young area of science and also because of the peculiarities of the study area. First of all, a lot more detailed research on the regional patterns of modern pollen spectra in the Indonesian waters as well as on factors influencing them are required. As our study reviled it for the SE Indian Ocean (**Chapter 3**), both regionally produced pollen and the one brought from a long distances are collected in marine sediments. The proportion of pollen originated from different vegetation sources changes due to the seasonal monsoon reversal and, therefore, reversal of marine currents. The picture became even more complex because pollen transport is depend not only on marine and wind currents, but is also controlled by river regime, local precipitation, vegetation specificity (Sun et al., 2002), flowering periods, processes of pollination, pollen production and pollen preservation. The role of all these factors and their relationships are still unclear and opens a room for further investigations. Moreover, winds/marine currents are not only bringing additional amount of pollen from long distance, they obviously also blowing/washing away some of the regionally produced pollen. Amount of this taken away pollen is so far uncertain and needs to be accurately calculated. This task, however, is not a trivial one, as most of registered taxa do have a broad areas of growth and can be found almost everywhere from South China and Malay Peninsula to Indonesian archipelago and North Australia.

With regard to our understanding of the late Holocene (about the last ca 3500 years BP) vegetation patterns in SE Kalimantan and NE Java (**Chapter 3**), proportion of mountain vegetation, for pollen spectrum of Java especially, seems to be overestimated. Most of Javanese natural forests are destroyed (e.g. Stuijts, 1993) so that the source vegetation for e.g. *Dacrycarpus, Dacrydium, Podocarpus* and *Phillocladus* in Java is limited. As this pollen easily travels over long distance, aeolian transport can contribute to the presence of vesiculate pollen of montane coniferous in marine sediments (Heusser and Balsam, 1977; Heusser, 1988; Sun, 1999), although the rate of this contribution has not been estimated precisely so far.

Another potential challenge is how to separate riparian and peatland forests species based on pollen types **(Chapter 4)**. As the most of riparian and peatland taxa can also grow elsewhere: in lowland forest (e.g. Anacardiaceae, *Celtis,* Dipterocarpaceae, *Elaeocarpus,* and Euphorbiaceae), submontane forest (e.g. *Engelhardia* and *Myrsine)* or can originate from the secondary vegetation (e.g. *Macaranga/Mallotus* and *Pandanus*), it is difficult to say with no doubt which vegetation type do they represent.

As for the fire records, which show enhanced burning since ca 1500 cal yr BP in East Java and since ca 980 cal yr BP in South Kalimantan, it remains unclear, whether these regional fires were of natural or of anthropogenic origin. Even though it is possible that fires can be lit naturally by lightning or during the hot days of droughts, it is often that fires are lit by people. Slush-and-burn system of agriculture is very popular in Indonesia even nowadays as it is simple, easily available and not only clears the land but also improves the soils by means of adding ash. We do not know exactly when this kind of agriculture has been started, but it is very old and widely used technique. Other reasons to set fire can be e.g. a road construction or a clearing place for a new settlement. Thus, the exact reason for relatively high microcharcoal concentrations in late Holocene sediments of the Java Sea is doubtful. We do not possess so far any evidences to prove or to discard any of above described versions.

Being perfect for research on the land use, forest dynamics, eutrophication and other processes related to human activity, cores 1412-19 (South Kalimantan) and 1609-30 (East Java) did not allow us to make any concrete and unequivocal conclusions on natural dynamics (e.g. connected to climate change or to sea level fluctuations) in the study area. The signals of natural dynamics that we discussed in our work were strongly biased by anthropogenic activity.

In terms on dinocyst analysis, our main uncertainties were connected to cosmopolitan species (i.e. *Operculodinium centrocarpum, Spiniferites ramosus, Sp. Pachydermus*) and indeterminate types of *Spiniferites* and *Operculodinium)* that occur in a broad range of salinity and trophic conditions and build up the most of dinocyst association of the core 1612-23 (**Chapter 5**). Whilst the most of these species are typical for warm waters, interpretation of their dynamics is difficult to conduct in terms of regional factors. Furthermore, pollen and dinocyst analysis, alike any other methods of relative stratigraphy, are based on a limited sets of radiocarbon data and linear approach in age-depth modelling that could require more accuracy.

In the light microscopy technique as it was used for pollen analysis, the level of taxonomic differentiation is restricted. Thus, in most cases determination of pollen grains was possible on the genus level or a combination of two or more genera, occasionally even on family level (Birks and Birks, 1980; Demske et al., 2013). This restriction can be crucial, for instance, to distinguish with sure crop cultures from other Poaceae (e.g. *Orhiza* type*;* **Chapter 6**). Sometimes one pollen/spore "type" can include including several different taxa under the same name, and it is not necessarily that they origin from the same vegetation type (e.g. Moraceae/Urticaceae

and psilate/not well preserved *Weinmannia* pollen, pollen of *Saurauia* and *Elaeocarpus*). In some cases, however, inseparable taxa have almost the same biological and ecological characteristics (e.g. in case of *Lithocarpus/Castanopsis* or *Macaranga/Mallotus*) while for the majority of fern spores light microscope determination is almost impossible. Unclear or ambiguous determinations highly influence pollen records reducing their accurateness.

7.3. Concluding remarks

The results obtained during this research project give a good illustration to all advantages of a combined use of independent proxies for environmental reconstructions in SE Kalimantan and NE Java as well as in the Java Sea. Pollen/spore and organic-walled dinocyst records, being applied together, allow better and more comprehensive interpretation on palaeoenvironmental conditions of the past. If driven by the same group of factors (e.g. related to human activity), they show a good correlation as our studies on marine sediment cores 1412-19 (South Kalimantan) and 1609-30 (East Java) illustrated. The hypotheses approached at the beginning of these studies can be addressed as following:

1. Main vegetation communities of SE Kalimantan and NE Java as well as their changes in time are documented in sediments from the Java Sea, although a roll of pollen transported from a long distance (e.g. from the continental Asia, Sumatra, and N Australia) needs to be considered.
2. Anthropogenic environmental changes play greater role in the dynamics of the past communities in SE Kalimantan and NE Java during the last ca 3500 cal yr; the signals of natural dynamics are strongly biased by anthropogenic activity.
3. Anthropogenic activity related to land use (e.g. logging, agriculture and plantations development, aquaculture and/or fires) increased during the Late Holocene/Anthropocene, particularly in Java.
4. Environmental changes are reflected both in pollen/spores and dinoflagellates assemblages; the pollen-based signal from land is delayed about 50-70 years compared to the dinocysts-based signal from the sea.
5. Anthropogenic environmental changes on the island of Java are evidenced to have started about 2000 yr earlier then on the island of Kalimantan.

7.4. Further perspective

Marine palynology in Indonesia is a young branch of research with an open future and a broad range of perspectives. Many efforts are still can be taken in order to understand all complex of relationships between source vegetation and pollen transportation factors that influence a composition of pollen assemblages in marine sediments. Our knowledge of ecosystem dynamics and climate variability in the region during the late Holocene is still limited by the lack of palaeoecological record. Marine sediments as potential palaeoclimate and palaeoenvironment archives are very promising, and further high-resolution multiproxy are expected in Indonesia, in particular in Kalimantan with its unique ecosystems and long history of vegetation development. We can expect increased interest to marine palynology in Indonesia in the nearest future and may look forward to improve our overall knowledge about magnificent nature of Palaeotropics with all its unique and intricate ecosystems on land and in sea. However, one who dears to come to nature for any, even for scientific purposes, should always remember to be as less destructive as one can.

7.5. References

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Appendix A

Complete lists of identified pollen, spores and organic-walled dinocysts types mentioned in the thesis

Appendix A1. Complete list of pollen and spore types mentioned in the thesis

Appendix A2. Microphotographs of all sporeans pollen types mentioned in the thesis

Appendix A1. Complete list of pollen and spore types mentioned in the thesis

name	pollen / spore type	plate	sediment trap JAM2	core 1412-19	core 1609-30	core 1612-23	core 1612-26
Davallia	monolate spore	19		*	*	*	
Schizaea	*monolate spore*	20		*		*	
Cyathea	trilate spore	1	*	*	*	*	*
Disconia	trilate spore	21	*			*	
Huperzia	trilate spore	22	*	*	*	*	
Lycopodium	trilate spore	23	*	*	*	*	*
Ophioglossum	trilate spore	24	*	*	*		
Selaginella	trilate spore	2	*	*	*	*	*
Cf. *Anthocerus*	trilate spore	25		*			
Acacia	polyade	50				*	
Acalypha	tricolporate	117	*	*	*	*	*
Acanthaceae indet.	tricolporate	69	*	*	*	*	
Agathis	inaperturate	55		*	*	*	
Aglaia	tricolporate	118				*	
Albizia	polyade	119					
Alchornea	tricolporate	51	*	*	*	*	
Ailanthus	tricolporate	120				*	
Allophylus, type 1	tricolporate	86	*	*	*		
Allophylus, type 2	tetraporate	99					
Alnus, type 1	tetraporate	98	*	*	*		
Alnus, type 2	5-porate	102	*		*	*	
Altingia	periporate	106				*	
Amaranthaceae indet.	peripor	107	*	*	*	*	
Anacardiaceae indet.	tricolporate	121	*	*	*	*	
Annona	inaperturate	52				*	
Apiaceae indet.	tricolporate	122				*	
Arceuthobium	heterocolp	76					
Areca	monosulcate	56				*	
Arecaceae indet., type 1	monosulcate	57	*	*		*	*
Arecaceae indet., type 2	monosulcate	58	*	*	*	*	
Arecaceae indet., type 3	monosulcate	59		*	*	*	
Arenga	monosulcate	60	*	*	*	*	
Artemisia	tricolporate	123				*	
Asteraceae indet., type 1	tricolporate	124	*	*	*	*	
Asteraceae indet., type 2	tricolporate	125			*	*	
Asteraceae indet., type 3	tricolporate	126			*	*	
Avicennia	tricolporate	165	*	*	*	*	
Barringtonia	tricolporate	127					
Bignoniaceae indet., type 2	tricolporate	128	*	*	*	*	
Bignoniaceae indet., type 2/Cf. Lamiaceae indet.	peripor	87	*	*	*		
Bombacaceae indet.	tricolporate	129				*	
Cf. Brassicaceae indet. type	tricolpate	130					
Bruguiera	tricolporate	61		*		*	
Calamus	monosulcate	108				*	
Caryophyllaceae indet.	peripor	62	*	*	*	*	
Caryota	monosulcate	131	*	*	*	*	
Casuarina	tricolporate	88	*	*	*	*	
Celtis	tricolporate	89	*	*	*	*	

Centauria	tricolporate	132				*	
Chloranthaceae indet.	monosulcate	105		*	*	*	
Asteraceae subfamily Cichorideae indet.	fenistrate	70	*	*			
Castanopsis/Lithocarpus	tricolporate	63	*	*	*	*	*
Clematis	tricolporate	71				*	
Combretaceae/ Melastomataceae indet., type 1	heterocolporate	133	*	*	*	*	*
Combretaceae/ Melastomataceaeindet., type 2	heterocolporate	77	*	*	*	*	*
Clethra type	tricolporate	78	*	*	*	*	
Cucurbitaceae indet.	triporate	90	*	*			
Cunoniaceae indet.	dicolpate	68	*	*	*	*	
Cyperaceae indet.	monoporate	109	*	*	*	*	
Dacrycarpus type	vesiculate	42	*	*	*	*	
Dacrydium type	vesiculate	43			*		
Dillenia	tricolporate	134				*	
Dipterocarpaceae indet.	tricolporate	135		*	*	*	
Durio	tricolporate	72				*	
Dysoxylum	tetraporate	100				*	
Elaeocarpus	tricolporate	136	*	*	*	*	*
Engelhardia	triporate	91	*	*	*	*	
Ericaceae indet.	tetrade	53	*	*	*	*	
Eucalyptus	tricolporate	137	*	*	*	*	
Euphorbiaceae indet.	tricolporate	138	*	*	*	*	
Fabaceae indet., type 1	tricolporate	92		*	*	*	
Fabaceae indet., type 2	tricolporate	139		*		*	
Ficus	diporate	84	*	*	*	*	
Garcinia	tetraporate	101				*	
Hibiscus	peripor	110				*	
Hopea	tricolporate	140					
Iridaceae/Liliaceae indet	monosulcate	141	*	*	*		
Ilex	tricolporate	64	*	*	*		
Ixora	tricolporate	142					
Juglandaceae indet.	peripor	111				*	
Loranthaceae indet., type 1	tricolporate	143		*	*	*	
Loranthaceae indet., type 2	tricolporate	144	*	*			
Loranthaceae indet., type 3	tricolporate	145		*	*		
Lythraceae indet.	triporate	146	*				
Macaranga-Mallotus	tricolporate	147	*	*	*	*	
Malvaceae indet., type 1	periporate	148	*	*			
Malvaceae indet., type 2	periporate	112			*		
Malpighiaceae indet	tricolporate	113			*		
Meliaceae type	4-colporate	163					*
Mimosaceae indet. type	polyade	54	*	*	*	*	
Moraceae/Urticaceae indet.	triporate	94	*	*	*	*	*
Myrica	tricolporate	93	*	*	*	*	*
Myrtaceae indet.	tricolporate	149	*	*	*	*	
Nypa	monosulcate	65	*	*	*	*	
Oleaceae indet., type 1	tricolporate	73	*	*	*	*	

