MANGROVE PALYNOLGY

by

G. THANIKAIMONI

Published by

UNDP/UNESCO Regional Project on Training and Research
on Mangrove Ecosystems, RAS/79/002, and the French Institute, Pondicherry

INSTITUT FRANÇAIS DE PONDICHÉRY
Travaux de la Section Scientifique et Technique
Tome XXIV
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MANGLEROVE PALYNOLOGY

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V. CONCLUSION
Within the guiding principles of the UNDP/UNESCO Regional Project on Training and Research of Mangrove Ecosystems, RAS/79/002, it was considered important to take a look at the palaeoecology of mangroves, as one more factor to help in the understanding of the structure and dynamics of present day mangroves.

This Manual was born from the necessity of adding new dimensions to the study of mangroves for a better management of this life sustaining ecosystem and for its perpetuation as an instrument of production.

We are grateful to Dr. B.S. Venkatachala of the Birbal Sahni Institute of Palaeobotany, Lucknow, who gave us the name of Dr. G. Thanikaimoni. The latter had plunged wholeheartedly in the study of the mangroves of the past, using palynology as a tool and during his unfortunately brief association with the project, he gave us all the benefit of his vast knowledge of both palynology and mangroves, and the benefit of his contagious and invaluable enthusiasm for an important work through his rich and generous personality. We had hoped for a very long association with him, but destiny decided otherwise and Dr. Thanikaimoni fell victim to international terrorism on his flight from Pondicherry to Woods Hole (U.S.A.) where he was to attend the 2nd International Conference on Palaeoceanography.

We are most grateful to Drs. C. Caratini, C. Tissot and Mrs K. Thanikaimoni who readily and generously accepted the difficult task of putting together Dr. Thanikaimoni’s notes and thus bringing to a good and quick conclusion the Manual, for the preparation of which Dr. Thanikaimoni had embarked in high spirits, convinced, as he was, that the Manual would not only fill a serious gap in knowledge, but also be very useful for practical purposes.

We hope that the users of the Manual will think likewise.

The final publication of the Manual was made possible by the enthusiastic cooperation extended by the French Institute, Pondicherry, through its Director, Dr. P. Legris and the Deputy Director, Mr. M. Deshayes, to whom we are all deeply indebted.

In conclusion, this Manual is one of the series of publications of the French Institute of Pondicherry and conceptually also an output of the Regional Project on Training and Research of Mangrove Ecosystems RAS/79/002. Two other Manuals are being prepared by the project, one on Hydrological and the other on Microbiological aspects of mangrove ecosystems. The Final Technical Report of RAS/79/002 is a cross section of the present day knowledge of the mangroves of Asia and the Pacific and their management within the framework of COMAR (Coastal and Marine Major Project) of UNESCO.
Fig. 1. Recent world mangrove distribution (from Kiener, 1973).
Mangrove ecosystems are among the most characteristic features of the low lying tropical coastlines, and, where environmental conditions are suitable, they extend southwards beyond the tropic of Capricorn and northwards beyond the Tropic of Cancer. The coastal zone everywhere, specially in the tropics, is highly dynamic, being exposed to land/sea/atmospheric interactions and to the interplay of hydrological, geological, meteorological and ecological factors and forces. The mangrove ecosystem represents a unique and irreplaceable adaptation to such a special environment.

Accordingly the condition of any mangrove ecosystem should be considered as the present stage in a long evolutionary history the rate of change of which varies from place to place. Changes are, for instance, very fast in the accretion areas of the delta of large rivers the waters of which carry large sediment loads, or in cyclone prone areas or those affected by volcanism, while they may be very slow in geologically steady coastlines without much change in mean sea level and tidal regime over long periods.

Thus an understanding of the dynamics of the ecosystem can benefit from a study of the past history of different mangroves; one of the aims of such studies is to try to predict the reaction of mangrove ecosystems to positive or negative changes in mean sea level. Such changes may be brought about by slow or quick geological coastal rising or sinking or by the global atmospheric warming, usually called the greenhouse effect or, eventually by the so called nuclear winter. Another aspect is the assessment of the land building capacity of mangrove ecosystems, this aspect also can benefit from a study of the past history of the mangroves of the same site.

Blasco (1984) emphasized the importance of palynology in the study of present and past mangrove ecosystems and summarized the knowledge to that date.

Palynology is a technique that allows for an analysis of the past history to be made with some precision specially in the coastal zone, because vegetation is the major component of the mangrove ecosystem. Because the vegetation is directly affected by climatic, geographical and geological changes, palynological studies may reveal not only the past extent of mangroves but the changes of environmental conditions over time as well. The establishment of correlations between species composition and extent of mangrove ecosystems over time thus appears to be the most important contribution that palynology can make to the understanding of contemporary mangrove ecosystems, their structure and dynamics, besides its use for oil prospection.

The inventory of the plant species composition from present day mangroves has been published by the National Mangrove Committees of each country, since the floristic species diversity is site specific, however it was deemed interesting to include in this Manual and in the context of palynological studies at large, an updated list of species from mangrove ecosystems that we hope will be of general interest and validity. Although debatable and by no means generally valid, for practical purposes and as a useful approximation, the distinction is made in the text, of "core mangroves" and "peripheral mangroves", where "core mangrove" species include obligatory mangrove ecosystem species that are restricted to the intertidal brackish water zones, such as the genera Aegiceras, Avicennia, Bruguiera, Ceriops, Kandelia, Lumnitzera, Nypa, Rhizophora, Sonneratia some of which (e.g. Avicennia) are found beyond the tropical belt.

"Peripheral mangrove species", or better designated "non obligatory" mangrove species, are those that are tolerant of a wide range of variation of ecological parameters and are not restricted to the intertidal tropical
zone, such as *Acrostichum* spp., *Hibiscus ilicaceus* or even *Acanthus ilicifolius*.

Within the spirit of the UNDP/UNESCO Regional Project on Training and Research of Mangrove Ecosystems, RAS/79/002 (1983-1986) and with the purpose of achieving a better understanding of the structure and dynamics of the mangrove ecosystem, we approached Dr. G. Thanika moni, a leading palynologist with a deep knowledge of mangroves; together with him and later with Drs. Caratini and Tissot we decided that a marriage between these two branches of ecology, namely palynology and community structure of tropical tidal forests or mangroves, would be fruitful for the development of both disciplines.

The author, and Drs. Caratini and Tissot who finalized the text after the tragic demise of Dr. Thanikaimoni, have endeavoured to prepare a practical manual for the use of scientists interested in palaeoecology as well as in contemporary ecology of tropical coastal systems. Each chapter focuses on different aspects of the palynological study of mangrove ecosystems.

It was considered useful to separate the work done on the Holocene and Pleistocene, from that done on the Tertiary. In fact the studies of the Quaternary can find support on the contemporary flora and on the pollen and spores of the mangrove vegetation. On the other hand, when studying the Tertiary, interpretations are unavoidably less precise; in these cases, pollen and spores of the mangroves are mainly used as stratigraphic or palaeogeographic markers. They are particularly interesting for oil research because pollen and spores from mangroves are frequently associated with sediments rich in organic matter, as are found in tropical deltas.

For what concerns methodologies, reference is made in the text to the specialised papers already published on the matter. The text deals in more detail on points usually untouched by earlier authors that are nevertheless necessary for reaching reliable conclusions on the palynology of mangrove ecosystems. These refer in particular to instruments and techniques for sampling the mangrove muds.

The more detailed part of this manual, because the authors believe it to be the most useful, is the one that refers to the morphology of pollen and spores. Accordingly the pollen of all Angiosperms and the spores of *Acrostichum aureum* one of the few ferns present in mangroves, are illustrated in detail. A key is proposed for their identification.

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Research and Training Pilot Programme on Mangrove Ecosystems
in Asia and The Pacific
PALYNOLOGICAL METHODOLOGY

An exhaustive description of the palynological methodology is far beyond the scope of the present work. However, some important publications may be mentioned which are necessary for a fair knowledge of palynological methodology.

One of them is the "Textbook of pollen analysis" from Fægri and Iversen (1975). It is desirable for a researcher wanting to deal with palynology to master this work.

Specially written for peat accumulation, this book provides useful data directly applicable to mangrove sediments.

1) Field technique

The types of peat borers commonly used for collecting sediments are given in Fægri and Iversen’s book with comments on their use, advantages and drawbacks.

De Beaulieu and Reille (1978) have described four kinds of borers with comparative studies of the pollen diagrams obtained by each type.

From this paper, it is obvious that the most commonly used "Hiller" hand peat-borer is not very reliable and should be abandoned. It is preferable to use the "soviet" hand peat-borer. As this device is not available, its diagram is given in figure 2. The borer is made up of two parts:

- the core chamber, which is half cylindrical and can be rotated around its axis;
- and the shutter, a flat part larger than the chamber. This part stays fixed in the sediment while the chamber rotates around it.

The use of this borer is very simple (Fig. 3). It is driven without rotating into the sediment with the chamber closed by the shutter (A). When the required depth is reached, a 180° clockwise rotation fills the chamber (B). Then, the borer is lifted upright, again without rotating (C). By rotating anticlockwise at 180° the borer (D) and the half cylindrical core can be collected and preserved in a semi-cylindrical plastic pipe without any disturbance or contamination. The core samples can be easily and safely transported in these plastic pipes.

In the tropics, it is advisable to poison the core samples with phenol to prevent the growth of fungi and/or bacteria in them.

For proper collection of samples in the field, it is necessary to make two borewells a few meters away from each other. One of them is systematically studied while the other is kept as a reference and studied only when the results obtained from the first one have to be checked or confirmed. It is essential to dig two holes in each borewell to avoid the collection of samples being disturbed by the base of the corer (Fig. 4).

2) Laboratory technique

The identification of fossil pollen is well developed in the "Textbook of pollen analysis". The sample processing as well as the indispensable "pollen herbarium", i.e. the collection of modern spores and pollen grains, are clearly explained in it.

The identification of fossil pollen grain is based on comparison of their morphological characters with those of the modern plants. This is the only method which ensures a certain degree of accuracy. Although an iconographical survey is useful in the early stages of investigation, the results obtained are not always reliable.

Another work which provides information on palynological preparatory techniques is that of Gray (1965). It gives a comprehensive account of physical and chemical techniques in addition to extensive references to earlier pertinent literature. Gray has stressed the need for an individualistic approach to sample processing whereby due regard is given to lithological characteristics; there is no one method of processing but a general protocol which has to be adapted to the particular characteristics of the current samples. Gray also insists on the desirability of successive monitoring of the residue at each step of process.
Fig. 2. Diagram of the "soviet" borer.

Fig. 3. Use of the "soviet" borer.
Ultrasonic sieving is a new device (Caratini, 1980) currently used in many laboratories to improve palynological processing of sediments. The advantages of this method are:

- maximum concentration of palynomorphs;
- clean slides with palynomorphs free of minute particles;
- quick preparation of samples.

3) Pollen diagrams and interpretation

The principles to be followed for pollen analysis and plotting of pollen diagrams have been dealt with in detail by Fægri and Iversen (op. cited).

New developments in data handling and computerization in recent years have considerably increased the approaches to their interpretation. For example, Tucker and Tucker (1985) article gives an idea of what could be achieved by computers.

Fig. 4. Technique of coring. Samples from Borewell 1 are for studies; cores from Borewell 2 are stored as reference material.
MANGROVE SPECIES OF THE WORLD

Core Mangrove

Areaceae
Nypa fruticans Wurbm.
Phoenix paludosa Roxb.