Oleaceae indet., type 2	4-colporate	164	*		*		
Onagraceae indet.	triporate	95				*	
Oncosperma	monosulcate	66	*	*	*	*	
Oryza type	monoporate	79	*	*	*		*
Pandanus	monoporate	80			*	*	
Phyllocladus	vesiculate	44		*	*		
Picea type	vesiculate	45	*				
Pinanga	monosulcate	67					
Pinus type 1	vesiculate	46	*	*	*		
Pinus type 2. Cf. *P. sylvestris*	vesiculate	47	*				
Plantago	peripor	114	*	*	*	*	
Plumbaginaceae indet.	tricolpate	74				*	
Poacaeae indet.	monoporate	81	*	*	*	*	*
Podocarpus	vesiculate	48	*	*	*	*	
Polygonaceae indet.	tricolporate	150				*	
Pometia	triporate	96	*	*	*		
Quercus	tricolpate	151	*	*	*	*	
Quintinia	5-porate	104				*	
Ranunculaceae indet. type	tricolpate	75	*		*		
Rhizophora	tricolporate	152	*	*	*	*	*
Rosaceae indet. type	tricolporate	153	*	*	*	*	
Rubiaceae indet.	tricolporate	154	*	*	*	*	
Rutaceae indet.	tricolporate	155	*	*	*	*	
Salix type	tricolporate	156		*	*		
Sapindaceae indet.	tricolporate	157	*	*	*	*	
Sapotaceae indet.	tricolporate	158	*	*	*	*	
Sonneratia	triporate	97		*	*	*	
Symplocos	tricolporate	159				*	
Thalictrum	periporate	115		*	*	*	
Thymeliaceae indet. type	inaperturate	116	*	*	*	*	
Trema	diporate	85	*	*	*	*	*
Tsuga type	vesiculate	49					*
Typha	monoporate	82		*			
Ulmus	tetraporate	103	*	*	*		*
Verbenaceae indet. type	tricolporate	160				*	
Vitaceae indet. type	tricolporate	161				*	
Weinmannia	tricolporate	162		*	*	*	
Zea mays	monoporate	83	*	*	*		

Note: “indet.” stays if more precise identification than a lavel of family for some objective resons is not possible; “type” indicates that more than one pollen type can be included; “Cf.” - stays for unclear or doubtfull identification; * indicates presence of the pollen/spore type in a sediment core or in the sediment trap samples. Empty cell stays for abcence.

Appendix A2. Microphotographs of all spore and pollen types mentioned in the thesis

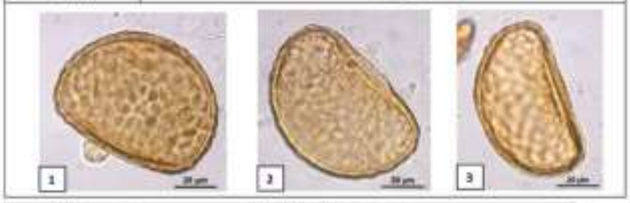


Plate 1
Davallia
Monolete spores

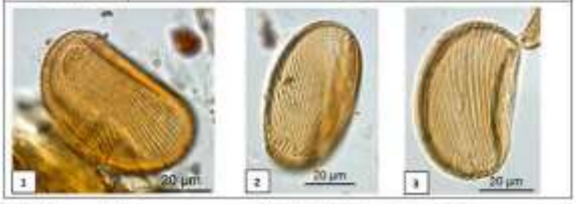


Plate 2
Schizaea
Monolete spores

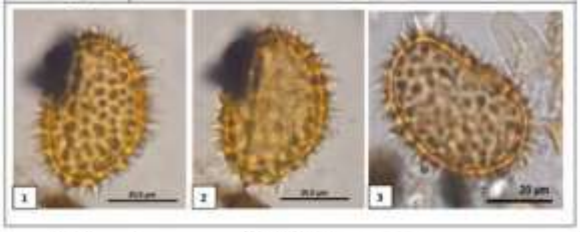


Plate 3
Indet., type 1
Monolete spores

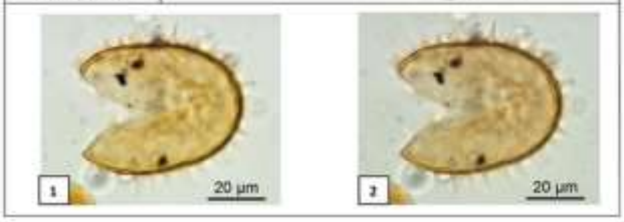


Plate 4
Indet., type 2
Monolete spores

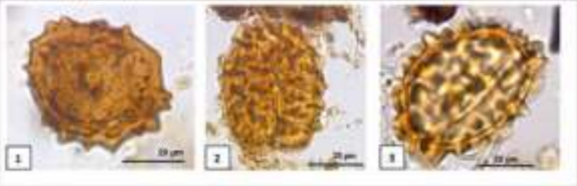


Plate 5
Indet., type 3
Monolete spores

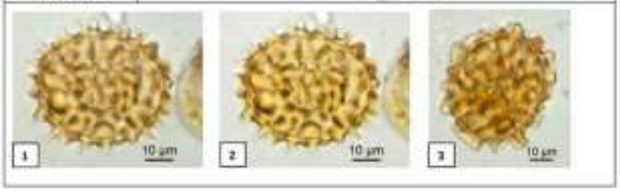


Plate 6
Indet., type 4
Monolete spores


Plate 7
Indet., type 5
Monolete spores

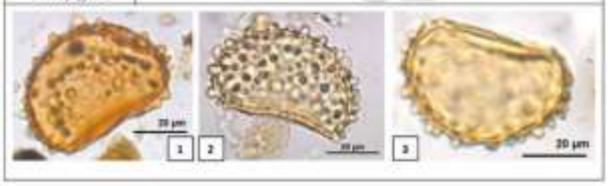


Plate 8
Indet., type 6
Monolete spores

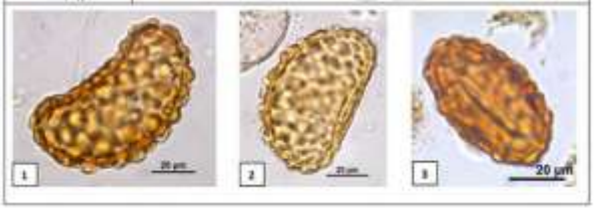


Plate 9
Indet., type 7
Monolete spores

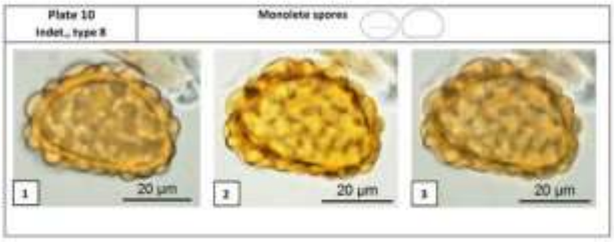


Plate 10
Indet., type 8
Monolete spores

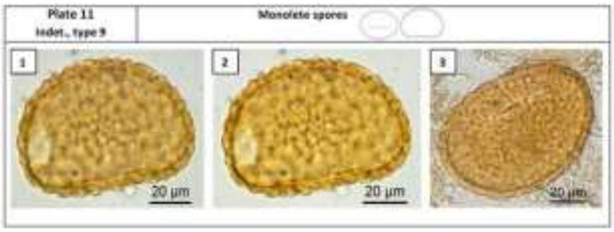


Plate 11
Indet., type 9
Monolete spores

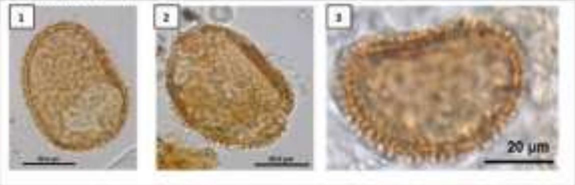


Plate 12
Indet., type 10
Monolete spores

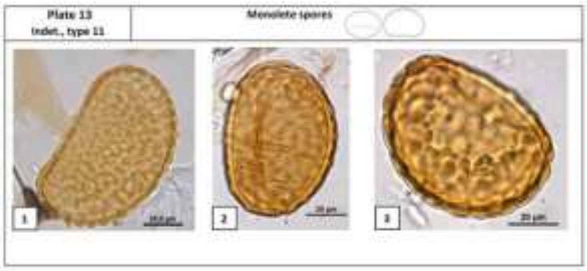


Plate 13
Indet., type 11
Monolete spores

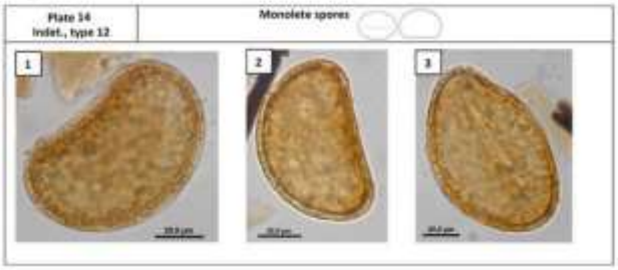


Plate 14
Indet., type 12
Monolete spores

Plate 15
Indet., type 13
Monolete spores

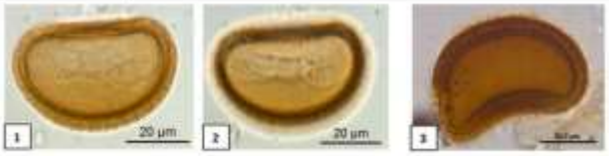


Plate 16
Indet., type 14
Monolete spores

Plate 17
Indet., type 15
Monolete spores

Plate 18
Indet., type 16
Monolete spores

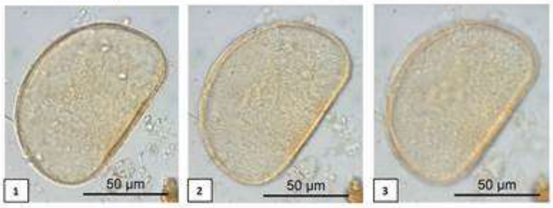


Plate 19
Cf. *Anthocerus*
Trilete spores

Plate 20
Cyathea
Trilete spores

Plate 21
Dicksonia
Trilete spores

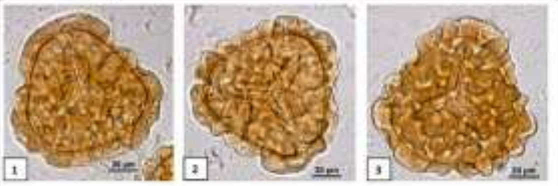


Plate 22
Huperzia
Trilete spores

Plate 23
Lycopodium
Trilete spores

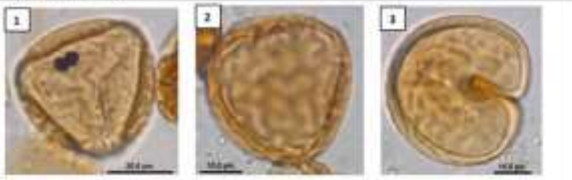


Plate 24
Ophioglossum
Trilete spores

Plate 25
Selaginella
Trilete spores

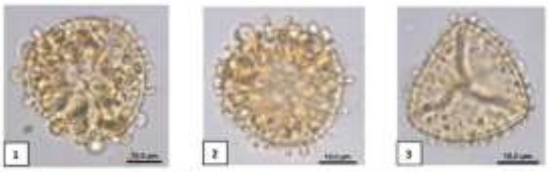


Plate 26
Type 1
Trilete spores

Plate 27
Type 2
Trilete spores

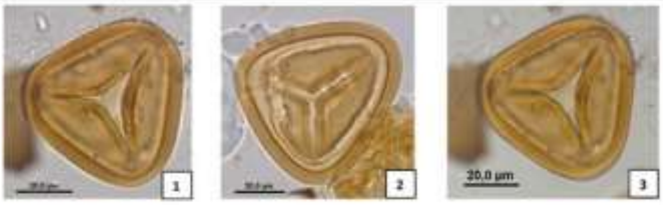


Plate 28
Type 3
Trilete spores

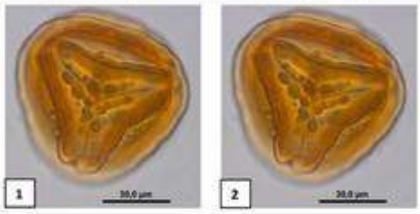


Plate 29
Type 4
Trilete spores

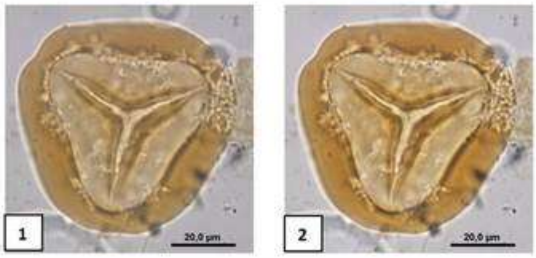


Plate 30
Type 5
Trilete spores

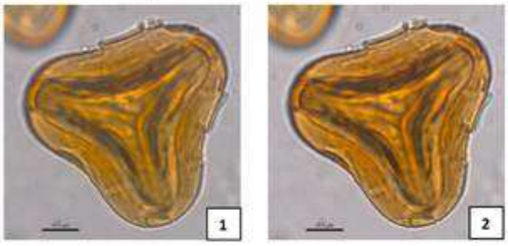


Plate 31
Type 6
Trilete spores

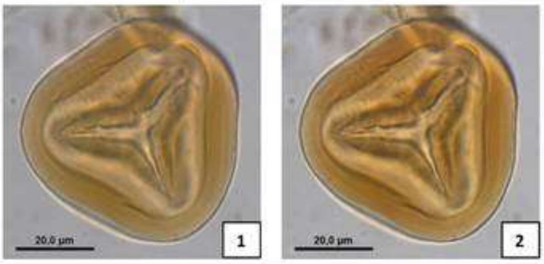


Plate 32
Type 7
Trilete spores

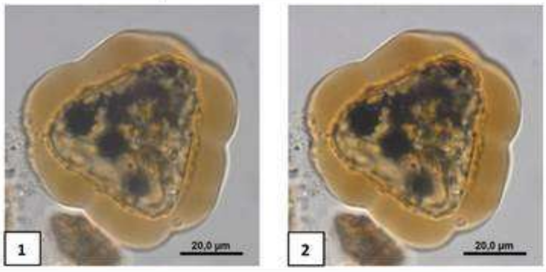


Plate 33
Type 8
Trilete spores

Plate 34
Type 9
Trilete spores

Plate 35
Type 10
Trilete spores

Plate 36
Type 11
Trilete spores

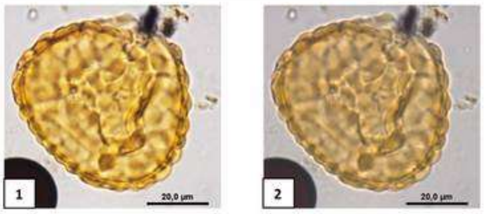


Plate 37
Type 12
Trilete spores

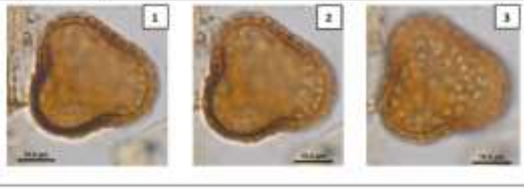


Plate 38
Type 13
Trilete spores

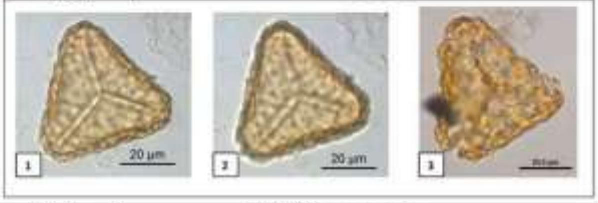


Plate 39
Type 14
Trilete spores

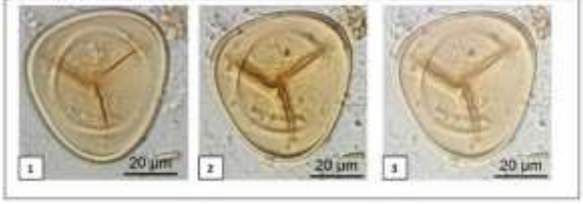


Plate 40
Type 15
Trilete spores

Plate 41
Type 16

Trilete spores

Plate 42
Dacrycarpus type

Vesiculate, saccate grains

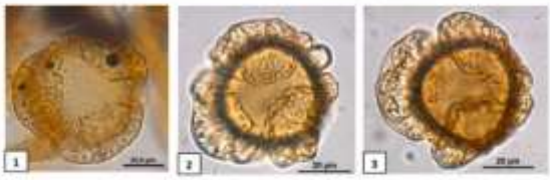


Plate 43
Dacrydium type

Vesiculate, saccate grains

Plate 44
Phyllocladus

Vesiculate, saccate grains

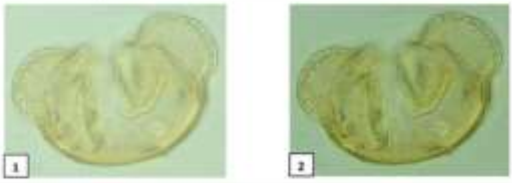


Plate 45
Picea type

Vesiculate, saccate grains

Plate 46
Pinus type 1

Vesiculate, saccate grains

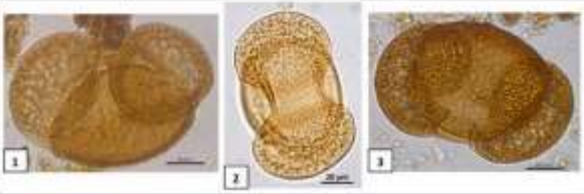


Plate 47
Pinus type 2. Cf. *P. sylvestris*

Vesiculate, saccate grains

Plate 48
Podocarpus

Vesiculate, saccate grains

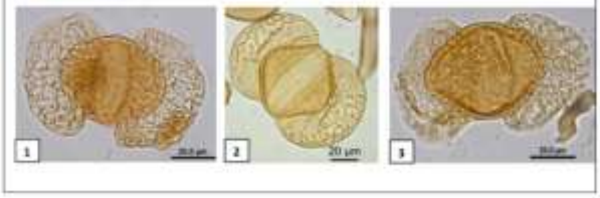


Plate 49
Tsuga type

Vesiculate, saccate grains

Plate 50
Acacia

Polyade grains

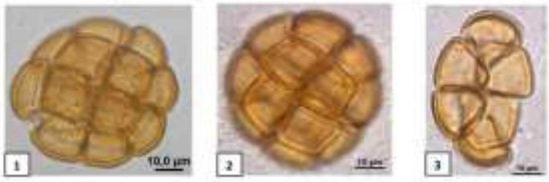


Plate 51
Albizia

Polyade grains

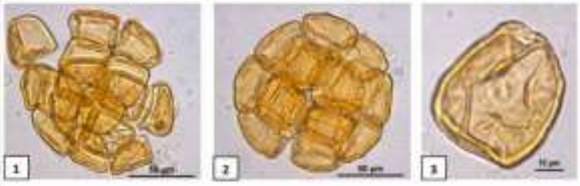


Plate 52
Annona

Tetrade grains

Plate 53
Ericaceae indet.

Tetrade grains

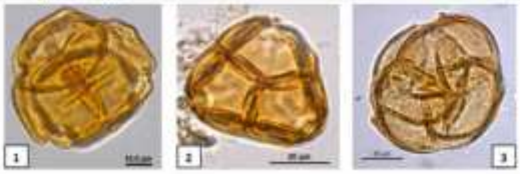


Plate 54
Mimosaceae indet. type

Tetrade grains

Plate 55
Agathis
Inaperturate grains

Plate 56
Areca
Monosulcate grains

Plate 57
Arecaceae indet., type 1
Monosulcate grains

Plate 58
Arecaceae indet., type 2
Monosulcate grains

Plate 59
Arecaceae indet., type 3
Monosulcate grains

Plate 60
Arenga
Monosulcate grains

Plate 61
Calamus
Monosulcate grains

Plate 62
Caryota
Monosulcate grains

Plate 63
Chloranthaceae indet.
Monosulcate grains

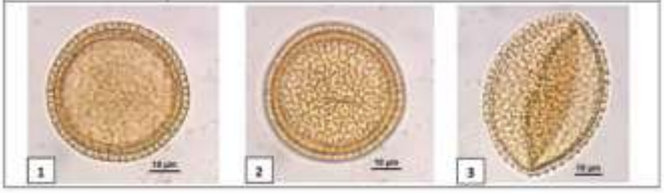


Plate 64
Iridaceae/Liliaceae indet.
Monosulcate grains

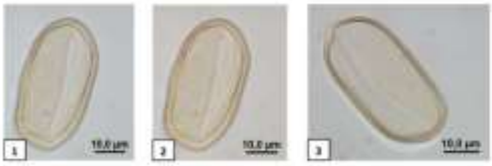


Plate 65
Nypa
Monosulcate grains

Plate 66
Oncosperma
Monosulcate grains

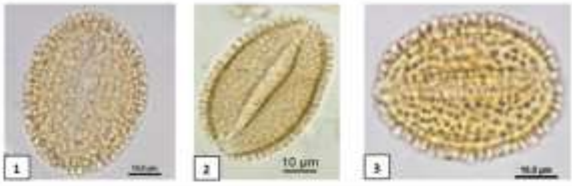


Plate 67
Pinanga
Monosulcate grains

Plate 68
Cunoniaceae indet.
Dicolporate grains

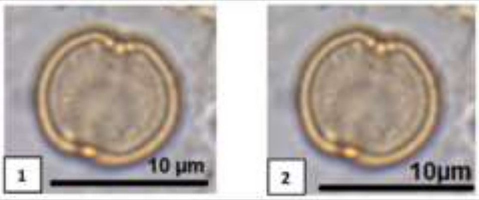


Plate 69
Acanthaceae indet.

Tricolpate grains

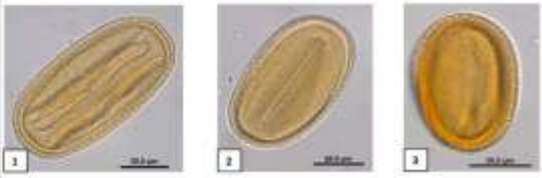


Plate 70
Cf. Brassicaceae indet. type

Tricolpate grains

Plate 71
Clematis

Tricolpate grains

Plate 72
Durio

Tricolpate grains

Plate 73
Oleaceae indet., type 1

Tricolpate grains

Plate 74
Plumbaginaceae indet.

Tricolpate grains

Plate 75
Ranunculaceae indet. type

Tricolpate grains

Plate 76
Arceuthobium

Heterocolpate grains

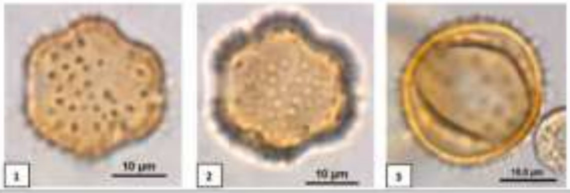


Plate 77
Combretaceae/Melastomataceae indet., type 1

Heterocolpate grains

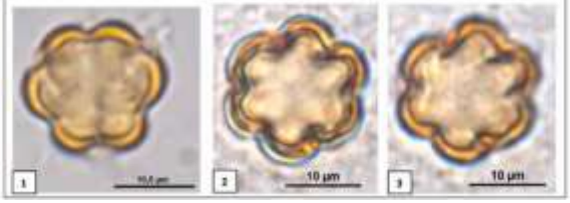


Plate 78
Combretaceae/Melastomataceae indet., type 2

Heterocolpate grains

Plate 79
Oryza type

Monoporate grains

Plate 80
Pandanus

Monoporate grains

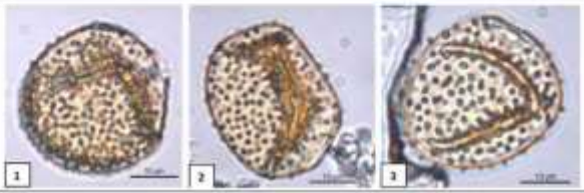


Plate 81
Poaceae indet.

Monoporate grains

Plate 82
Typha

Monoporate grains

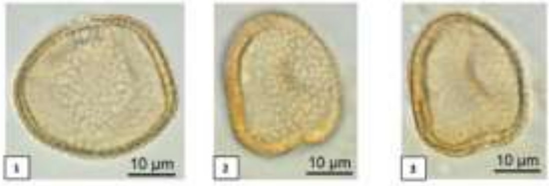


Plate 83
Zea mais

Monoporate grains

Plate 84
Ficus

Diporate grains

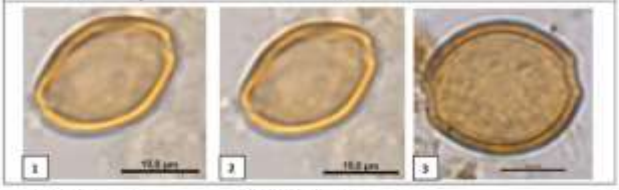


Plate 85
Trema

Diporate grains

Plate 86
Allophylus, type 1

Triporate grains

Plate 87
Bignoniaceae indet., type 2

Triporate grains

Plate 88
Casuarina

Triporate grains

Plate 89
Celtis

Triporate grains

Plate 90
Cucurbitaceae indet.