Avicenniaceae
Avicennia africana P. Beauv.
Avicennia alba Bl.
Avicennia balanophora Stapf. & Moldenke
Avicennia bicolor Standl.
Avicennia eucalyptifolia Zipp. ex Miq.
Avicennia germinans L.
   (Avicennia nitida Jacq.)
Avicennia lanata Ridl.
Avicennia lanceolata (Engelh.) Moldenke
Avicennia marina (Forsk.) Vierh.
   var. acutissima (Stapf.) Moldenke
   var. australasica (Walp.) Moldenke
   var. anomala Moldenke
   var. resinifera (Forsk.) Bakh.
   var. rumphiana (Hallier) Bakh.
Avicennia officinalis L.
Avicennia schaueriana Stapf. & Leechman
Avicennia tonguzii Moldenke

Bombacaceae
Camptosperm philippinensis (Vid.)
Becc.
Camptosperm schultzii Mast.

Caesalpiniaceae
Cynometra iripa Kostel.
   (C. ramiflora L. var. mimosoides Bak.)
Cynometra ramiflora L.

Combretaceae
Conocarpus erectus L.
Laguncularia racemosa (L.) Gaertn. f.
Lumnitzera littorea (Jack) Voight
   (L. coccinea Wt. & Arn.)
Lumnitzera racemosa Willd.

Euphorbiaceae
Excoecaria agallocha L.

Meliaceae
Xylocarpus australasicus Ridley
Xylocarpus benadinensis Mattei
Xylocarpus granatum Koenig
   (Carapa obovata Bl.)
Xylocarpus mekongensis Pierre
   (X. gangeticus Parkison, Carapa moluc-
   censis Lam. var. gangeticus)
Xylocarpus moluccensis (Lam.) Roem.
   (Carapa moluccensis Lam.)
Xylocarpus minor Ridley

Myrsinaceae
Aegiceras corniculatum (L.) Blanco
   (A. majus Gaertn.)
Aegiceras floridum Roemer & Schultes

Myrtaceae
Osbornia octodonta F. Muell.

Pelliceriaceae
Pelliciera rhizophorae Pl. & Tr.

Plumbaginaceae
Aegialitis annulata R. Br.
Aegialitis rotundifolia Roxb.

Poaceae
Porteresia coarctata (Roxb.) Takeoka
   (Oryza coarctata Roxb.)

Rhizophoraceae
Bruguiera cylindrica (L.) Bl.
   (B. caryophylloides (Burm. f.) Bl.)
Bruguiera exaristata Ding Hou
Bruguiera gymnorrhiza (L.) Lam.
   (B. conjugata Merr.)
Bruguiera hainesii C.G. Rogers
Bruguiera parviflora (Roxb.) Wt. & Arn.
   ex Griff.
Bruguiera sexangula (Lour.) Poiret
   (B. eriopetala Wt. & Arn.)
Ceriops decandra (Griff.) Ding Hou
   (C. roxburghiana Arn.)

Ceriops tagal (Perrottet) C. B. Robinson  
(C. candollea Arnt.)
Kandelia candel (L.) Druce  
(K. rheedi Wt. & Arn.)
Rhizophora apiculata Bl.  
(R. candelaria DC.)
Rhizophora harrisonii Leechman
Rhizophora lamarckii Montrouzier
Rhizophora mangle L.
Rhizophora mucronata Lam.
Rhizophora racemosa G. Meyer
Rhizophora stylosa Griff.  
(R. mucronata Lam. var. stylosa
(Griff.) Schimper)
Rubiaceae  
Scyphiphora hydrophyllacea Gaertn.

Peripheral mangrove species (often or occasionally recruited) from fresh water swamps, salt marshes and strand flora

Acanthaceae  
Acanthus ebracteatus Vahl.
Acanthus ilicifolius L.
Acanthus volubilis Wall.

Aizoaceae  
Sesuvium portulacastrum L.

Arecaceae  
Mauritia flexuosa L. f.
Onosperma tigillarium (Jack) Ridley  
(O. filamentosum Bl.)

Barringtoniaceae  
Barringtonia asiatica (L.) Kurz
Barringtonia racemosa Roxb.

Bignoniaceae  
Dolichandrone spathacea (L. f.) K. Schum.

Blechnaceae  
Stenochlaena palustris (Burm.) Bedd.

Caesalpinaceae  
Caesalpinia crista L.  
(C. nuga L.)
Intisia bijuga (Colebr.) Ktze.  
(I. retusa (Colebr.) Kurz)
(Afzelia retusa Kurz)

Chenopodiaceae  
Atriplex stockii Boiss.

Sonneratiaceae  
Sonneratia alba J.E. Smith
Sonneratia apetala Buch.-Ham.
Sonneratia caseolaris (L.) Engl.  
(S. acida L.)
Sonneratia griffithii Kurz  
(S. acida L. var. griffithii Kurz)
Sonneratia ovata Baker

Hybrids:  
Sonneratia alba x caseolaris
Sonneratia alba x ovata

Sterculiaceae  
Heritiera fomes Buch.-Ham.  
(H. minor Roxb.)
Heritiera littoralis Aiton ex Dryander

Halosarcia indica (Wild.) P.G. Wilson  
(Arthrocnemum indicum (Willd.) Moq.)
Salicornia brachiata Roxb.
Salsola foetida Del.
Salsola kali L.
Suaeda fruticosa Forsk.
Suaeda maritima (L.) Dum.
Suaeda monoica Forsk.
Suaeda nudiflora Moq.

Clusiaceae  
Symphonia globulifera L. f

Convolvulaceae  
Ipomoea macrantha Roemer & Schultes  
(I. tuba (Schlecht.) Don)
Stictocardia tiliifolia (Desr.) Hallier f.

Flagellariaceae  
Flagellaria indica L.

Loranthaceae  
Dendrophthoe falcata (L. f.) Etting.

Lythraceae  
Pemphiis acidula J.R. & G. Frost.

Malvaceae  
Hibiscus tiliaceus L.

Meliaceae  
Aglaia cucullata  
(Amoora cucullata Roxb.)
Mimosaceae
    *Prosopis chilensis* (Mol.) Stuntz

Myrtaceae
    *Melaleuca leucodendron* L.

Papilionaceae
    *Dalbergia horrida* (Dennst.) Mabberley
        (*D. spinosa* Roxb.)
    *Derris heterophylla* (Willd.) Back.
        (*D. trifoliata* Loen., *D. uliginosa* Benth.)

Poeae
    *Myriostachya wightiana* (Nees ex Stendel)
        Hook. f.

Pteridaceae
    *Acrostichum aureum* L.

Salvadoraceae
    *Azima tetracantha* Lam.
    *Salvadora persica* L.

Solanaceae
    *Solanum trilobatum* L.

Tiliaceae
    *Brownlowia argentata* Kurz
    *Brownlowia elata* Roxb.
    *Brownlowia tersa* (L.) Kosterm.
        (*B. lanceolata* Benth.)

Taxodiaceae
    *Taxodium distichum* (L.) Rich.

Verbenaceae
    *Clerodendrum inerme* Gaertn.
SPECIES AND SPECIMENS EXAMINED

The abbreviations used for the herbaria are in accordance with Holmgren & Keukens' Index Herbarium:

BO = BOGOR (Indonesia): Herbarium Bogoriense.
BSI = POONA (India): Botanical Survey of India.
CAL = CALCUTTA (India): Botanical Survey of India, Head office, Central National Herbarium.
DD = DEHRA DUN (India): Forest Research Institute and Colleges.
G = GENEVE (Switzerland): Conservatoire et Jardin Botaniques.
HIPF = PONDICHERY (India): Institut Français.
K = KEW (Great Britain): Royal Botanical Gardens.
L = LEIDEN (Netherlands): Rijksherbarium.
M = MUNCHEN (Federal Republic of Germany): Botanische Staatssammlung.
MH = COIMBATORE (India): Botanical Survey of India.
P = PARIS (France): Muséum National d'Histoire Naturelle, Laboratoire de Phanérotype.
PCM = MADRAS (India): Presidency College.
SING = SINGAPORE (Republic of Singapore): Herbarium & Library, Botanic Garden.
TL = TOULOUSE (France): Faculté des Sciences, Laboratoire de Botanique.
US = WASHINGTON (U.S.A.): National Herbarium, Department of Botany.
YA = YAOUNDE (Cameroon): Service des Eaux et Forêts du Cameroun.

Pteridaceae

Acrostichum aureum L., Goa (India), G. Thanikaimoni 1131 – HIPF.

Arecaceae

Phoenix paludosa Roxb., Sundarbans (India), G. Thanikaimoni s.n. – HIPF.
Nypa fruticans Wurmb., Cameroon, Villiers & Caratini 746 – YA.
Nypa fruticans Wurmb., Madras, G. Thanikaimoni s.n. – HIPF.

Acanthaceae

Acanthus ebracteatus Vahl., Brunei, Van Niel 4366, slide IFP 814.
Acanthus ebracteatus Vahl., Singapore, Sainclaire s.n. – L.
Acanthus ilicifolius L., Goa (India), K. Naresh Babu 2794 – DD.

Plumbaginaceae

Aegialitis annulata R. Br., Queensland (Australia), Stoddart 4991 – US.
Aegialitis rotundifolia Roxb., Sundarbans (India), G. Thanikaimoni s.n. – HIPF.

Rubiaceae

Scyphiphora hydrophyllacea Gaertn., Singapore, Debeaux 106 – P.

Euphorbiaceae

Excoecaria agallocha L., Goa (India), K. Naresh Babu 2791 – DD.

Rhizophoraceae

Bruguiera cylindrica (L.) Bl., Pichavaram (India), Caratini & Meher-Homji s.n. – HIPF.
Bruguiera exaristata Ding Hou, Queensland (Australia), Stoddart 4785 – US.
Bruguiera gymnorrhiza (L.) Lam., Andaman Islands, K. Thothathri 9054 – MH.
Bruguiera gymnorrhiza (L.) Lam., Nicobar Islands, K. Thothathri 9335 – MH.
Bruguiera gymnorrhiza (L.) Lam., Godavari (India), T. Seshagiri Rao s.n., slide IFP 2483.
Bruguiera hainesii C.G. Rogers, Sundarbans (India), Mukherjee 6245 – CAL.
Bruguiera parviflora (Roxb.) Wt. & Am. ex Griff., Solomon Islands, L.J. Brass 3108 – G.
Bruguiera sexangula (Lour.) Poiret, Sundarbans (India), Blasco 3041 – TL.
Ceriops decandra (Griff.) Ding Hou, Pichavaram (India), Blasco 10 – HIFP.
Ceriops tagal (Perrottet) C.B. Robinson, Karumbar Islands (India), G. Thanikaimoni 1087 – HIFP.
Ceriops tagal (Perrottet) C.B. Robinson, – PCM.
Kandelia cadel (L.) Druce, Orissa (India), G. Thanikaimoni & Caratini s.n. – HIFP.
Rhizophora apiculata Bl., Karwar (India), G. Thanikaimoni 1146 – HIFP.
Rhizophora harrisonii Leechman, Panama, Erlanson 13 – US.
Rhizophora lamarckii Montrouz., Queensland (Australia), W.T. Jones s.n., slide IFP 19339.
Rhizophora x lamarckii Montrouz., Pichavaram (India), G. Thanikaimoni 1783 – HIFP.
Rhizophora mangle L., Guadeloupe, A. Raynal-Roques & Jérémie 2113 – P.
Rhizophora mucronata Lam., Krusadai Islands (India), – PCM.
Rhizophora mucronata Lam., Goa (India), G. Thanikaimoni 1140 – HIFP.
Rhizophora mucronata Lam., Godavari (India), T. Seshagiri Rao s.n., slide IFP 3157.
Rhizophora racemosa G. Meyer, Angola (?), Gosweiler 808 – US.
Rhizophora stylosa Griff., Lamlea Dutch E. India, L.S. Gibbs 6293, slide IFP 15724.