Triporate grains

Plate 91
Engelhardia

Triporate grains

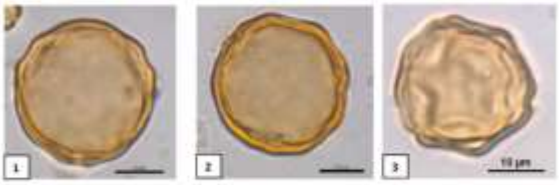


Plate 92
Fabaceae indet., type 1

Triporate grains

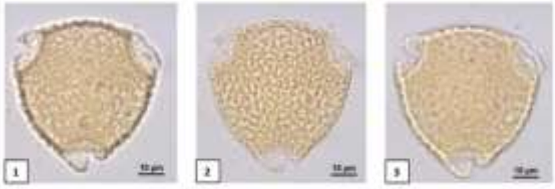


Plate 93
Myrica

Triporate grains

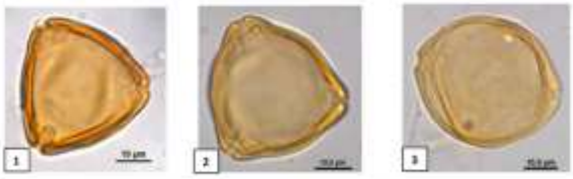


Plate 94
Moraceae/Urticaceae indet.

Triporate grains

Plate 95
Onagraceae indet.

Triporate grains

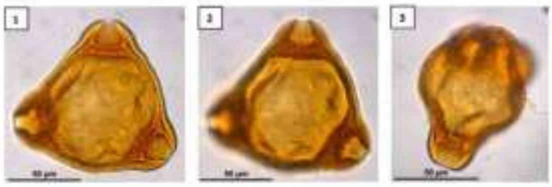


Plate 96
Pometia

Triporate grains

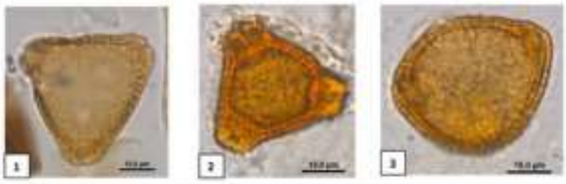


Plate 97
Sonneratia
Triporate grains

Plate 98
Alnus, type 1
Tetraporate grains

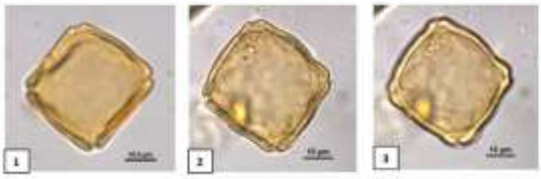


Plate 99
Allophylus, type 2
Tetraporate grains

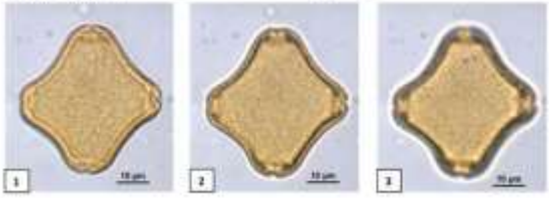


Plate 100
Dysoxylum
Tetraporate grains

Plate 101
Garcinia
Tetraporate grains

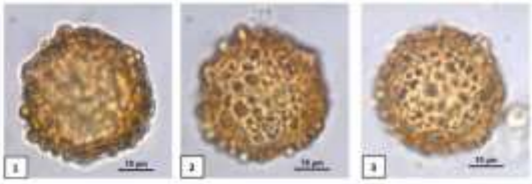


Plate 102
Alnus, type 2
4-6-porate, stephanoporate grains

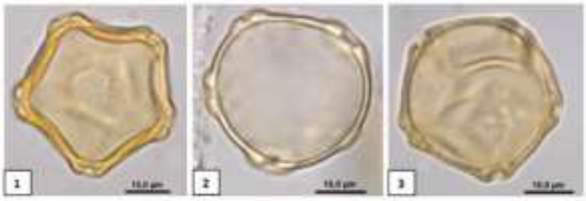


Plate 103
Ulmus
4-6-porate, stephanoporate grains

Plate 104
Quintinia
5-colpate grains

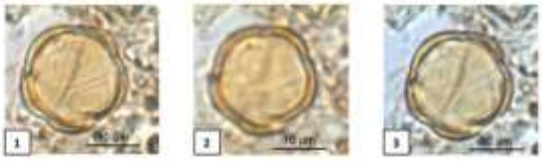


Plate 105
Cf. Bignoniaceae/Cf. Lamiaceae indet. indet., type 2
6-colpate grains

Plate 106
Altingia
Periporate grains

Plate 107
Amaranthaceae indet.
Periporate grains

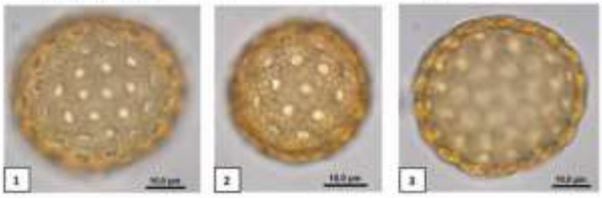


Plate 108
Caryophyllaceae indet.
Periporate grains

Plate 109
Cyperaceae indet.
Periporate grains

Plate 110
Hibiscus
Periporate grains

Plate 111
Juglandaceae indet.

Periporate grains

Plate 112
Malvaceae indet., type 1

Periporate grains

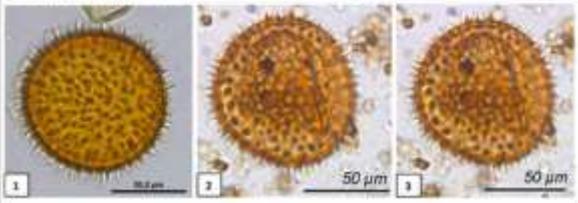


Plate 113
Malvaceae indet., type 2

Periporate grains

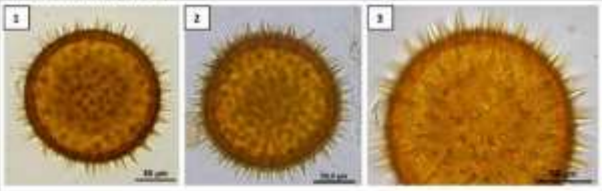


Plate 114
Plantago

Periporate grains

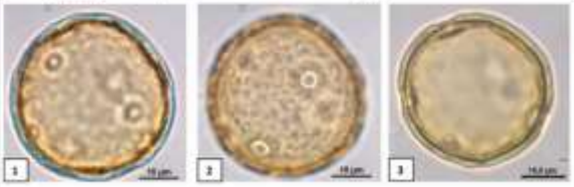


Plate 115
Thalictrum

Periporate grains

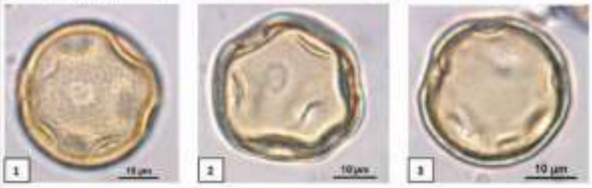


Plate 116
Thymelaeaceae indet. type

Periporate grains

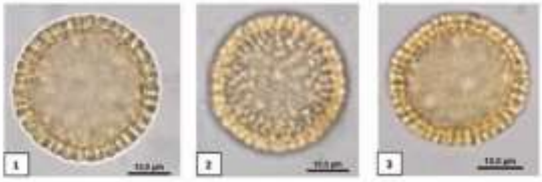


Plate 117
Acalypha

Tricolporate grains

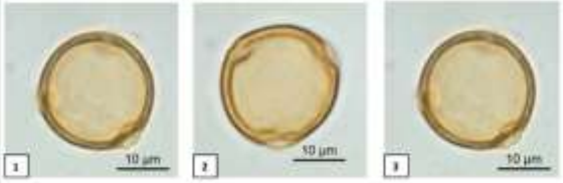


Plate 118
Aglaia

Tricolporate grains

Plate 119
Ailanthus

Tricolporate grains

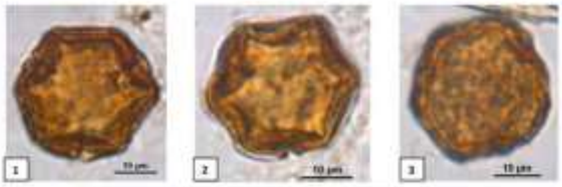


Plate 120
Alchornea

Tricolporate grains

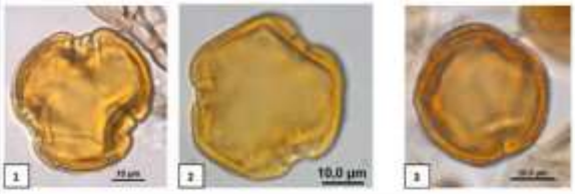


Plate 121
Anacardiaceae indet.

Tricolporate grains

Plate 122
Apiaceae indet.

Tricolporate grains

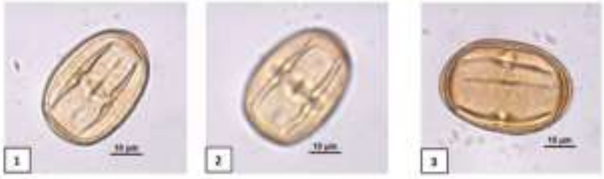


Plate 123
Artemisia

Tricolporate grains

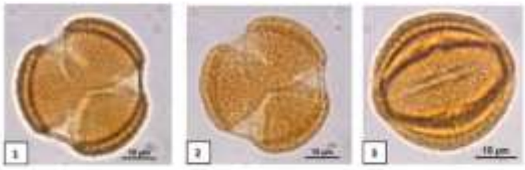


Plate 124
Asteraceae indet., type 1

Tricolporate grains

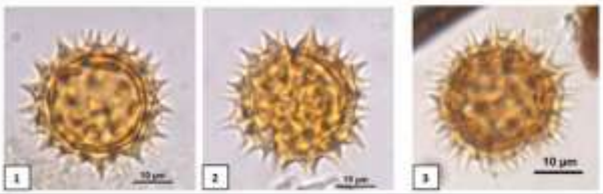


Plate 125
Asteraceae indet., type 2
Tricolporate grains

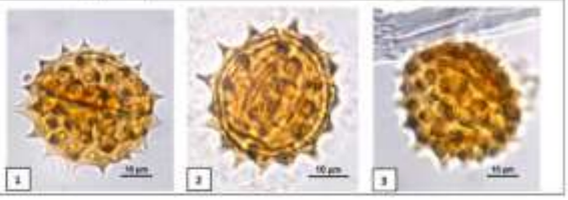


Plate 126
Asteraceae indet., type 3
Tricolporate grains

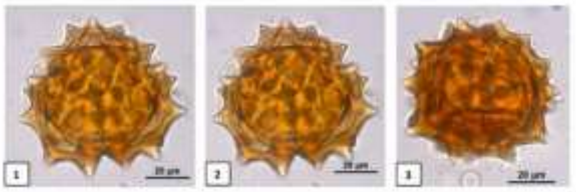


Plate 127
Avicennia
Tricolporate grains

Plate 128
Barringtonia
Tricolporate grains

Plate 129
Bombacaceae indet.
Tricolporate grains

Plate 130
Bruguiera
Tricolporate grains

Plate 131
Castanopsis/Lithocarpus
Tricolporate grains

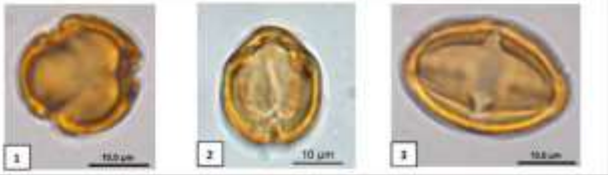


Plate 132
Centaurea
Tricolporate grains

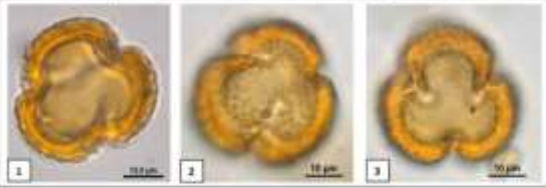


Plate 133
Clethra type
Tricolporate grains

Plate 134
Dillenia
Tricolporate grains

Plate 135
Dipterocarpaceae indet.
Tricolporate grains

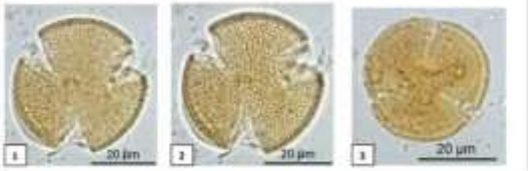


Plate 136
Elaeocarpus
Tricolporate grains

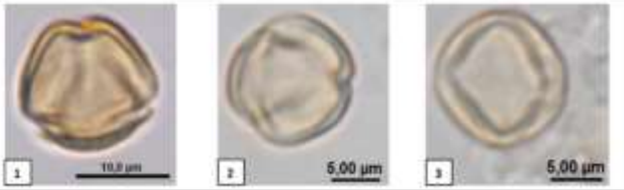


Plate 137
Eucalyptus
Tricolporate grains

Plate 138
Euphorbiaceae indet.
Tricolporate grains

Plate 139
Fabaceae indet., type 2

Tricolporate grains

Plate 140
Hopea

Tricolporate grains

Plate 141
Ilex

Tricolporate grains

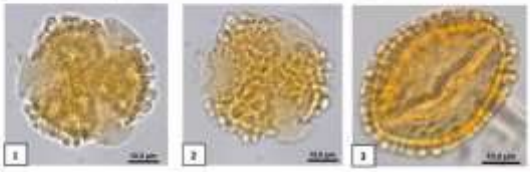


Plate 142
Ixora

Tricolporate grains

Plate 143
Loranthaceae indet., type 1

Tricolporate grains

Plate 144
Loranthaceae indet., type 2

Tricolporate grains

Plate 145
Loranthaceae indet., type 3

Tricolporate grains

Plate 146
Lythraceae indet.