Combretaceae

Conocarpus erectus L., Salvador, Eyerdam 8756 – US.
Laguncularia racemosa Gaertn. f., British Honduras, Spellman & Stoddart 2228 – US.
Lumnitzera litoraea (Jack) Voight, Andaman Islands, K. Thothathri s.n. – MH.
Lumnitzera racemosa Willd., Krusadai Islands (India), G. Thanikaimoni s.n. – HIFP.
Lumnitzera racemosa Willd., Godavari (India), T. Seshagiri Rao s.n., slide IFP 3154.

Myrsinaceae

Aegiceras corniculatum (L.) Blanco, Karumbar Islands (India), G. Thanikaimoni 1809 – HIFP.
Aegiceras corniculatum (L.) Blanco, North Kanara (India), – PCM.
Aegiceras floridum Roemer & Schultes, Arboina (Molucaas), C.B. Robinson 253 – P.

Sterculiaceae

Heritiera fomes Buch.-Ham., Orissa (India), L.K. Banerjee 8980 – HIFP.
Heritiera littoralis Aiton ex Dryander, Spiracha Bang Pua, D.J. Collins 1924, slide IFP 15569.

Avicenniaceae

Avicennia africana P. Beauv., Nigeria, W.G. Chaloner s.n. – K.
Avicennia alba Bl., Java, S.H. Koorders 9694 – BO.
Avicennia bicolor Standl., Panama, H. Pittier 4968 – P.
Avicennia germinans L., British Guyana, S.G. Harrison 1534 – K.
Avicennia lanata Ridl., Malaya, K.M. Kochummen 77728 – K.
Avicennia lanata Ridl., Malaya, H.M. Burkill 1831 – SING.
Avicennia marina var. marina (Forsk.) Vierh., Pichavaram (India), G. Thanikaimoni s.n. – HIPF.
Avicennia marina var. marina (Forsk.) Vierh., Queensland (Australia), Flecker s.n., slide IFP 14521.
Avicennia marina var. acutissima Stapf. & Mold. ex Mold., Thana (India), G. Thanikaimoni 1121a – HIPF.
Avicennia marina var. resinifera (Forsk.) Bakh., Papua, L.J. Brass 882 – BO.
Avicennia marina var. rumphiana (H. Hallier) Bakh., Moluccas, Fika-Fika 933 – BO.
Avicennia officinalis L., Pichavaram (India), G. Thanikaimoni s.n. – HIPF.
Avicennia officinalis L., Goa (India), K.C. Kanodia s.n. – BSI.
Avicennia schaueriana Stapf. & Leechman, Brasil, Lützelburg 401 – M.
Avicennia tonduzii Moldenke, Costa Rica, Tonduz 10060 – M.

Caesalpinioideae

Cynometra ramiflora L., Andaman Islands, K. Thothathri 9121 – MH.

Myrtaceae

Osbornia octodonta F. Muell., Queensland (Australia), Thozet s.n. – P.

Tiliaceae

Brownlowia argentata Kurz, Papua, L.J. Brass 28839 – US.
Brownlowia elata Roxb., Kalimantan (Indonesia), C. Caratini s.n. – HIPF.
Brownlowia tersa (L.) Kosterm., Sundarbans (India) – CAL.

Pellicieraceae

Pelliciera rhizophorae Planchon & Triana, Panama, Hayes 76 – K.

Bombacaceae

Camptostemon philippinensis (Vid.) Becc., Philippines, L. Escritor 1584 – P.

Meliaceae

Xylocarpus australasicus Ridley, Papua, Hoogland 4302 – US.
Xylocarpus granatum Koenig, Malaya, Diemont & Van Wingaarden 89 – HIPF.
Xylocarpus granatum Koenig, Java – L.
Xylocarpus mekongensis Pierre, Pichavaram (India), Kannan s.n. – HIPF.
Xylocarpus moluccensis (Lam.) Roem., Java, F.C.V. Faber s.n. – M.

Sonneratiaeae

Sonneratia alba J.E. Smith, South Kanara (India), Fyson 5517 – PCM.
Sonneratia alba J.E. Smith, Elephanta Islands (India), G. Thanikaimoni 1122 – HIPF.
Sonneratia alba x caseolaris, Brunei, J. Muller 11 – L.
Sonneratia alba x ovata, Brunei, J. Muller 8 – L.
Sonneratia griffithii Kurz, Burma, Kermode 7136 – K.
Sonneratia ovata Baker, Singapore, H.N. Ridley 8434 – SING.
Sonneratia ovata Baker, Brunei, J. Muller 7 – L.
Sonneratia caseolaris (L.) Engl., Honnavar (India), G. Thanikaimoni 1817 – HIPF.
Sonneratia apetala Buch.-Ham., Elephanta Islands (India), G. Thanikaimoni 1123 – HIPF.
Sonneratia apetala Buch.-Ham., Godavari (India), – P.
TERMINOLOGY

The following are the definitions of select terms used in this key (see also: APLF, 1975; Faegri & Iversen, 1975; Nilsson & Muller, 1978; Thanikaimoni, 1978).

aperture: morphologically it is an opening or a thinning of exine (except in operculate apertures) where the intine is thickened; physiologically it could be either a germinative zone or a harmomegathus, or both.

apertural membrane: thin exine of the aperture.

colpus (adj. colpate): meridional simple aperture having length/breadth ratio > 2.

colporus (adj. colporate): meridional composite aperture having an elongated ecto-aperture (colpus) and an endoaperture (os).

columnellae (adj. columnellate): infratectal columnar elements of the sexine.

costae: thickening of the nexine bordering the apertures.

costae colpi: costal thickening accompanying colpus.

costae equatoriales: girdle like costal thickening at the equator.

costae pori: costal thickening accompanying the pore or os.

extexe: outer layer of exine staining red with fuchsin B and differing from the endexine by electron density as seen in TEM.

ectoaperture: the thinning or opening in the ectexine/nexine.

endexine: inner layer of exine that appears faintly pink after staining with fuchsin B and differing from the ectexine by electron density as seen in TEM.

endoaperture: thinning or opening in the endexine/nexine, also known as os.

endosculpture: sculpture of the inner surface of the nexine or endexine.

equatorial axis: the greatest axis, perpendicular to the polar axis, except when the pollen is constricted at the equator. When the equatorial contour is elliptic or rectangular, two equatorial axes E1 and E2 are measured.

exine: external wall of pollen containing sporopollenin.

fastigium (pl. fastigia): cavity in a colporate grain caused by a separation or discontinuity of nexine and accompanied by a dome shaped sexine in the area of the endoaperture.

fossula (adj. fossulate): ± elongated irregular depressions.

foveola (adj. foveolate): ± circular depressions.

heteropolar: pollen grain with asymmetrical distal and proximal parts.

infractectum: situated under the tectum.

intine: part of the pollen wall between the exine and the cytoplasm. It lacks sporopollenin and does not resist acetylsis.

isopolar: pollen grain with ± symmetrical distal and proximal parts.

lumina: meshes of the reticulum.

meridional: surface features perpendicular to the equatorial plane.

nexine: inner exine representing either sole (foot layer), or endexine, or both.

operculum: thickened exine covering the aperture, often getting detached after acetylsis.

os (pl. ora; adj. orate): nexinal or endexinal part of the composite aperture; also known as endoaperture.

pilum (pl. pila, adj. pilate): sculptural element consisting of a ± swollen apex and a
rod-like neck.

**polar axis**: line between the proximal and distal poles.

**poles**: the two extremities of the axis oriented towards the centre of the tetrad at the time of pollen (and spore) development.

**porus or pore** *(adj. porate)*: simple aperture with length/breadth ratio < 2. The pores are equatorial in position. When they are distributed over the entire surface of the pollen grain, the latter is described as periporate.

**pseudocolpus**: symmetrically distributed, elongated exinal thinning or opening resembling the colpus but not associated with an underlying intimal thickening.

**reticulum** *(adj. reticulate)*: net work with walls (muri) encircling the lumina.

**rugulae** *(adj. rugulate)*: irregularly elongated sculptural elements.

**scabrae** *(adj. scabrare)*: sculptural elements of < 1 μm dimension.

**sexine**: outer, usually sculptured, layer of exine.

**spine** *(adj. spiny or echinate)*: pointed sculptural elements.

**sulcus** *(adj. sulcate)*: distal elongated aperture.

**syncolpate**: fused colpi.

**synorate**: fused ora.

**tectum**: the outer stratum of the sexine found over a columellar or granular stratum; it may be either continuous (imperforate) or discontinuous with perforations (per-reticulate, per-foveolate, per-fossulate). The tectum is either homogeneous (simple) or heterogeneous (structurate).

**verrucae** *(adj. verrucate)*: ± isodiametrical sculptural elements with basal diameter equal to or greater than the height.
KEY TO MANGROVE POLLEN AND SPORES

(Digits between brackets refer to the plate numbers)

1. Heteropolar spore with triradiate tetrad mark
   Acrostichum aureum (1, 2)

1. Heteropolar pollen, monosulcate, reticulate
   Phoenix paludosa (3)

1. Isopolar pollen

2. meridionosulcate (with meridional girdle like aperture), spinulate, finely reticulate in between spines, sometimes spines incompletely developed (± warty), acetylised and fossil pollen often broken into halves along the aperture
   Nypa fruticans (4)

2. tricolpate

3. reticulate with a free columellar element in the lumina, 3 lobed in polar view, acetylised pollen sometimes broken along the colpus
   Acanthus ebracteatus (5)
   Acanthus ilicifolius (5)

   3. densely pilate, nexine honey comb like, aperture membrane operculoid; pollen rarely 2-syncolpate or 6-pericoline

2. tricolporate

3. without pseudocolpi

4. ectoaperture long (longicolporate), generally free, pollen longiaxial to equiaxial, sometimes breviaxial, endoaperture perpendicular to the ectoaperture
   Aegialitis annulata (6, 7)
   Aegialitis rotundifolia (8, 9)

5. aperture 3-partite (ectoaperture, mesoaperture and endoaperture), nexine endosculptured, sexine reticulate; pollen rarely disyncolporate.
   Scyphiphora hydrophyllacea (10)

6. fastigate, ectoaperture constricted at the equator, endoaperture perpendicular to the ectoaperture.
7. infractectum distinctly columellate, exine reticulate, endoaperture narrowly elliptic

7. infractectum faintly columellate, exine scabrous to finely reticulate

8. costae prominent

9. endoaperture wide, with uneven lateral ends; pollen sometimes tetracolporate or dicolporate; often syncorate or nearly so in *Rhizophora* sp.

9. endoaperture broadly elliptic

9. endoaperture papiliform; rarely tetra-(peri)syncolporate

8. costae feeble, endoaperture elliptic

6. non fastigate, ectoaperture wide at the equator, endoaperture circular or elliptic (parallel to the ectoaperture)

7. reticulate, infractectum columellate; costae absent; sometimes dicolporate with ectoapertures free or fusing at poles or 6-pericolporate (dyads?) or inaperturate without content

7. rugulate-verrucate, rugulae and warts anastomosing, infractectum not distinctly columellate, costae colpi present

4. ectoapertures fused at poles (syncolporate), brevialxial, exine scabrous, thin, pollen triangular in polar view, rarely tetracolporate (quadrangular in polar view)

4. ectoapertures short (brevicolporate), free, pollen brevialxial to equialxial

5. tricolporate

6. reticulate-fossulate, costae discontinuous at the equator, endoaperture parallel to the ectoaperture

6. foveolate-fossulate, sometimes verrucate-

*Excoecaria agallocha* (11)

*Bruguiera* spp. (12)

*Ceriops* spp. (13)

*Kandelia* spp. (14)

*Rhizophora* spp. (15-17)

*Laguncularia racemosa* (18)

*Aegiceras corniculatum* (18)

*Aegiceras floridum* (18)

*Heritiera fomes* (19)

*Heritiera littoralis* (19)

*Avicennia* spp. (20-28)

*Cynometra ramiflora* (29)

*Osbornia octadonta* (29)

*Brownlowia argentata* (30)

*Brownlowia elata* (30)
rugulate, costae colpi discontinuous at the equator, endoaperture perpendicular to the ectoaperture

6. spinulate, endoaperture with costae pori

5. tetracolporate-pentacolporate, rarely tricolporate, finely reticulate-scabrous, fastigiate, costae colpi and costae pori present

3. with 3 pseudocolpi

4. 6-lobed in polar view, more or less elliptic in meridional view, rugulate-reticulate, infractectum not distinctly columellate, endoaperture perpendicular to the ectoaperture

5. polar axis 11-13 μm

5. polar axis 28-37 μm, dome shaped in polar optical section

6. exine rugulate-reticulate

6. exine reticulate

4. not 6 lobed in polar view, exine verrucate-rugulate at the equatorial region, smooth or perforate or verrucate-rugulate at polar region, colpi and pseudocolpi sometimes poorly or not differentiated; abnormal pollen 4 or 6 aperturate

5. colpi and pseudocolpi more or less readily distinguishable

6. exine smooth to perforate at polar region, verrucate-rugulate at the equatorial region

6. exine ± uniformly verrucate-rugulate

5. colpi and pseudocolpi rarely distinguishable, aperture almost reduced to pores (triporate)

6. exine smooth-peforate at polar region, verrucate-rugulate at equatorial region

6. exine uniformly rugulate

2. triporate: see just above, § 4.

Pelliciera rhizophorae (31)
Camptostemon philippensis (32)
Xylocarpus spp. (33, 34)
Conocarpus erectus (35)
Lumnitzera littorea (35)
Lumnitzera racemosa (35)
Sonneratia spp. (36-42)
Sonneratia alba (36-38)
Sonneratia griffithii (39)
Sonneratia ovata (40)
Sonneratia caseolaris (41)
Sonneratia apetala (42)
Sonneratia spp. (36-42)
PLATE 1. Pteridaceae: *Acrostichum aureum* 1–6, x 1000, acetolysed.
PLATE 2. Pteridaceae: *Acrostichum aureum* 7–19, x 1000, Wodehouse technique.
PLATE 3. Arecaceae: Phoenix paludosa 20–25, x 1000, Wodehouse technique; 26–33, x 1000, acetolysed. Nypa fruticans 34–35, x 1000, Wodehouse technique; 36–37, x 1000, acetolysed.
PLATE 5. Acanthaceae: *Acanthus ilicifolius* 44–47, x 1000, Wodehouse technique (apertural membrane with granules); 48–50, x 1000, acetolysed. *Acanthus ebracteatus* 51–52, x 750, acetolysed; 53–59, x 1000, acetolysed.
PLATE 7. Plumbaginaceae: Aegialitis annulata 66–69, x 1000, acetolysed.
PLATE 8. Plumbaginaceae: Aegialitis rotundifolia 70–75, x 1000, acetolysed.
PLATE 11. Euphorbiaceae: *Excoecaria agallocha* 109–120, x 1000, acetolysed; 121, x 1000, Wodehouse technique; 122–123, x 1000, acetolysed.
PLATE 14. Rhizophoraceae: *Kandelia candel* 212–237, x 1000, acetolysed; 238, x 1000, Wodehouse technique, abnormal grain, tetracolporate.
PLATE 15. Rhizophoraceae: Rhizophora apiculata 239–248, x 1000, acetolysed; Rhizophora harrisonii 249–263, x 1000, acetolysed; 264–265, x 1000 Wodehouse technique.
PLATE 16. Rhizophoraceae: Rhizophora lamarckii 266–283 and 289–300, x 1000, acetolysed; 284–288, x 1000 Wodehouse technique; Rhizophora mangle 301–307, x 1000, acetolysed.
PLATE 25. Avicenniaceae: Avicennia marina var. acutissima 527-532, x 1000, acetolysed; 533, x 1000, Wodehouse technique. Avicennia marina var. resinifera 534-543, x 1000, acetolysed; 544-546, x 1000, Wodehouse technique.
PLATE 27. Avicenniaceae: Avicennia schaueriana 569–578, x 1000, acetolysed; 577–578: abnormal grain, inaperturate; 579–580, x 1000, 3 young pollens, Wodehouse technique; 581–584, x 1000, abnormal dyad with 6 periapertures, Wodehouse technique.
PLATE 31. Pellicieraceae: *Pelliciera rhizophorae* 629–634, x 1000, acetolysed.
PLATE 32. Bombacaceae: Camptostemon philippinensis 635–637, x 1000, Wodehouse technique; 638–643, x 1000, acetolysed.
PLATE 34. Meliaceae: *Xylocarpus mekongensis* 660–661, x 1000, acetolysed; 662–663, x 1000, Wodehouse technique; 663: pentacolporate grain. *Xylocarpus moluccensis* 664–673, x 1000, acetolysed (3, 4 and 5 colporate grains).
PLATE 36. Sonneratiaceae: Sonneratia alba 709-712, x 1000, acetolysed.
PLATE 38. Sonneratiaceae: *Sonneratia alba* 723–725, x 1000, acetolysed. *Sonneratia alba* x *caseolaris*, 726–727, x 1000, acetolysed. *Sonneratia alba* x *ovata*, 728–730, x 1000, acetolysed.
PLATE 39. Sonneratiaceae: Sonneratia griffithii 731–742, x 1000, acetolysed.
PLATE 41. Sonneratiaceae: Sonneratia caseolaris 756–764, x 1000, acetolysed.
PLATE 42. Sonneratiaceae: *Sonneratia apetala* 765–769 and 771–772, x 1000, acetolysed; 770, x 1000, Wodehouse technique, abnormal grain, tetraaperturate.
DISSEMINATION AND SEDIMENTATION OF MANGROVE POLLEN SPORES AND MARINE MICROPLANKTON

To attain a reasonable degree of accuracy in the palynological reconstruction of palaeoenvironments, a knowledge of the following conditions is very useful:

1) the ecological requirements of the extant genera corresponding to fossil pollen;
2) the relationships between the vegetation and the palynological assemblage preserved in recent sediments.

Recent mangrove sediments

Some important works dealing with palynological analyses of surface sediment samples collected in various geographical sites around the world provide data on the relationships within the mangrove community. Among them may be mentioned:

Australia
Grindrod (1985)
Cameroon
Boyé et al. (1975)
Florida
Riegel (1965)
Gabon
Aoutin (1967)
India
Caratini et al. (1973)
Indonesia
Caratini & Tissot (in press)
Malaysia (Sarawak)
Anderson & Muller (1975).

An example from one of these studies (Caratini et al., 1973) is given briefly below.

**Pichavaram (India)**

In the mangroves of Pichavaram, at the mouth of the Cauvery delta, three main vegetation zones can be presently recognized (Fig. 5):

- *Rhizophora* zone with *Bruguiera cylindrica* and *Ceriops decandra*;
- *Avicennia marina* zone;
- back mangroves with *Suaeda*, stunted non-fruiting *Avicennia marina* and *Excoecaria agallocha*.

Pollen analysis of the surface samples from these three zones gives a picture of a vegetation that is not fundamentally different from the recent floristic composition (Fig. 6). This deviation is mainly due to:

- over-representation of *Rhizophoraceae* and *Sonneratia*;
- normal representation of *Suaeda*;
- under-representation of *Avicennia* and other mangrove taxa such as *Excoecaria agallocha*, *Acanthus ilicifolius*, *Lumnitzera racemosa*; 
- presence of allochthonous pollen belonging to hinterland flora which constitutes nearly 25% of the total pollen grains extracted from the sediments.

![Fig. 5. Zonation of the mangrove vegetation in Pichavaram, Cauvery delta, India (from Blasco and Caratini, 1973).](image)
Marine sediments

The sedimentation of mangrove pollen and spores in recent marine deposits has also been investigated offshore several areas:

- Orinoco delta: Muller (1959)
- Gulf of California: Cross et al. (1966)
- Ivory Coast: Caratini et al.
  (in press)

From these studies, the most striking data concerning the degree of representativity of pollen in the sediments are as follows:

- over-representation of Rhizophoraceae.

Hence this family is the best marker for mangroves, but in some cases this rule may not apply. For example, although Rhizophora is abundant along the coasts of the Gulf of California, its pollen is not found in large numbers in the bottom sediments. Nearer the shore, its distribution closely approximates its range along the coast (Cross et al., 1966).

- normal representation of Sonneratia.

Despite the fact that the Sonneratraceae are bat-pollinated, the pollen of this genus has always been recorded in the areas where this family is represented.

under-representation of Avicennia and Nypa.

Marine microplankton

The palynomorphs with a marine origin often occur in mangrove sediments.

Among the Dinoflagellates kysts, most frequent are Operculodinium centrocarpum, Hemicystodinium zoharii and Spiniferites sp. Foraminifera are also recorded but they can not be identified with accuracy because after the palynological processing only their organic tests which show no characteristic features are preserved.

The marine palynomorphs, although generally poorly represented, may be useful environmental markers. In the surface sediments, a good relationship does exist between:

- the marine palynomorphs/continental palynomorphs ratio;
- the location of the samples in the mangrove.

This relationship is particularly clear (Fig. 7) in the Mahakam delta, Kalimantan, Indonesia (Caratini and Tissot, in press).
Fig. 7. Mahakam delta, Kalimantan: Schematic representation of the ratio between marine and continental palynomorphs in surface samples collected from the apex of the delta (top of the diagram) to its offshore part (bottom of the diagram).

Aeropalynology

Although dissemination of pollen and spores by wind is the first step towards sedimentation, not much data are available concerning the aeropalynology of mangrove pollen taxa.

Offshore Senegal and Gambia where mangrove forests are found along some parts of the coast and along the Gambia river, a pollen trap was exposed during the oceanographic cruise ORGON III (Caratini and Cour, 1980). The pollen of Rhizophora, the only mangrove pollen genus recorded, constitutes 1.91% of the total airborne pollen.

In Indonesia, within and offshore the Mahakam delta (Kalimantan), three aeropalynological samples were investigated during the MISEDOR borewell drilling (Caratini and Tissot, in press).

Such a limited study is not sufficient for drawing conclusions, but the following features (Fig. 8) may be mentioned:

- Rhizophoraceae: as expected, this family has the best representation, attaining 58.5% offshore where the only mangrove pollen recorded is Ceriops;
- Nypa: the greater part of the deltaic plain is called "Nypa plain" because it is covered by about 99% of Nypa fruticans. Although these palms produce flowers throughout the year, only one pollen grain of Nypa was trapped. This species may be considered as entomophilous which may explain the consistently low percentage of Nypa pollen found in the Holocene and recent sediments.
- Sonneratia: the very low percentages of Sonneratia (0.4 and 0.8%) are not in accordance with the surrounding vegetation where Sonneratia is common nor with the rather frequent occurrence of the pollen of this genus generally observed in estuarine and marine sediments.