Tricolporate grains

Plate 147
Macaranga/Mallotus

Tricolporate grains

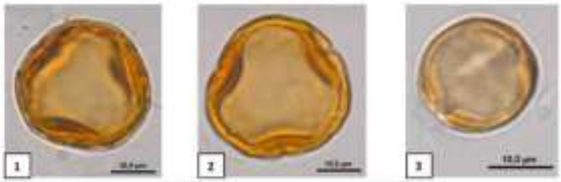


Plate 148
Malpighiaceae indet.

Tricolporate grains

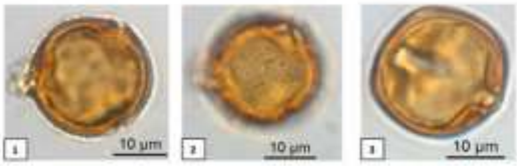


Plate 149
Myrtaceae indet.

Tricolporate grains

Plate 150
Polygonaceae indet.

Tricolporate grains

Plate 151
Quercus

Tricolporate grains

Plate 152
Rhizophora

Tricolporate grains

Plate 153
Rosaceae indet. type

Tricolporate grains

Plate 154
Rubiaceae indet.

Tricolporate grains

Plate 155
Rubiaceae indet.
Tricolporate grains

Plate 156
***Salix* type**
Tricolporate grains

Plate 157
Sapindaceae indet.
Tricolporate grains

Plate 158
Sapotaceae indet.
Tricolporate grains

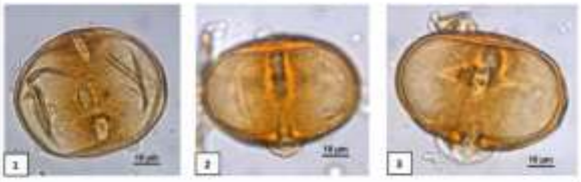


Plate 159
Symplocos
Tricolporate grains

Plate 160
Verbenaceae indet. type
Tricolporate grains

Plate 161
Vitaceae indet. type
Tricolporate grains

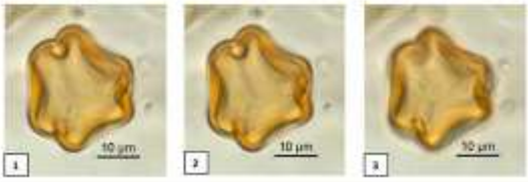


Plate 162
Weinmannia
Tricolporate grains

Plate 163
Meliaceae type
4-colporate grains

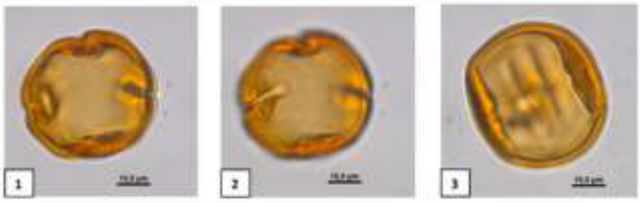


Plate 164
Oleaceae indet., type 2
4-colporate grains

Plate 165
Asteraceae subfamily Cichorideae indet.
Fenestrate grains

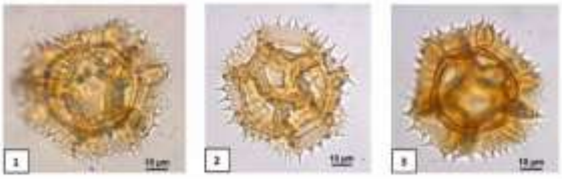


Plate 166
Indeterminate type 1
? Tetrade grains

Plate 167
Indeterminate type 2
Inaperturate grains

Plate 168
Indeterminate type 3
Tricolpate grains

Plate 169
Indeterminate type 4

? Tricolpate grains

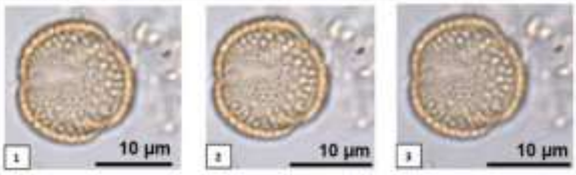


Plate 170
Indeterminate type 5

? Tricolpate grains

Plate 171
Indeterminate type 6

Tricolporate grains

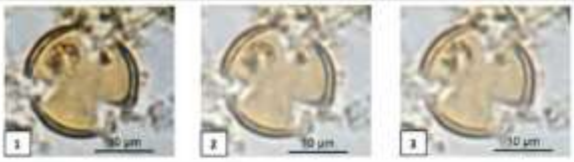


Plate 172
Indeterminate type 7

Tricolporate grains

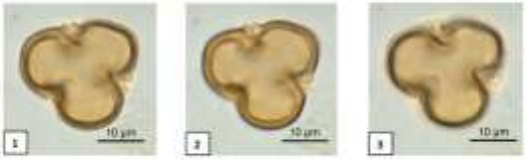


Plate 173
Indeterminate type 8

Tricolporate grains

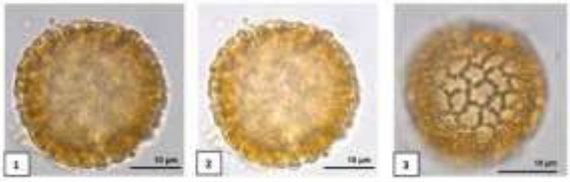


Plate 174
Indeterminate type 9

Tricolporate grains

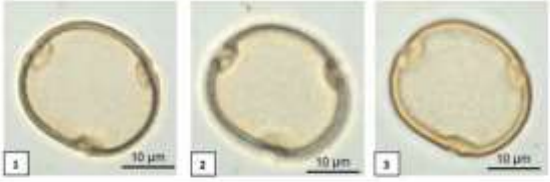


Plate 175
Indeterminate type 10

Tricolporate grains

Plate 176
Indeterminate type 11

Tricolporate grains

Plate 177
Indeterminate type 12

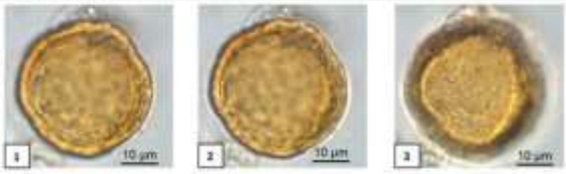
Tricolporate grains

Plate 178
Indeterminate type 13

? Tricolporate grains

Plate 179
Indeterminate type 14

Unknown



Appendix B

Complete list of organic-walled dinocysts types mentioned in the thesis

name	core 1412-19	core 1609-30	core 1612-23
Ataxodinum choanum	*		*
Bitectatodinium spongium	*	*	*
Bitectatodinium spongium			*
Brigantedinium spp. (Round Brown Cyst)	*	*	*
cyst of *Polykrikos kofoidii*	*	*	*
cyst of *Polykrikos schwartzii*	*	*	*
Dalella chathamensis	*		
Echinidinium delicatus	*		
Echinidinium granullatum	*	*	*
Echinidinium monospinum	*		
Echinidinium transparantum	*	*	*
Echinidinium zonneveldiae	*	*	*
Impagidinium aculeatum	*		*
Impagidinium plicatum			*
Impagidinium sphaericum			*
Impagidinium ssp	*	*	
Impagidinium strialatum	*		*
Impagidinium variaseptum	*	*	
Lejeunecysta oliva	*	*	*
Lejeunecysta paratenella	*		
Lejeunecysta sabrina	*		*
Lingulodinium machaerophorum, normal processies	*	*	*
Lingulodinium machaerophorum, redusuced processies	*	*	
Nematosphaeropsis labyrinthus	*	*	*
Operculodinium centrocarpum	*	*	*
Operculodinium israelianum	*	*	*
Operculodinium spp	*	*	*
Cyst of *Pentapharsodinium dalei*	*	*	*
Polysphaeridium zoharyi	*	*	*
Quinquecuspis concreta			*
Selenopemphix nephroides	*	*	*
Selenopemphix quanta	*		*
Spiniferites elongatus type	*		
Spiniferites mirabilis	*	*	*
Spiniferites pachydermus	*	*	*

Spiniferites ramosus	*	*	*
Spiniferites spp	*	*	*
Stelladinium robustum type	*		
Stelladinium stellatum	*		
Trinovantedinium applanatum			*
Tuberculodinium vancampoae	*		*
Votadinium calvum	*	*	*
Votadinium spinosum	*	*	*
Xandarodinium xanthum	*	*	

Note: (*) indicates presence of the dinocyst type in the core material. Empty cell stays for abcence.

Appendix C

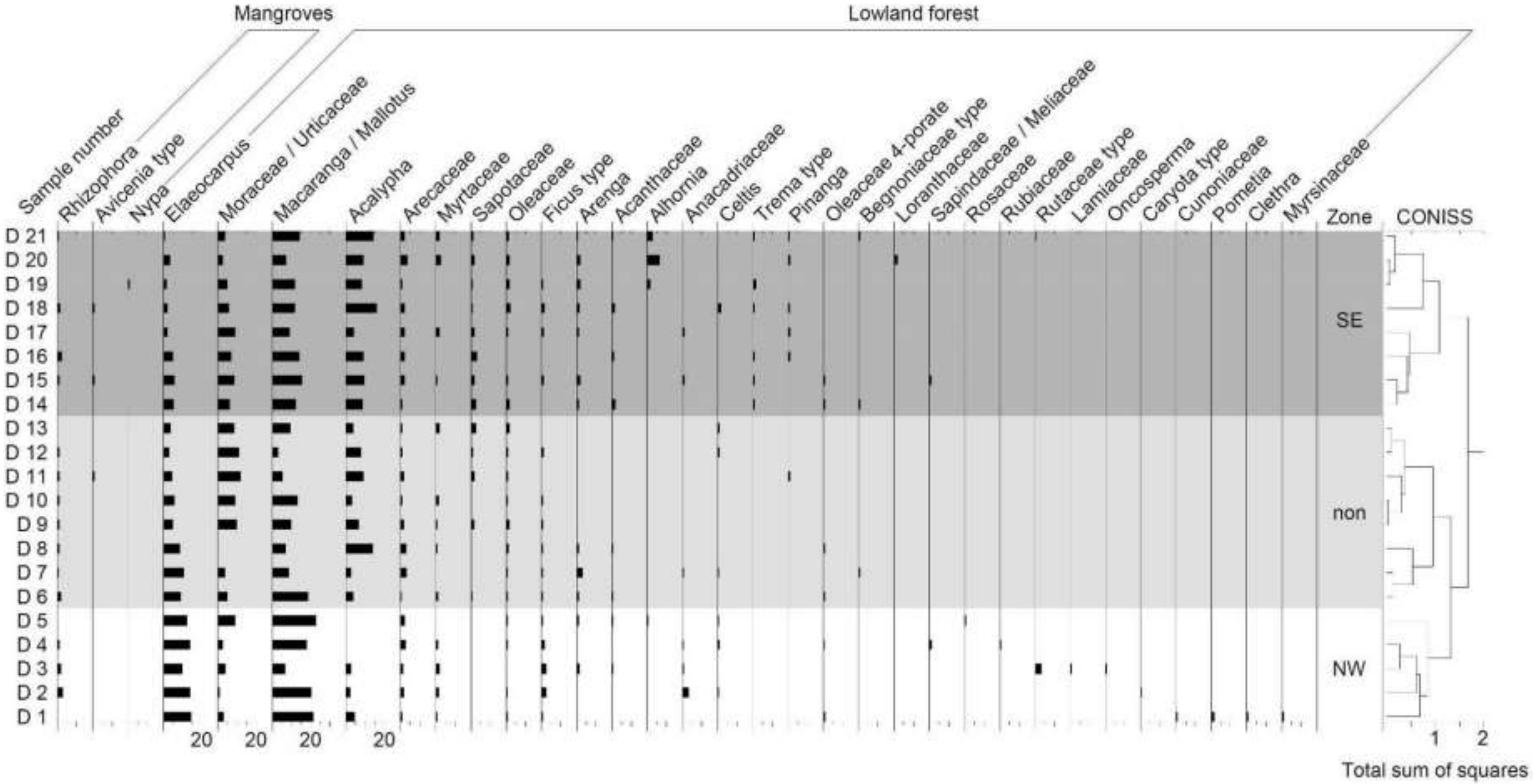
Complete Pollen Records

Appendix C1. Complete pollen record (%) of sediment trap JAM-2 showing percentages of pollen of mangroves, lowland and montane trees, herbs and fern spore as well as pollen and Pteridophyta sums and pollen accumulation rate (PAR) under changing monsoon conditions in the Indian Ocean off SW Java.