- the under-representation of other mangrove or back-mangrove species, already noticed in surface sediments, is confirmed.

Fig. 8. Aeropalynology in the Mahakam delta, Kalimantan, Indonesia (data from Caratini & Tissot, in press).
EVOLUTION OF MANGROVE VEGETATION DURING THE QUATERNARY

Palynological investigations have provided plenty of data on the history of the mangrove vegetation in the intertropical regions during the Quaternary. Generally, these studies based on palynological analysis of core samples, conclude that, around the site of the coring, the vegetation has changed throughout the concerned periods. The dispute among present ecologists to decide whether the mangroves are a "steady state" or a "successional ecosystem" (Lugo, 1980) loses its meaning when analysing the evidence from the past and the cyclic nature of the mangrove environment. However, the aims of the authors are not only to trace the history of the mangrove vegetation but also:

1) to reconstruct the evolution of the palaeoenvironments;
2) to identify, eventually, the external factors responsible for the changes with attempts at their quantification.

In fact, there are several external factors which maintain the mangroves under stressing conditions. Among them, are factors related to:

- water: salinity, fresh water supply, temperature, energy i.e. tidal flows, storms, currents, etc;
- relative sea level changes: geomorphology, sedimentation rates, ...
- climate on which depend temperature, fresh water supply, salinity, ...
- human activity which, although recent has a strong (and unfavourable) influence.

All these factors are more or less strongly interlinked. However, as the mangrove forests are always located at the ocean-continent interface, they are directly related to changes in the sea level, i.e. they mostly depend on global events. Local factors may also have an influence on the nature and development of mangrove forests. However, during the Quaternary, the glacial fluctuations which dominated sea level changes, have consequently affected the fate of the mangroves as shown in the following survey of the reconstruction of mangrove history in the tropics during this period.

INDIAN SUBCONTINENT

The vegetation maps (Gaussen et al., 1961-1978) and the monograph on the mangroves of India by Blasco (1975), as also the bibliography on Indian mangroves (Untawale et al., 1976) give a fair picture of the present state of the mangrove vegetation in India. Using the pollen morphological descriptions of tropical Asian plants, particularly those published by Guinet (1962), it has been possible to identify the palynological elements found in recent and fossil sediments and to trace the evolution of mangroves in some localities (Fig. 9). In most of the investigated sites, a severe degradation of the mangrove vegetation due to anthropic pressure has been noticed during the last few centuries.

Cauvery delta

1. Muthupet

At present the mangroves of Muthupet are essentially composed of the highly salt tolerant Suaeda. Avicennia marina and Excoecaria agallocha are found mainly along the channel banks (Blasco, 1975). Palynological analyses of sediments (Tissot, 1980) indicate the following sequence of the vegetation during the last two millennia (Fig. 9):

- periods A and B: establishment and extension of Avicennia, Excoecaria and Suaeda;
- period C: increase in Avicennia;
- period D: Avicennia now being replaced by Excoecaria and Suaeda.
The evolution of the mangrove vegetation and its deterioration during the last stages are due to natural evolution. The heavy sedimentation supplied by the Cauvery induces a progradation process and the seaward shifting of the shoreline. Hence, the increasing distance between the drilling site and the seashore is reflected by variations in the percentages of marine microfossils along the core.

2. Pichavaram

It is estimated that the mangrove sediments of Pichavaram are not more than 1500 years old (Tissot, 1980), on the basis of the rate of sedimentation calculated since the first occurrence of *Casuarina* pollen (introduced in India about two centuries ago) in the sediments and radiocarbon dating near the site of the cores. Three phases are recognized in the palynological evolution of the Pichavaram vegetation (Fig. 9):

1) phase A, the deepest: establishment of the mangrove vegetation;
2) phase B: extension of *Avicennia, Rhizophora, Sonneratia* and *Excoecaria*,
3) phase C: phase of gradual elimination of *Sonneratia*.

Recent ecological studies show that there is very little regeneration in the *Avicennia marina* zone. Along the water’s edge, *Avicennia officinalis* is mostly represented by old trees with a feeble rate of reproduction. It is well on the way to disappearing and its place is being taken by *Avicennia marina*. Likewise, *Lumnitzera* also seems to be vanishing since it has become quite rare and its regeneration is rather limited. Further, the mangrove area is getting reduced because of encroachment by the sea on one hand and sand on the other (Kerrest, 1980). There is also considerable human interference, as shown by palynological analysis (Tissot, 1980). One of the most important causes is the damming in the hinterland which induces soil hypersalinity and a drastic selection of species able to withstand these extreme edaphic conditions. Hence urgent measures should be taken to conserve this mangrove (Meher-Homji, 1985).

**Godavari delta**

In the Godavari region, about 13,000 hectares are said to be covered by mangroves but a greater part of this is constituted by bushy thickets of *Avicennia, Sonneratia* and *Rhizophora* intermixed with recruits from the hinterland. Two core samples from this locality were analysed palynologically. In one of the cores (Balasudippa, Fig. 9), from a site near the sea, there is the constant presence of mangrove and marine elements such as Microforaminifera and Dinoflagellates. In the other site (Bairavapalayam, Fig. 9), far from the sea, the palynological assemblages are characteristic of a back-mangrove with less mangrove pollen; marine elements are rare and Chenopodiaceae are well developed.

The presence of *Casuarina* throughout the core offers an interesting chronological marker. It is quite likely that these pollen come from the *Casuarina* plantations in this region, which do not appear to be more than 50 years old. The old light-house, now situated about a dozen kilometres inland, also attests to the rapid sedimentation of this delta. As the pollen analyses show very little vegetational changes, it is inferred that the degradation of the local mangroves must have begun at least a few decades ago (Caratini *et al.*, 1980).

**Brahmani delta**

In Kalibhanja Dian Island, bathed by the Dhamra river, there are patches of degraded mangroves in the form of thickets. No distinct zonation is seen in this region where the flora consists of *Avicennia officinalis, Sonneratia apetala, Bruguiera gymnorrhiza, Phoenix paludosa, Excoecaria agallocha, Kandelia candel, Aegiceras corniculatum, Heritiera fomes, Xylocarpus spp.*, and several species from the hinterland.

Two cores from this region were analysed palynologically (Caratini *et al.*, 1980). They seem to be of a relatively recent age and offer no trace of change in the local vegetation which seemed to have been already greatly disturbed prior to the deposition of
Fig. 9. Evolution of mangrove vegetation in India during the Upper Holocene.
these sediments. The relative abundance of *Heliotropium curassavicum* in these samples probably corresponds to the extensive destruction of the forest following excessive fellings (Fig. 9). The bottom of a deeper core sample from Talchua, an adjacent village where the mangrove lands have been reclaimed for cultivation, shows a fairly good representation of the mangrove vegetation (Fig. 9).

**Sundarbans**

Once an extensive forest of *Heritiera* (Mukherjee, 1972), Sundarbans is the only mangrove of the Indian subcontinent where the Bengal tigers live protected in their natural habitat. This is also the only place in India where we find *Nypa fruticans*, the survival of which is threatened by the unfavourable regional geomorphological evolution as well as by increased human interference (Blasco, 1975; 1980).

From the palynological evidences provided by Vishnu-Mitre and Gupta (1972), a brackish water mangrove composed of *Heritiera*, Rhizophoraceae, *Sonneratia*, *Excoecaria*, *Phoenix* and a hinterland with fresh water *Typha* swamps existed in the Bengal Basin (Fig. 9); there is no positive indication of climatic changes during the past 6000 years, nor is there proof of agrarian practice. On the basis of further investigations, Gupta (1981) interpreted the vegetational history of the northern part of the Bengal Basin as follows: brackish water mangrove with *Heritiera* and *Phoenix paludosa*, followed by a phase of increased representation of Gramineae and a reduction in *Phoenix paludosa*; the next phase is marked by the abundance of *Sonneratia* and a reduction of *Heritiera*, the last phase by the disappearance of *Sonneratia* while *Heritiera* and Rhizophoraceae exhibit a gradual increase.

The presence of well preserved vertical stumps of *Heritiera* is suggested as proof of subsidence due to diastrophic activity.

For the history of the southern part of Bengal Basin, in Namkhana, Gupta (1981) has suggested the following sequence (Fig. 9):

- a tidal mangrove with Rhizophoraceae and *Sonneratia* at the bottom;

- the elimination of Rhizophoraceae but retention of *Sonneratia*;

- a subsequent phase of restoration of Rhizophoraceae associated with the appearance of *Nypa*;

- the fourth phase is marked by an increase in *Sueda* which drops in the last phase.

**Kathiawar**

In Miani and Salaya of the Kathiawar region, the mangroves are represented by bushy thickets of *Avicennia marina* var. *acutissima*, the leaves of which are grazed or collected as fodder. But on the islands of Gulf of Kutch subjected to a lesser degree of exploitation by man, *Ceriops tagal* and sometimes *Rhizophora murrayana* are also found. The entire region is populated by salt swamp elements such as *Sueda*, *Salicornia* and *Sesuvium*. Pollen analysis of a core sample from Navlakhi (Caratini et al., 1980), at the eastern end of the Gulf of Kutch, indicates the following vegetational sequence (Fig. 9):

- an abundance of Chenopodiaceae with very few *Avicennia* and Rhizophoraceae in the deepest part of the cores;

- followed by the domination of *Avicennia*;

- and then its subsequent decrease and loss of Rhizophoraceae.

The paucity of mangrove pollen in the recent sediments seems to reflect the prevalence of grazing and fodder collection.

Palynological analyses have been carried out offshore in the recent sediments of the Gulf of Kutch (Ratan and Chandra, 1983).

The relatively high percentages of *Avicennia* pollen, attaining 19% in some samples, are quite unusual in marine sediments. Such rates could be explained by the surrounding mangrove vegetation, mostly composed of *Avicennia*, but because of over-browsing by goats and camels, *Avicennia* generally form low dense thickets, very often without flowers and regenerating almost always by vegetative growth. Since the total amount of the pollen recorded is not given in this paper, the significance of the percen-
tages obtained for each palynological taxon cannot be ascertained.

**Bombay**

There are many pockets of mangroves in the Bombay region (Blasco, 1975).

The mangrove pollen from the bottom layer offshore Bombay seems so irregularly distributed that it is difficult to draw a relationship between the geographical location of the samples, the mangrove vegetation and its induced palynological records (Ratan and Chandra, 1984).

Pollen analysis of a core sample near Thana (Caratini et al., 1980) indicates the presence of *Casuarina* pollen at the lower level suggesting that the sediments are very recent. The mangroves are represented by Rhizophoraceae, Avicennia and Sonneratia. A slight increase in their proportion is noticed in the most recent sediments (Fig. 9). Similar values for Rhizophoraceae were also reported by Vishnu-Mittre (1975) near Bombay.

**Offshore Kerala and Karnataka**

In the sediments from two cores collected at about 10°N offshore Kerala and 15°N offshore Karnataka, the variations in the percentages of the mangrove pollen taxa are related to the regional climatic history of the Upper Pleistocene and Holocene. The succession is as follows (Van Campo, 1983):

- 22,000-18,000 years BP: minimum extent of the mangrove; dry period. No mangrove pollen has been recorded offshore Karnataka and only a few offshore Kerala;
- 11,000 years BP: maximum representation of the mangrove; humid period;
- after 6000 years BP: regression of the mangrove; climatic transition to Recent.

In the most recent layers, anthropic pressure which has hastened this natural regression is clearly seen.

**SRI LANKA**

Old maps of Sri Lanka and place names provide proof that a century ago the mangroves occupied a larger area (Abeywickrama, 1964). Most of it has been reclaimed for agriculture or for building construction. The preliminary palynological survey (Thanikaimoni, unpublished) of a 5 m deep core sample (Radio carbon age of the basal 30 cm of the core being 820 ± 80 BP: GIF 5619) from Kalutara, near Colombo, indicates (Fig. 10 and Plate 43):

- the constant presence of *Rhizophora*;
- loss of *Oncosperma* from the vicinity of the mangrove since 600 years;
- increase in the weed *Acrostichum*, from

![Fig. 10. Pollen diagram related to the evolution of the coastal vegetation at Kalutara, Sri Lanka (Thanikaimoni, unpublished). The pollen of the cultivated plants (Areca, Cocos and Gramineae) is more frequent in the upper part of the core.](image-url)
the turn of the last century when this region seems to have been reclaimed for the cultivation of *Cocos*, *Areca* and other crops.

It is noteworthy that the number of pollen grains of *Cocos*, *Areca* and Gramineae is higher in the upper part of the sediments.

**SOUTH EAST ASIA**

**Thailand (Satingpra)**

The floristic composition of mangroves of Thailand has been studied by S. Aksornkoae (1979) and D. Banijbatana (1957). Regarding their recent evolution, pollen analysis (Fig. 11) provides evidence of a former (2600 BP) mangrove composed of Rhizophoraceae, Nypa, Avicennia and *Excoecaria* in the archaeological site of Satingpra (Thanikaimoni, 1983). The hinterland was characterized by saline swamps with *Suaeda* and fresh water swamps with *Myristica* and the lowland forest of Dipterocarpaceae. The paucity of marine planktons and the relative abundance of fresh water swamp elements suggest that the site was originally a lagoon separated from the sea by a sandy spit populated with *Ipomoea*.

The palynological sequence indicates perceptible decrease in the mangrove vegetation probably due to human activity such as extraction of fuel wood, corroborated by the simultaneous quantitative increase of *Acrostichum*, a fern which grows in the cleared areas of the mangrove. The peak of human activity is registered in the sediment at −370 to −365 cm zone which is poor in pollen and spore content. Excessive felling might have resulted in the denudation of both the mangroves and the fresh water swamp forest. But subsequently there seems to have been an extensive reclamation of land for the cultivation of the traditional local rice. The local *Borassus* palm appears to have been planted on the bunds of the paddy fields. Effective drainage operations against excessive inundation seems to have adversely affected the mangrove site which, due to the increase in its salinity, seems to have yielded place to *Suaeda*.

Palynological data corroborate the array of archaeo logical evidences of significant human activity in the Satingpra region (Stargardt, 1976, 1977).

![Fig. 11. Simplified pollen diagram of Satingpra, Thailand (from Thanikaimoni, 1983). Notice the decrease of mangrove taxa due to human activity.](image)
PLATE 43. Fossil pollens from Kalutara (Sri Lanka): 773–777, x 1000, Rhizophoraceae; 778–779, x 1000, Oncosperma tigillarium; 780–784, x 1000, Lumnitzera sp.; 785–788, x 1000, Acrostichum aureum; 789–792, x 1000, Areca sp.; 793, x 1000, Cocos nucifera; 794–795, x 1000, Cassia sp.; 796–797, x 1000, Elaeocarpus sp.; 798–799, x 1000, Ficus sp.; 800–801, x 1000, Ammonnia sp.; 802, x 1000, Isoetes sp.; 803–804, x 1000, Lycopodium cernuum.
Malaysia (Johore)

Near Pekan Nanas (Johore state), Haseldonckx (1977) has brought to light a Holocene vegetation succession in relation to sea level changes. Three main ecological phases have been reconstructed as follows:
- a riparian fringe forest at the bottom of the core;
- an open swamp vegetation with mangrove influence;
- a marginal peat swamp with river bank vegetation.

Rhizophoraceae pollen remains a constant background feature throughout the sequence and this is considered as an indication that mangroves were in close proximity to the depositional site.

Borneo

Anderson and Muller (1975) have studied a Holocene peat from NW Borneo at Marudi. At around 4270 BP, the profile starts on a mangrove sediment because of the abundance of Rhizophora, Nypa and Oncosperma. Then succession proceeded from mangrove to peat swamp.

Further south, another palynological study has been carried out on the development and vegetation dynamics of an extensive Holocene lowland peat swamp from the Sebangu River in Kalimantan Tengah (Morley, 1981). Brackish water mangrove pollen belonging to Rhizophora, Nypa, Brownlowia, Oncosperma, Acanthus and spores of Acrostichum were found in the lower half of the profile. Their presence implies a considerable coastal advance as at present the coastline is 80 km further south. Since the amount of mangrove pollen is rather low, it is likely that they were not produced exactly at the pollen site, but brought from a local source by tidal action.

A continuously cored borewell, the MISEDOR project, about 650 m deep, located in the Mahakam delta (East Kalimantan), has been extensively studied. From the palynological investigations of this drilling, Caratini and Tissot (in press) deduce:

- the perenniality of the deltalic environ-

ment of the site from the Upper Pliocene to the present;
- a great diversity of the environmental conditions with a constant shifting of the shoreline due to the combined effects of the regression-erosion-transgression-progradation, within the delta.

The sedimentary sequence from the period of maximum cooling, at about 18,000 BP up to now, can be followed with great accuracy with the paleoenvironmental reconstruction of the vegetation near the MISEDOR drilling site:

- about 18,000 BP: low sea level; the site was located within a swamp forest; no mangrove elements were recorded;
- from 18,000 BP to 5000 BP: rising sea level; because of the landward shift of the shoreline, the site was successively surrounded by a back-mangrove vegetation, then the mangrove forest and a marine environment marking maximum transgression. With the progradation and edification of the delta, the shoreline shifted seawards in the reverse direction to that of the previous movement, and the MISEDOR site which was earlier occupied by the mangrove now stands in the back-mangrove Nypa plain.

Hence MISEDOR provides a clear example of a transgressive sequence followed by progradation.

Java

A recent survey of the mangroves of Java and Bali has been published by Sukardjo and Sutorno (1982).

In the region of Jakarta, Blasco (1982) described a transect in the Tji Tarum delta (Fig. 12). In the same area, Polhaupessy (1981) has demonstrated the following Upper Quaternary succession:

- first a Rhizophoraceae dominated mangrove;
- then Rhizophora, Avicennia, Sonneratia;
- Rhizophora, Avicennia, Sonneratia, Nypa;
- and lastly fresh water swamp with Cyperaceae, Typha, Nymphaea in the upper part of the core.
In Central Java, pollen analyses of Pliocene and Pleistocene sediments have yielded for the most part, the remains of mammals and hominids; Sangiran, in Central Java, may be cited as one of the more important sites (SEMAH, 1982).

The aim of this research is to reconstruct the vegetation and its evolution at the time of the island's colonisation by vertebrates and man, as well as to obtain information on the nature and evolution of the climate.

This study has brought to light the presence of mangrove pollen in a large number of the stratigraphic sections sampled. Several characteristic genera have been recorded, some of the important ones being those belonging to Rhizophoraceae (including several species of Rhizophora), Sonneratia-ceae (among its species Sonneratia caseolaris has been consistently identified), Excoecaria agallocha, Avicennia, Nypa fruticans, Acanthus ilicifolius, Clerodendrum, etc.

Qualitative and quantitative analyses of these pollen types have enabled us to show the existence of a fossil shore-line. By studying the evolution it is possible to follow the shifting in the shore-line and the phenomenon of the island's emergence conditioning the eventual colonisation of the land by man and animals.

Fig. 12. Transect across a mangrove of Java, Tji Tarum delta (from Blasco, 1982).
The mangrove vegetation is totally disturbed by human activity.

AUSTRALIA

The recent mangrove forests of Australia are among the best known of the world (Clough, 1982). Some data are now available on their Holocene history.

To reconstruct the mangrove evolution on a prograded shore, Grindrod (1985) examined two core samples collected in North Queensland. Pollen analysis of a core sequence from bare high tide flats (Fig. 13) and another from a site immediately landward of a major long low ridge or "chenier" have provided a comparison of mangrove successions which have proceeded with or without interruption of a major chenier building event. The fossil pollen sequences are as follows:

- **Peak of *Arthrocnemum***
  - **Peak of *Arthrocnemum***
  - **Decline of *Rhizophora***
  - **Increase in *Rhizophora***
  - **Decrease of *Rhizophora***
  - **Opening of canopy due to storm or cyclonic activity***
  - **Increase in *Rhizophora***

- **Rhizophora peak**
- **Avicennia peak**

Moderate value of *Rhizophora*, equal amount of non mangrove sedimentation outside the *Rhizophora* formation.
Fig. 13. Major trends of mangrove pollen representation and suggested corresponding vegetation changes near the site, North Queensland, Australia (from Grindrod, 1985).
These sequences provide sufficient records of mangrove and salt marsh succession which relate to coastal land form development and the results are compatible with the present zonation as well as to pollen deposition.

WEST AFRICA

Congo

Caratini and Giresse (1979) have used palynology and particularly the mangrove pollen as a tool to trace the palaeogeography of coastal Congo related to sea level changes during the last 35,000 years:
- the last intra-Würm transgression which ends at about 30,000 years BP is marked with an extension of mangrove and tropical forest under a humid and hot climate;
- the pre-Holocene regression, with a decrease in mangrove, extension of savannas inland and increase in planktonic biomass due to the more active upwelling;
- the Holocene transgression, characterized by the development of mangrove.

Ivory Coast

Fredoux (1980) has brought out the variations of shore lines and climate during the past 40,000 years in the vicinity of the Ivory Coast. The fall in sea level, −110 m around 17,000 BP, was contemporaneous to an open graminaceous formation in this region presently covered by a rich ombrophilous forest. The peat containing the mangrove pollen are the most revealing as they testify to the local vegetational history:
- mangroves;
- arid climate and Graminae (Savanna);
- marine transgression;
- mangroves;
- swamp forest.

Nigeria

In the Niger delta, a borewell 35 m deep provides, among other data, the evolution of the genus Rhizophora during the Upper Pleistocene and the Holocene (Sowunmi, 1981).

The two deepest samples investigated, older than 35,000 years BP, contain less than 10% of Rhizophora pollen (Fig. 14) at a period when the upper deltaic flood plain extended further south beyond its present limit. Hence these two samples correspond to a lower sea level with an undetermined age.

Above these layers, the representation of Rhizophora is consistently higher than 50%. The fluctuations in its rate, ranging more or less between 60 and 80%, have no palaeogeographical significance since such high rates are usually found in any surface

Fig. 14. Rhizophora pollen in the Niger delta (Nigeria) during Holocene and Upper Pleistocene (from Sowunmi, 1981). Notice the permanence of Rhizophora representation from about 22 m to the top.
sediment samples in the recent Rhizophora forests. Regarding the mangrove vegetation, the only conclusion that can be drawn is the establishment of a well developed Rhizophora forest earlier than 7300 years BP, the oldest significant C14 dating being obtained at a depth of 13 m. It is remarkable that in this region the forest has remained more or less unchanged, without any disturbance and this may be due to the feeble anthropic pressure because of the low population density.

**Benin**

During the oceanographic cruise Benin (Klingebiel et al., 1975), 14 cores from Holocene and Upper Pleistocene have been taken from the sea-bed of the Gulf of Guinea. The palynological data are diluted among the results of other disciplines (sedimentology, micropalaeontology, organic and mineral geochemistry, etc.) and so do not stand out. Nevertheless, it can once again be noticed that the pollen of Rhizophora was the most useful palynological marker to precise the stratigraphy and palaeogeography.