Appendix C2. Complete pollen record (%) of the sequence 1412-19 showing relative frequencies of pollen and spore types, main vegetation groups, pollen and microcharcoal concentrations.

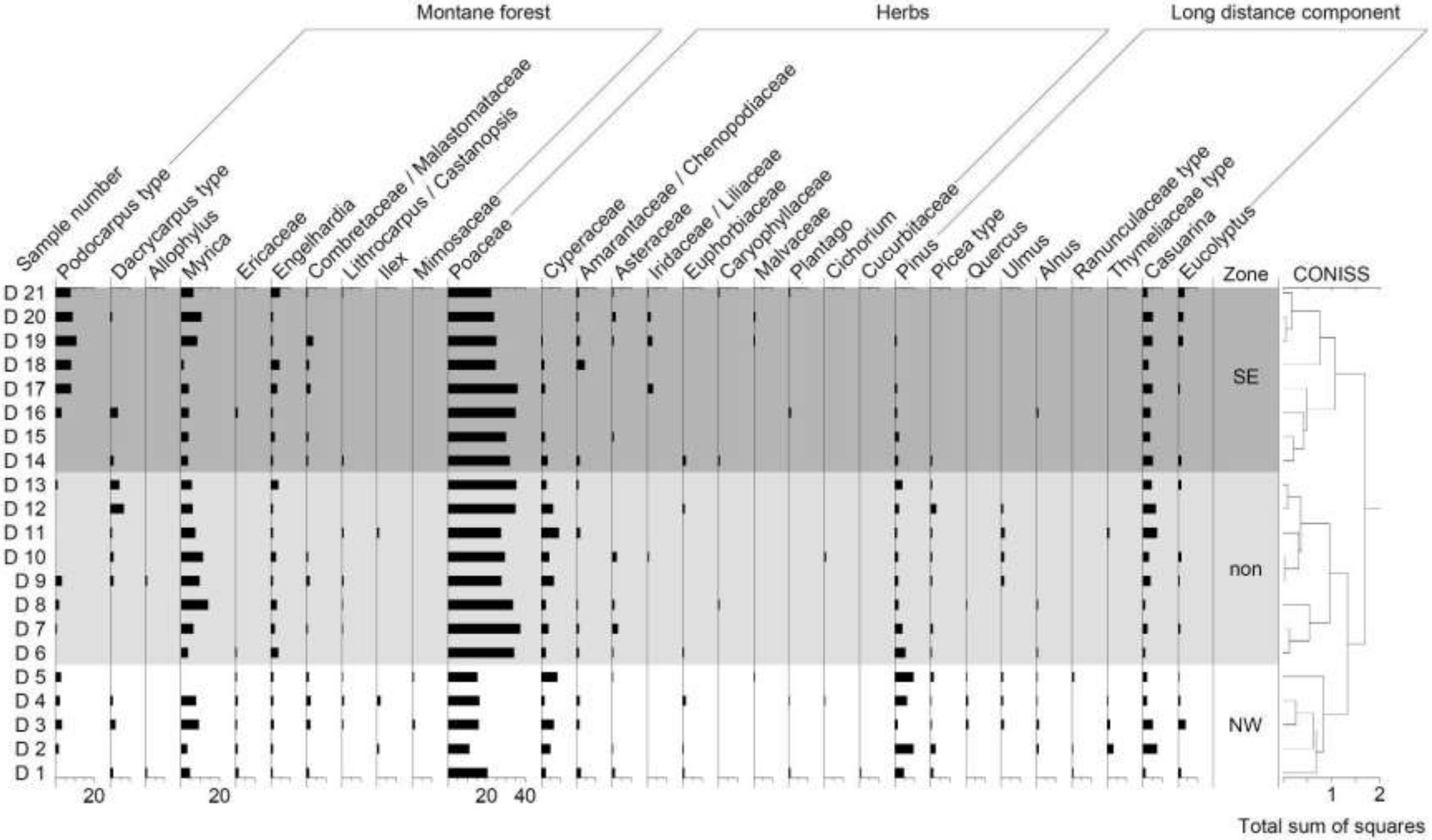
Appendix C3. Complete pollen record (%) of the sequence 1609-30 showing relative frequencies of pollen and spore types, main vegetation groups, pollen and microcharcoal concentrations.

Appendix C1. Complete pollen record (%) of sediment trap JAM-2 showing percentages of pollen of mangroves, lowland and montane trees, herbs and fern spore as well as pollen and Pteridophyta sums and pollen accumulation rate (PAR) under changing monsoon conditions in the Indian Ocean off SW Java.



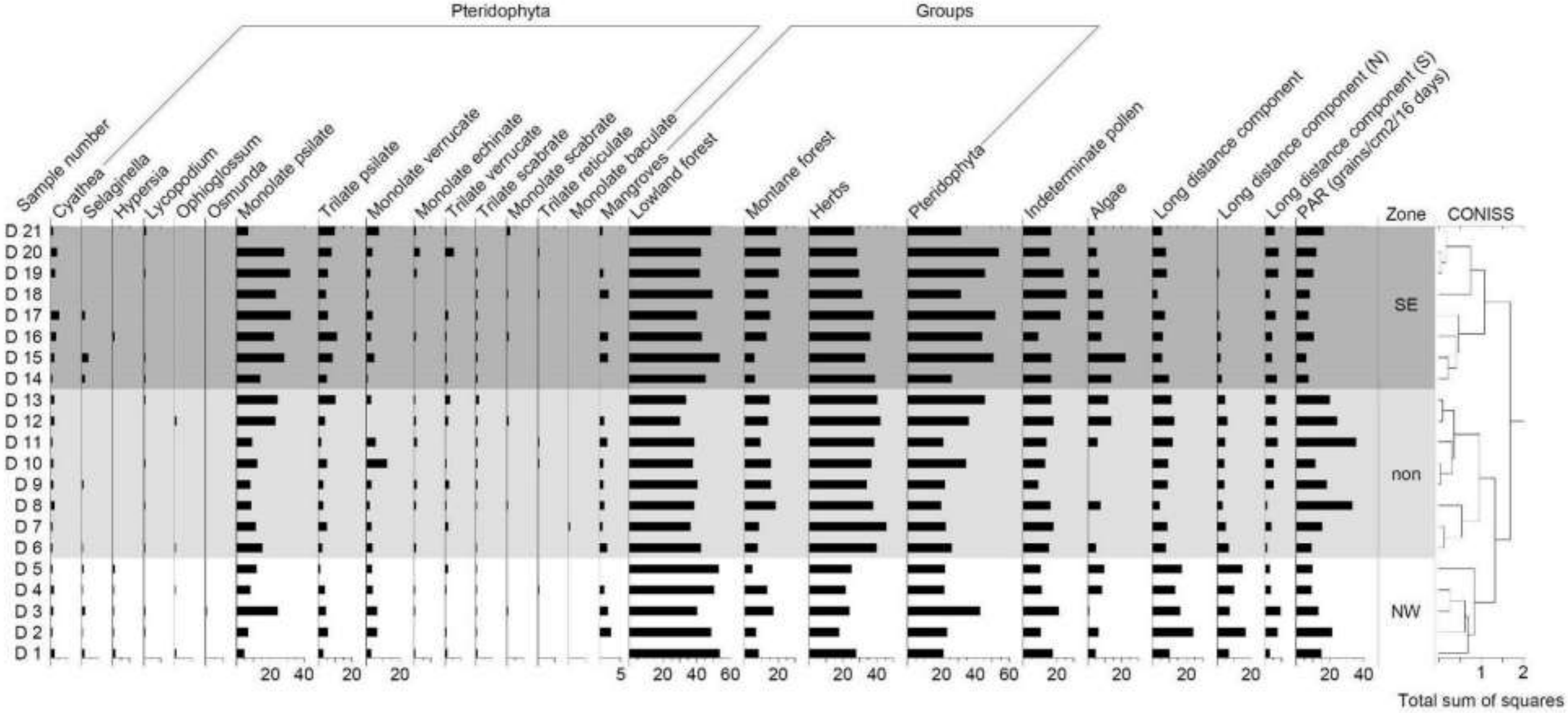
Notes: The abbreviations indicate the following: NW - northwest monsoon; non (light-grey shading) - intermonsoon period; SE (dark-grey shading), southeast monsoon; LDS – long distance component; N - long distance component collected during the northwest monsoon; S - long distance component collected during the southern monsoon.

Appendix C1. Complete pollen record (%) of sediment trap JAM-2 showing percentages of pollen of mangroves, lowland and montane trees, herbs and fern spore as well as pollen and Pteridophyta sums and pollen accumulation rate (PAR) under changing monsoon conditions in the Indian Ocean off SW Java (continuation).



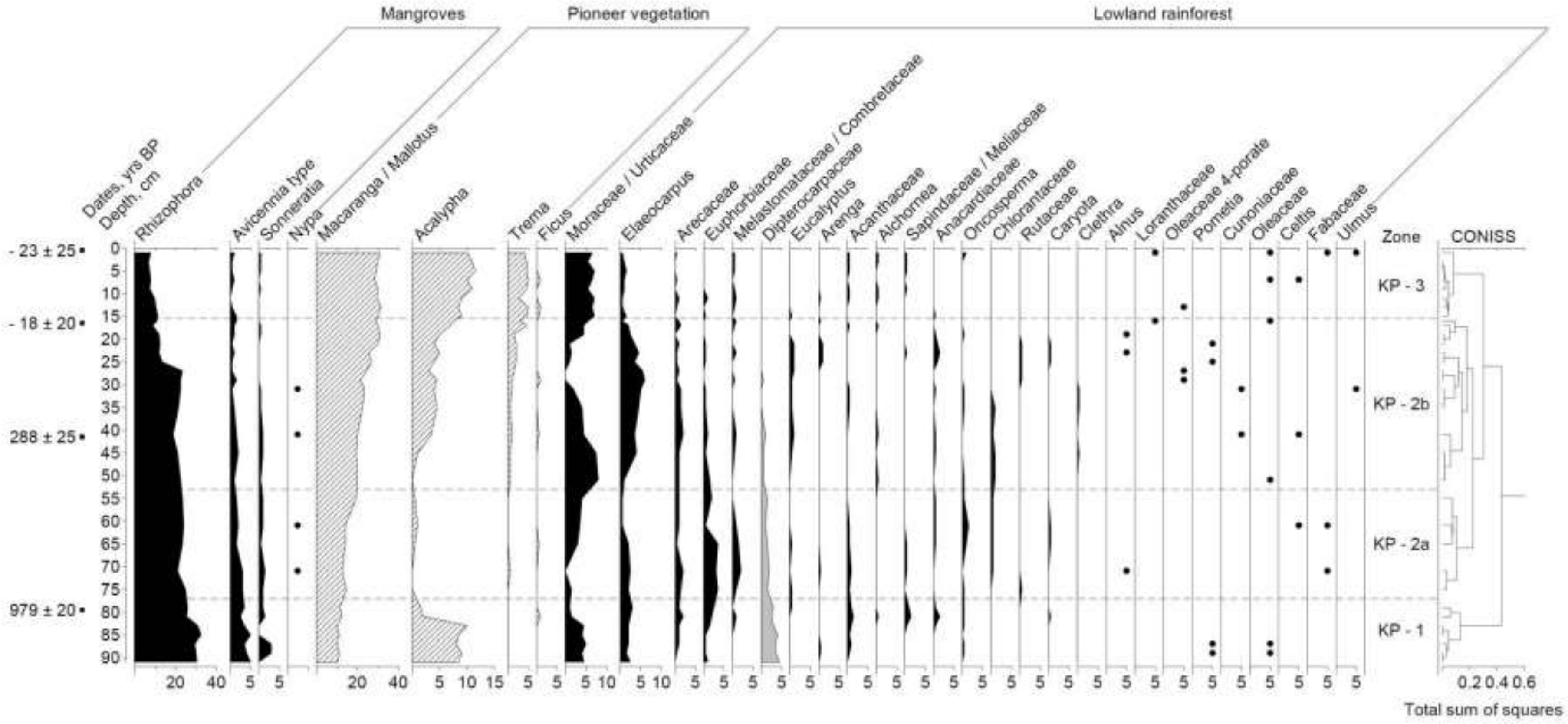
Notes: The abbreviations indicate the following: NW - northwest monsoon; non (light-grey shading) - intermonsoon period; SE (dark-grey shading), southeast monsoon; LDS – long distance component; N - long distance component collected during the northwest monsoon; S - long distance component collected during the southern monsoon.

Appendix C1. Complete pollen record (%) of sediment trap JAM-2 showing percentages of pollen of mangroves, lowland and montane trees, herbs and fern spore as well as pollen and Pteridophyta sums and pollen accumulation rate (PAR) under changing monsoon conditions in the Indian Ocean off SW Java (ending).



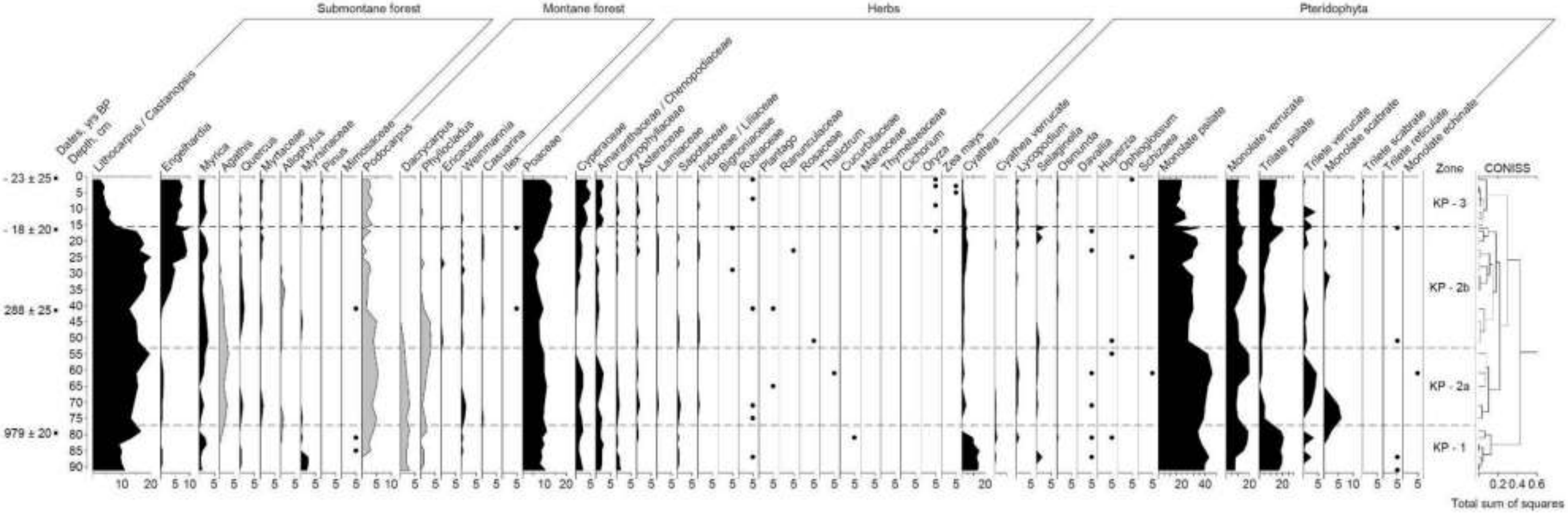
Notes: The abbreviations indicate the following: NW - northwest monsoon; non (light-grey shading) - intermonsoon period; SE (dark-grey shading), southeast monsoon; LDS – long distance component; N - long distance component collected during the northwest monsoon; S - long distance component collected during the southern monsoon.

Appendix C2. Complete pollen record (%) of the sequence 1412-19 showing relative frequencies of pollen and spore types, main vegetation groups, pollen and microcharcoal concentrations.



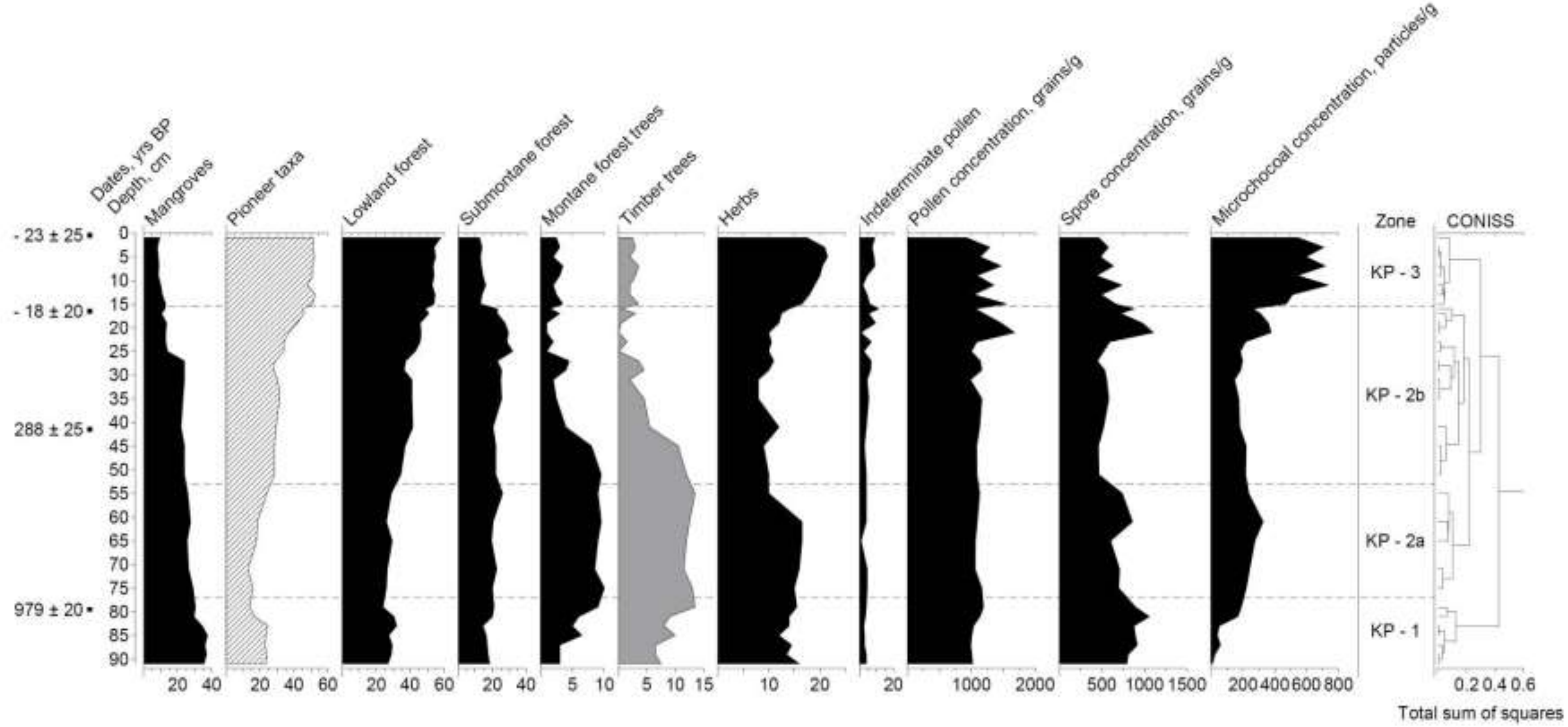
Note: Pollen types of pioneer taxa have striped profiles; pollen types of timber tree taxa have grey profiles. Presence of cysts types contributing to the dinocyst total sum less than 2% on average depicted as black dots.

Appendix C2. Complete pollen record (%) of the sequence 1412-19 showing relative frequencies of pollen and spore types, main vegetation groups, pollen and microcharcoal concentrations (continuation).



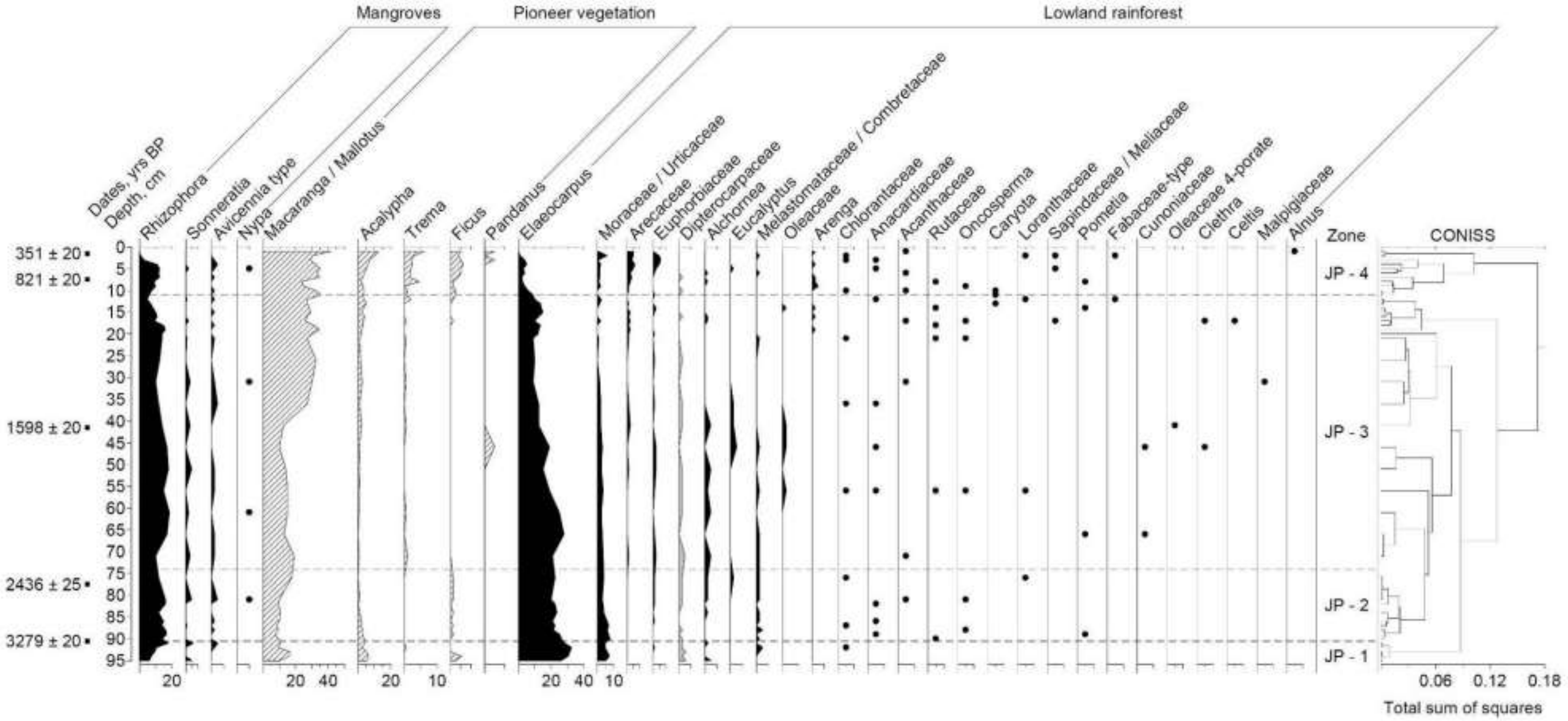
Note: Pollen types of pioneer taxa have striped profiles; pollen types of timber tree taxa have grey profiles. Presence of cysts types contributing to the dinocyst total sum less than 2% on average depicted as black dots.

Appendix C2. Complete pollen record (%) of the sequence 1412-19 showing relative frequencies of pollen and spore types, main vegetation groups, pollen and microcharcoal concentrations (ending).