**Senegal**

About 250 km inland from the present shoreline, in the Senegal river valley, the occurrence of Rhizophora pollen in sediments dating 5500 BP permits the accurate location of the past shoreline and to emphasize on the width of the inward shifting of the sea (Assemien, 1969).

The recent and sub-recent (± 4000 years) coastal sediments from Casamance have been studied by Tissot et al. (1983). Palynological, mineralogical as well as chemical-physical palaeofacies point towards the homogeneity of the organo-mineral sedimentation and to the allochthonous origin of the sedimental organic matter. During the entire period of sedimentation, Rhizophora mangrove seems to have been the only major vegetation present in this region.

Other studies by Lezine et al. (1985) of a Late Holocene sequence, near Dakar, have established the relationships between sea level changes, palaeohydrological fluctuations and the mangrove vegetation.

In three cores located on the slope offshore Senegal (Rossignol–Strick and Duzer, 1979), the mangrove characterized by Rhizophora is rarely represented during most of the Late Pleistocene. From 12,000 BP, just before the Holocene limit, the percentages of Rhizophora rise rapidly, attaining about 40% of the pollen spectrum and then come down to 6%, at about 7,000 BP. This evolution, which is the reverse of that observed for Chenopodiaceae, is interpreted in terms of changes in the coastal vegetation, the mangrove forest being replaced by sebkhas with Salicornia during the arid phase corresponding to the Würm.

In the DSDP site 367, leg 41 (Sittler et al., 1980), located further offshore at a depth of 4,700 m, during the Pliocene, the percentage of mangrove pollen ranges from 11 to 27%. These values are much higher than those obtained during the Pleistocene: 2 to 6%. Such a difference, regarded as a result of the rising sea level, could rather be the consequence of the falling sea level which is a global event occurring at the Tertiary-Quaternary boundary.

**TROPICAL AMERICA**

**Panama**

Bartlett and Barghoorn (1973) have reconstructed the phytogeographic evolution of the Panama isthmus during the past 12,000 years. They emphasize that the mangrove was more equatorially restricted during the cold period than they are today.

**Guyana and Surinam**

In Guyana (Fig. 15), Late Pleistocene and Holocene succession from dryland communities (grass savannas) to Avicennia mangroves, and then to Rhizophora mangroves consequent to an early Holocene eustatic rise of the sea level and reversion to Avicennia mangroves due to rapid silting (?), has been reported on the basis of palynological studies (Van der Hammen, 1974).

The geographically widespread nature of these changes is indicated by several other cores from Guyana. The cyclic nature of these changes has also been demonstrated from the pollen analysis of a core from Surinam (Wijmstra, 1971).
Fig. 15. Evolution of coastal vegetation in Guyana, Surinam and Venezuela during Late Pleistocene and Holocene showing the relationships between sea level and pollen spectra: the transgressive sequences are characterized by the high values of Rhizophora pollen.

Venezuela

Classical studies of recent Orinoco delta sediments by Muller (1959) have provided the palynological basis for tracing the depositional history of the mangroves.

In the Cariaco trench (Fig. 15), the Holocene sediments yielded kerogen which is mainly composed of marine amorphous organic matter. The perfect state of preservation of this organic matter implies that it must be autochthonous. The pollen and spores present in the organic matter correspond to the flora of the Orinoco basin (including mangroves) which is probably an indication that the Guyana current carried these pollen and spores to the Cariaco trench (Caratini et al., 1975).

Florida

The almost continuous geological evidence of mangroves in Florida since 3000-4000 years indicates that Avicennia has probably been present in the northern Gulf region throughout that period (Hoffmeister and Multer, 1965).

Other palynological data on the mangrove history are provided by peat formations (Riegel, 1965).
TERTIARY RECORDS OF MANGROVE TAXA

In their extensive palynological studies on the Tertiary of tropical areas, Germéraud et al. (1968) have reported the stratigraphic range and geographic distribution of mangrove pollen taxa in some areas such as the Caribbean region, Venezuela, Nigeria. Their conclusions on these sedimentary basins are still valid to date.

New data are now available in other countries. A survey of the records of the fossil mangrove pollen taxa in these regions is given below.

India

The following picture of fossil history emerges from our survey of the mangrove taxa represented in the fossil pollen records from the sedimentary basins of the Indian subcontinent. *Nypa* can be traced back up to Upper Cretaceous, Rhizophoraceae up to Middle Eocene, *Avicennia* and *Aegialitis* up to Miocene and *Sonneratia* with certitude up to Lower Miocene.

**Fossil records**

**Bengal Basin** (Baksi and Deb, 1980)

*Nypa* Upper Cretaceous-Recent

*Cauvery Basin*

*Karaikal* (Venkatachala and Rawat, 1972, 1973)

*Nypa* Palaeocene-Middle Eocene

*Rhizophoraceae* Middle Eocene-Miocene

*Mannargudi* (Venkatachala and Rawat, 1972, 1973)

*Nypa* Lower-Middle Eocene

*Rhizophoraceae* Middle Eocene

*Madanam* (Venkatachala and Rawat, 1972, 1973)

*Nypa* Middle Eocene

*Rhizophoraceae* Middle Eocene-Middle Miocene

*Neyveli* (Ramanujam and Reddy, 1984)

*Rhizophoraceae* Miocene

*Avicennia*: Miocene

*Warkali* (Thanikaimoni *et al.*, 1984)

*Aegialitis*: Miocene

*Ratnagiri* (Kulkarni and Phadtare, 1981)

*Nypa*: Miocene

*Cambay Basin*

*Lower Eocene* (Venkatachala, 1972)

*Nypa* Lower Eocene (Mathur and Chowdhary, 1977)

*Rhizophoraceae* Lower Eocene

(Venkatachala and Chowdhary, 1977)

*Sonneratia*: Lower Eocene (*ibid.*)

*Himachal Pradesh* (Mathur, 1984)

*Nypa*: Eocene

*Rhizophora*: Lower-Middle Eocene

*Sonneratia*: Lower-Middle Eocene

*Kutch Basin* (Venkatachala and Kar, 1969; Kar, 1985)

*Nypa* Palaeocene-Oligocene

*Rhizophoraceae* Palaeocene-Oligocene

*Sonneratia* Eocene

Europe

The distribution and palaeogeographic value (Fig. 16) of *Nypa* pollen in the Eocene of Europe has been studied by Ollivier-Pierre and Caratini (1984). According to Collinson (1983), the occurrence of *Nypa* fruits in London Clay is an indication of the seaward deposition of mangrove debris. Core mangrove species are rarer than the back-mangrove genus *Nypa* in London Clay, but *Rhizophoraceae* are represented by seedlings of *Ceriops* and *Palaeobruguiera*. The absence of *Rhizophoraceae* pollen from London Clay seems to support the paucity of this family in Eocene types (Wilkinson, 1981, 1983).
In France, Gruas-Cavagnetto (in press) has reported pollen grains of *Bruguiera*, *Ceriops* associated with *Nypa* in the Ypresian (Eocene) of Soissonnais (France). She has recognized another type of mangrove with *Avicennia* during the Middle Eocene (Aversian) in Manche. From these mangrove taxa, as well as other tropical taxa, the evolution of the palaeoclimate during the Paleogene has been reconstructed by Ollivier-Pierre *et al.* (in press).

During the Lower and Middle Miocene, some occurrences of *Avicennia* pollen (Bessédik, 1981; 1985) on the north-western Mediterranean shores suggest the development of mangrove in this region.

**Burma**

Some aspects of the present distribution pattern of mangrove vegetation in Burma have been studied in several sites along the coast (Myint and Soe, 1985). Twenty-one species of mangroves were observed. Among the important species are *Avicennia officinalis*, *A. elliptica*, *Sonneratia griffithii*, *Ceriops decandra*, *Dalbergia spinosa* and *Excoecaria agallocha*.

According to Reimann and Aye Thaug (1981), the Middle Miocene beds of the South Western part of Chindwin Basin in Kalamyo and Kalewa, were deposited in coastal, marine, brackish, shallow water zones. To support their contention, the authors have drawn attention to the pollen of *Rhizophora* and *Sonneratia* as well as the Microforaminifera and Histrichosphaerids found in the samples. They feel that the presence of *Florschuetzia levipoli* (*Sonneratia* pollen) in the sediment is an index of Miocene age.

**Borneo**

In his palynological studies on the history of the mangrove vegetation of Borneo, Muller (1964) stressed the fact that the fossil pollen types attributed to mangroves match well in detail with those of the extant mangrove taxa. They are associated in both

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**Fig. 16. Range and geographical distribution of Nypa during Eocene in W Europe**

(from Ollivier-Pierre and Caratini, 1984).
recent and fossil sediments of Borneo; there is an unbroken succession of mangrove pollen from the Lower Tertiary upwards to the recent. The stratigraphic ranges of mangrove pollen types in Borneo as updated by Morley (1978) are as follows:

*Nypa*  
Eocene up to present

*Brownlowia* type  
Eocene up to present

*Rhizophora* type  
Oligocene up to present

*Sonneratia alba* type  
Miocene up to present

*S. caseolaris* type  
Miocene up to present

---

**Avicennia** type  
Middle Miocene to present

**Aegialitis**  
Middle Miocene to present

Barré-de Cruz (1982) studied a period as old as the Upper Miocene up to now (Fig. 17) from the Tunu 1 drilling in the Mahakam delta. She has confirmed the ranges of the main markers and gives the following palaeogeographical results:

- perenniality of the deltaic conditions;
- diversity of the palaeoenvironments within this delta.

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Fig. 17. Stratigraphical ranges, palaeogeography and palynological evolution of the site of Tunu 1 drilling, Mahakam delta, Kalimantan, Indonesia (from Barré-de Cruz, 1982).
China

In the coastal areas of Fujian and Guangdong, mangrove forests seem to have existed during the Tertiary period (Wang, 1984). It is noteworthy that in Beibu (South China Sea), Barré-de Cruz (1982) has recorded *Florschuetzia levipoli*, *Daedryum* and *Stenochlaena laurifolia* (Fig. 18). The first two taxa have Miocene-Pliocene range whereas the last one does not extend beyond Upper Miocene. In Beibu, the simultaneous occurrence of Dinoflagellate cysts and mangrove taxa during the Miocene suggests that the site of study was near the sea or in a marine environment.

In the northern part of South China Sea (Sun and Li, 1984), *Florschuetzia* appeared in the Late Eocene and flourished in the Miocene. It evolved quickly both here as well as in SE Asia. Many other pollen types were common to both areas, but this area lacked the most evolved type, *F. meridionalis*, which appeared in the Late Miocene in SE Asia.

Fig. 18. Beibu borewell, China Sea: Palynological zonation and palaeogeographical evolution of the site (from Barré-de Cruz, 1982).
Japan

The available fossil evidence indicates that Bruguiera (Rhizophoraceae), Sonneratia (Sonneratiaceae), Excoecaria (Euphorbiaceae) as well as the Teloscyptum-Geloina biocenosis characteristic of mangroves existed during Middle Miocene of South West and Central Japan. After 15 million years, the tropical and mangrove swamp elements disappeared rapidly (Yamanoi et al., 1980; Tsuda et al., 1984).