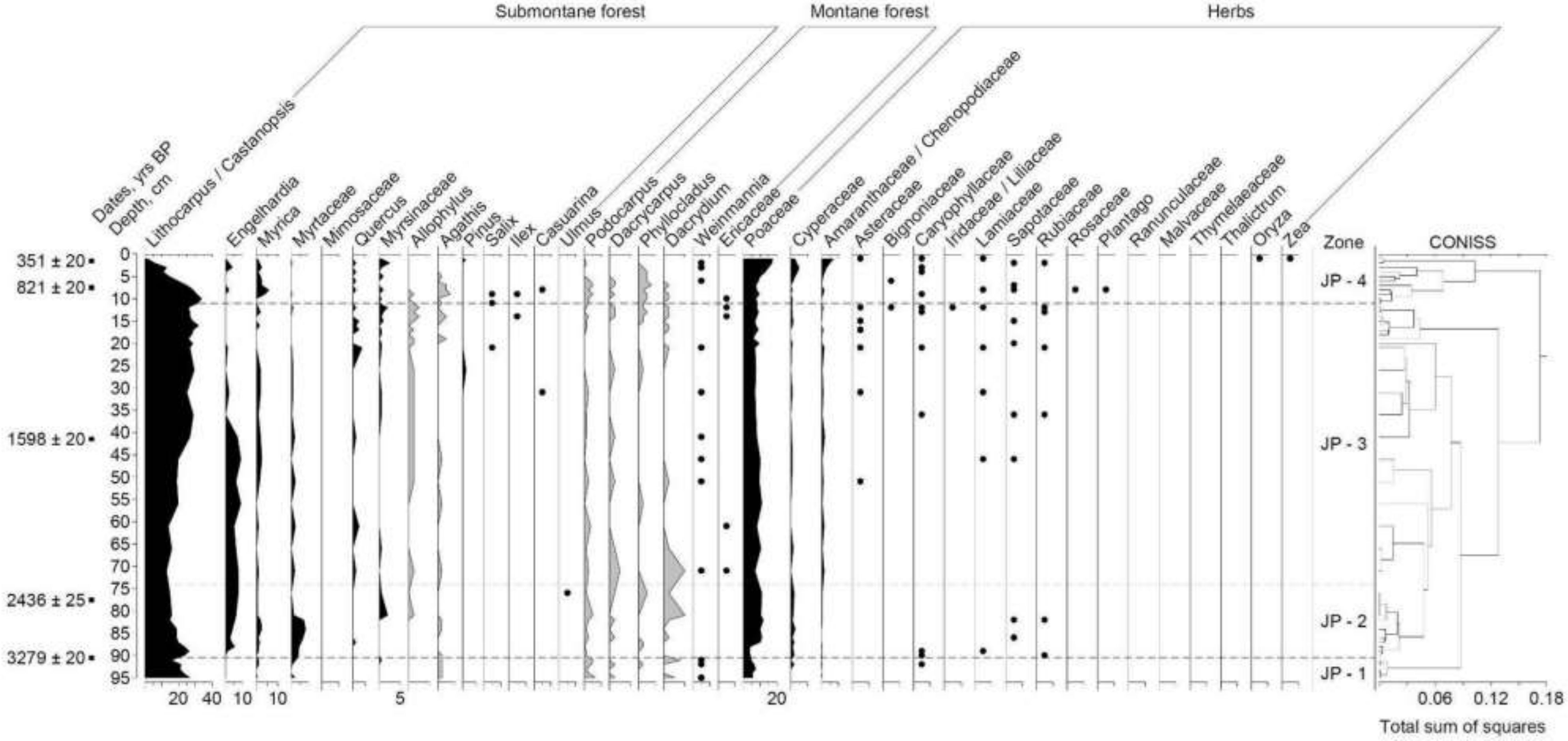
Note: Pollen types of pioneer taxa have striped profiles; pollen types of timber tree taxa have grey profiles.

Appendix C3. Complete pollen record (%) of the sequence 1609-30 showing relative frequencies of pollen and spore types, main vegetation groups, pollen and microcharcoal concentrations.



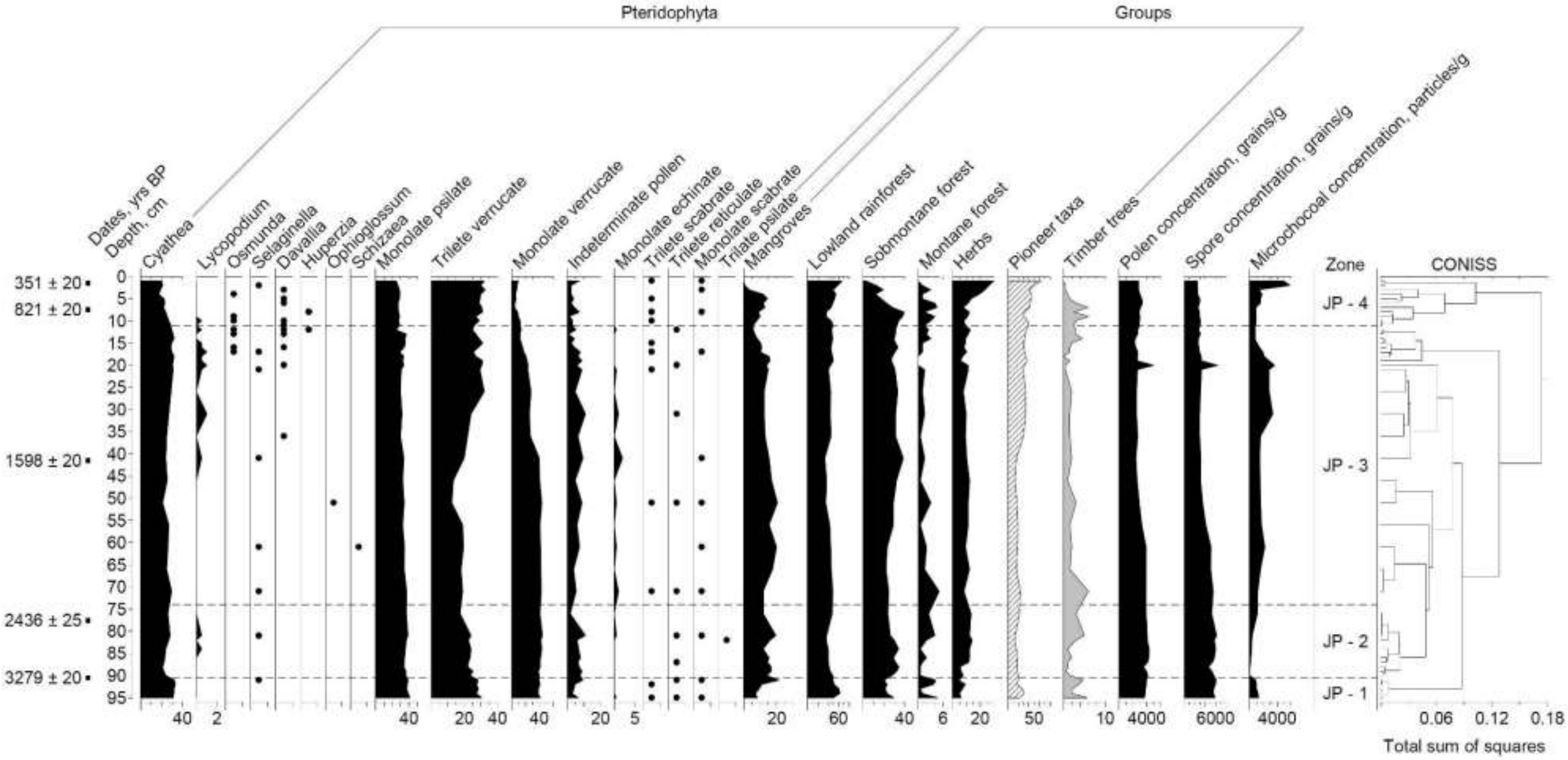
Note: Pollen types of pioneer taxa have striped profiles; pollen types of timber tree taxa have grey profiles. Presence of cysts types contributing to the dinocyst total sum less than 2% on average depicted as black dots.

Appendix C3. Complete pollen record (%) of the sequence 1609-30 showing relative frequencies of pollen and spore types, main vegetation groups, pollen and microcharcoal concentrations (continuation).



Note: Pollen types of pioneer taxa have striped profiles; pollen types of timber tree taxa have grey profiles. Presence of cysts types contributing to the dinocyst total sum less than 2% on average depicted as black dots.

Appendix C3. Complete pollen record (%) of the sequence 1609-30 showing relative frequencies of pollen and spore types, main vegetation groups, pollen and microcharcoal concentrations (ending).



Note: Pollen types of pioneer taxa have striped profiles; pollen types of timber tree taxa have grey profiles.Presence of cysts types contributing to the dinocyst total sum less than 2% on average depicted as black dots.

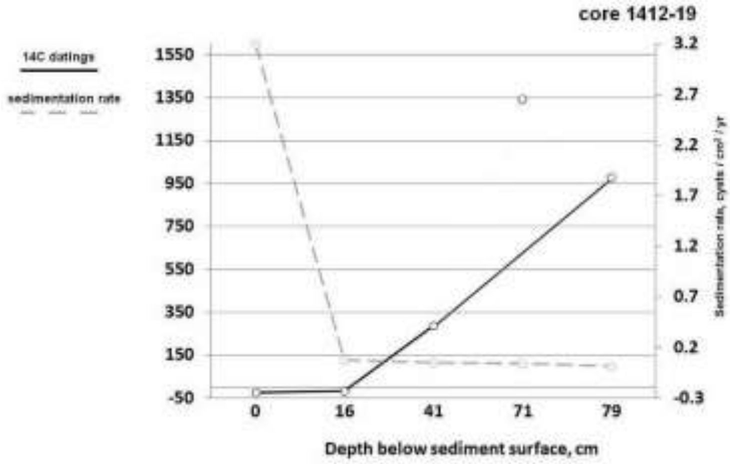
Appendix D

Core Stratigraphy and Radiocarbon Dating

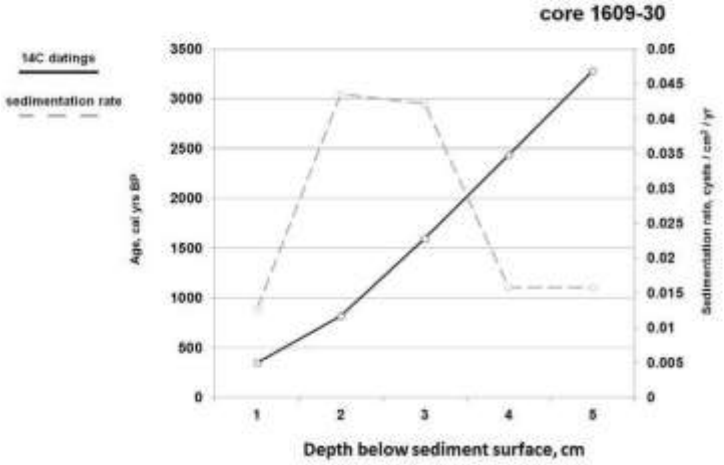
Appendix D1. Stratigraphy of the core 1412-19 and calibrated age model (linear interpolation, cal yr BP vs core depth) based on the radiocarbon dates from Table 1 (Chapter 2) and the estimated sedimentation rate. The outlet at 71-72 cm is depicted as a point unconnected to other dating points.

Appendix D2. Stratigraphy of the core 1609-30 and calibrated age model (linear interpolation, cal yr BP vs core depth) based on the radiocarbon dates from Table 1 (Chapter 2) and the estimated sedimentation rate.

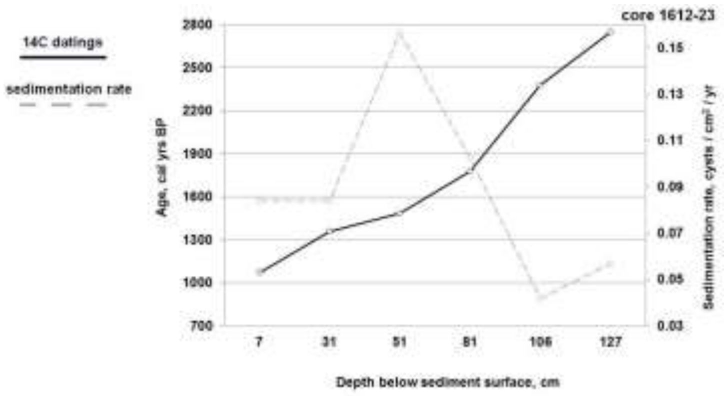
Appendix D3. Stratigraphy of the core 1612-23 and calibrated age model (linear interpolation, cal yr BP vs core depth) based on the radiocarbon dates from Table 1 (Chapter 4) and the estimated sedimentation rate.



Appendix D1. Stratigraphy of the core 1412-19 and calibrated age model (linear interpolation, cal yr BP vs core depth) based on the radiocarbon dates from Table 1 (Chapter 2) and the estimated sedimentation rate. The outlet at 71-72 cm is depicted as a point unconnected to other dating points.



Appendix D2. Stratigraphy of the core 1609-30 and calibrated age model (linear interpolation, cal yr BP vs core depth) based on the radiocarbon dates from Table 1 (Chapter 2) and the estimated sedimentation rate.



Appendix D3. Stratigraphy of the core 1612-23 and calibrated age model (linear interpolation, cal yr BP vs core depth) based on the radiocarbon dates from Table 1 (Chapter 4) and the estimated sedimentation rate.

Declaration of originality and certificate of ownership

I, Anastasia Poliakova, hereby declare that I am the author of the present dissertation entitled „The late Holocene history of vegetation, climate, fire dynamics and human impacts in Java and southern Kalimantan". All references and data sources that I used in the dissertation have been appropriately acknowledged and cited. I furthermore declare that this work has not and will be not submitted elsewhere in any form as part of another dissertation procedure.

Göttingen, September 2015 (Poliakova A.)