Australia

Pollen of the following mangrove taxa were reported from the fossil beds of Australia (Hekel, 1972; Churchill, 1973; Stover and Evans, 1973; Martin, 1982):

- Rhizophoraceae
- Rhizophora stylosa is now found in Western Australia (Semeniuk et al., 1978).
- Brownlowia type from Eocene
- Nypa (Spinizonocolpites prominatus) Late Eocene-Lower Miocene
- Sonneratia from Oligocene

Churchill (1973) reported Sonneratia pollen in the Eocene of Western Australia but since the exine structure and sculpture are not described in detail, the identification cannot be accepted.

- Acanthus from Late Miocene
- Aegialitis from Late Miocene
- Avicennia from Late Miocene
- Camptostemon from Late Miocene
**Table**

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**Diagram**

[Diagram with a line graph showing data trends over time.]
EVOLUTION OF MANGROVE TAXA
FROM UPPER CRETACEOUS TO RECENT

Several extinct pollen are considered to be characteristic of a mangrove vegetation. Their stratigraphical ranges are given in fig. 19. However, since no definite argument can be provided, taxa such as Echiperiportites trianguliformis and Proxapertites will not be retained in this survey of fossil records of the pollen attributed to mangrove taxa.

A well documented palaeoecological review of fossil mangrove pollen and spore taxa, specially for the Early Tertiary period, is found in Frederiksen (1985).

ARECACEAE

*Nypa*

This genus seems to have had a vast fossil distribution. Pollen comparable to that of *Nypa* are reported from the Upper Cretaceous and Tertiary of the Caribbean, Venezuela, Nigeria, Borneo and India. The fossil pollen grains are described under the morphological name *Spinizonocolpites* Muller 1968. Several species have been considered within this genus but the distinction between them is not clear since all the intermediates can be found. Nevertheless, it has been noticed (Germerraad et al., 1968) that in the Upper Cretaceous-Paleocene sediments, *S. baculatus* Muller 1968 is the dominant form, while later *S. echinatus* Muller 1968 is found exclusively.

Its extinction at the Eocene-Oligocene boundary in Central America and West Africa is approximately contemporaneous with a widespread increase in the incidence of mottled shales indicating a climatic change with a more pronounced seasonal rainfall. It is conceivable that such a change could have caused *Nypa* to disappear since it is now mainly restricted to the wet tropics in the Indo-Malaysian area (Germerraad et al., 1968).

In Europe *Nypa* left its traces in the Lower-Middle Eocene sediments. Its distribution has been clearly elucidated by Haseldonckx (1972); its climatic (Muller 1980) and palaeogeographic (Ollivier-Pierre and Caratini, 1984) implications have been deduced (Fig. 16).

In Australia, the stratigraphic range of this genus is from Palaeocene to Middle Miocene. According to Muller (1980), its disappearance may be due to the movement of Australia to a more arid climatic belt and not to a decrease in temperature.

AVICENNIAE

*Avicennia*

The earliest occurrence of *Avicennia* is in the Lower Miocene in Marshall Islands in the West Pacific (Leopold, 1969). It has been recorded in the Upper Miocene of NW Borneo (Anderson & Muller, 1975) and has been traced up to the Pliocene of Guyana (Wijmstra, 1971). In India, it has been reported from the Miocene (Ramanujam and Reddy, 1984). In Europe, several pollen grains of *Avicennia* may have been identified from Paleogene (Grua-Cavagnetto et al., in press) and Miocene (Bessedik, 1981).

BOMBACACEAE

*Camptostemon* pollen type was first recorded from the Lower Miocene of NW Borneo (Muller, 1970).

*Malvaearumpollis papuensis* Khan 1976 which has equatorial apertures, reported from the Upper Miocene of Papua, is probably *Camptostemon* pollen (Muller, 1981).

PELVICIERACEAE

Jimenez (1984) tried to explain the present restricted distribution of this mangrove
Fig. 19. Range of mangrove pollen and spore taxa.

genus which has only one species *Pelliciera rhizophorae* in Central and Northern South America although it was widespread in the Carribbean Tertiary deposits (Graham, 1985).

**Fossil pollen records**

*Pelliciera*
- Graham (1977): Lower-Middle Eocene, Jamaica
- Langenheim *et al.* (1967) Oligo-Miocene, Mexico

*Psilatricolporites crassus* V. der H. et Wijm. 1964 = (Verrucatricolporites crassus)
- Pares Regali *et al.* (1974 a & b): Middle Eocene to Miocene, Brasil
- Salard-Cheboldaef (1976): Oligocene, Cameroon

**PLUMBAGINACEAE**

*Aegialitis*

Pollen comparable to *Aegialitis* have been reported from the Miocene to Pliocene of Borneo (Morley, 1978) where this genus is now absent. According to Muller (1972), the discontinuity in its present distribution may be due to its failure to adapt itself to drier climates.

In India, it has recently been reported from the Miocene of Warkalli, in the coastal region of Kerala (Thanikaimoni *et al.*, 1984) under the name *Warkallipollenites erdimanii* Ramanujam & Rao, 1984.

**RHIZOPHORACEAE**

The earliest occurrence of this family, with the morphological genus *Zonocostites* is in the Eocene of the Carribbean region,
India and Borneo. It gradually becomes a dominant element in the Miocene-Pliocene mangrove communities. In Queensland, its earliest report is from Oligocene (Martin, 1982). In Nigeria, its first occurrence and that too with sudden abundance is in the Lower Miocene.

According to Muller and Caratini (1977), this family must have originated in the Eocene of SE Asia with inland relatives such as Anisophylla and Carallia and extended eastwards via transpacific land bridge to tropical South America. It seems to have reached the Caribbean region before the origin of the Panama Isthmus and from there crossed the Atlantic to settle along the west coast of Africa during Early Miocene.

According to Van Steenis (1962), the lack of Rhizophora species common to east and west coasts of Africa is due to the colder climate of South Africa. But Germerea et al. (1968) have suggested that by the time the present Indo-Malaysian species of Rhizophora had developed and started to extend their range viz. in the Oligocene-Miocene period, the Tethys connection to the Atlantic Ocean had either already become closed or was situated too far north in a cooler climatic zone.

Regarding the occurrence of Rhizophoraceae fossils in London Clay, Germerea et al. (1968) expressed the view that during the Eocene the tropical belt extended to higher latitudes. Before the compression and over-thrusting of the ancient Tethys sediments that accompanied the origin of the Alps, the Eocene southern shores could have been situated further south than its present location.

According to Gruas-Cavagnet (in press), the pollen taxa Bruguiera and Ceriops would have been recorded in the Ypresian of France.

**RUBIACEAE**

Scyphiphora type pollen has been recorded by Leopold (1969) and compared to S. hydrophyllacea from the Lower Miocene of the Marshall Islands in the West Pacific.

**SONNERATIACEAE**

**Sonneratia**

According to Muller (1985), Sonneratia is an Asian genus. The Eocene ancestors of this taxa may have been plants from the Tethys shore adapted to pollination by fruit eating bats which appear in fossil records about the same time as the first pollen record. The increase in pollen production and in gregariousness are probably caused by adaptation to bat pollination. Muller (1968) has suggested the following evolutionnary sequence:

Lagerstroemia (insect pollination) → Florschuetzia trilobata → Sonneratia (bat pollination).

The generic changes anticipated in some of the recent polulations of Sonneratia alata and S. caseolaris could conceivably lead to the origin of a new species which, in order to be evolutiionally successful, should also change its ecology so that it could invade a new niche or replace its parent, as has probably happened in the Early Miocene (Muller, 1985).

Sonneratia pollen and its ancestors Florschuetzia constitute a phylogenetic series which provides the best stratigraphical markers of the Oligocene and Neogene of South East Asia (Germerea et al., 1968).

**TILIACEAE**

**Brownlowia**

In Borneo this back mangrove as well as swamp forest genus occupied the same ecological niche throughout the Tertiary (Muller, 1964, 1968, 1981; Barré-de Cruz, 1982). In India, pollen grains comparable to Brownlowia have been reported under the name Lacrimapollis from the Miocene of the Caunty delta and the Miocene-Pliocene sediments of Tripura (Thanikaimoni et al., 1984). In Australia (Harris, 1965; Stover and Evans, 1973) the same morphological type named Tiliaepollenites notabilis Harris 1965 ranges in the Eocene.
Fig. 20. Scale of human impact on world mangrove vegetation (data from Saenger et al., 1983).
CONCLUSION

The volume and diversity of palynological studies devoted to mangroves can be explained by some of the most original characteristics of this ecosystem viz: its location at the ocean-continent interface in tropical regions and in their vicinity. These fundamental aspects constitute the basic criteria for the interpretations put forward by palynologists. Depending on their field of specialization, researchers analyze the data and attempt to reconstitute, explain or show the changes in the course of rivers, variations in the sea level, climatic fluctuations that occurred over the course of time, etc.

The lines of research on Tertiary sediments are different from those of the Quaternary. In Quaternary research the method followed in most cases is to reconstruct the evolution of the mangrove vegetation. The interpretations and hypotheses are derived from an understanding of this evolution. As regards the Tertiary and Upper Cretaceous, the pollen and spores of mangroves are no longer considered as elements of a population, but as isolated individuals constituting stratigraphic or palaeogeographic markers. Their frequency in marine and coastal sediments is due to the fact that mangrove pollen are liberated directly into the ocean where conditions are favourable (low oxidation) for their preservation and fossilization. Moreover, since mangrove forests are particularly abundant in deltaic zones which are well known for their organic matter deposits, palynologists devoted to oil research have since long considered the study of mangrove pollen and spores of potential interest. This is particularly true for Rhizophora-Zonocostites, the most familiar sporomorph taxon of the mangroves, as well as for Sonneratia-Florschuetzia recorded in south-east Asian region.

When the recent past, i.e. the last few centuries, is taken into consideration, palynology enables us to follow the evolution of mangrove vegetation and to better understand the present state of the ecosystem by locating it in its proper place during the course of evolution. In fact, because of the changing dynamism to which the mangroves are subjected, the present stage of the ecosystem cannot be properly explained if the time factor is not taken into consideration.

In the past, natural events such as the deterioration in climatic conditions or the shifts in the course of rivers may have locally affected the mangroves but their impact was not great when compared to the spate of destruction which has just begun with the (human) population explosion, particularly in Asia. For example, when rivers are dammed the mangroves receive less silt and fresh water. This increases the salinity, resulting in the death of the mangroves sooner or later. Man's impact on mangroves is striking (Saenger et al. 1983) and deserves to be taken seriously (Fig. 20).

As mangrove forests protect the coast from erosion and from the fury of tides and cyclones and as they contribute the much needed organic matter for the population of the fishes, shrimps and crabs of the tidal ecosystem and to some extend even of the sea, the role played by them is essential for the preservation of the entire ecosystem. Thus it is time that integrated multidisciplinary approaches, including palynology, are initiated with a view to use on sustained yield basis without causing destruction of these coastal regions and to launch educational campaign to protect and maintain them because we need mangroves and not man made mangrove.
CONCLUSION

In conclusion, the recent trends in the field of technology have significantly impacted the healthcare industry. The advancements in digital health have made it possible to monitor patients remotely and provide early interventions, thus improving outcomes and reducing costs. Telehealth services have become increasingly popular, offering patients the convenience of medical care from their homes.

However, these advancements come with their own set of challenges. The integration of technology into healthcare requires careful consideration of privacy and security issues. The implementation of new technologies must also account for the varying skill levels of healthcare providers and the potential for technology to exacerbate existing inequalities.

As we move forward, it is crucial to address these challenges while also embracing the potential benefits of technology. This requires collaboration between healthcare providers, technology developers, and policymakers to ensure that technological advancements are implemented in a safe and equitable manner.

In conclusion, technology has the potential to transform healthcare, but careful consideration is needed to realize its full benefits.


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