Holocene history of mangrove vegetation in India : a palynological interpretation

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Mangroves are defined as the tropical intertidal plant community which thrives both on the eastern and western coasts in India. Considerable work has been carried out on the floristics and economic potential of mangrove vegetation. It has been recently realised that the major part of coastland is transformed into the bareland, though no definite single reason can be assigned for the extermination of mangroves from the Indian coasts.

In view of problems, related to the causes of degradation and extermination of mangroves, the awareness amongst palaeobiogeographers and palynologists is well exemplified by undertaking palynological investigations of estuarine sediments. It has been observed that the eastern and western coasts of India are not comparable, rather they differ greatly in the vegetational composition. The investigated areas are: Gangetic-Sunderbans, Mahanadi-Brahmani, Godavari and Cauvery deltas on the eastern coast and back water sediments from Kutch, Maharashtra, Gujarat, Kerala and Karnataka on the western coast. A synthesis and interpretation of available palynological data, has been given in order to reconstruct the palaeofloristics and translate them in terms of various events and episodes which had occurred during the Holocene Epoch. The causes of mangrove deterioration in time and space and coordinated scheme for greening the coastland have also been discussed.

Key-words—Palynology, Mangroves, Holocene, Eastern and Western coasts, India.

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सारांश

भारत में मैंग्रोव वनस्पति का होलोसीन कालीन इतिहास : परागाणविक व्याख्या

आशा खंडेलवाल

मैंग्रोव भारत के पूर्वी एवं पश्चिमी दोनों ही तटों पर मिलते हैं। ये पौधे उष्णकटिबन्धीय अन्तर-ज्वारीय क्षेत्र में पाये जाते हैं। इन पर काफी अनुसन्धान कार्य किया जा चुका है। अभी हाल में यह पाया गया है कि तटीय भूमि का काफी बड़ा भाग बंजर भूमि में बदल गया है। इसके लिए मात्र अकेला कारण नहीं है बल्कि कई अन्य कारण भी हैं।

परागाणुविज्ञानीयों एवं पुराभूगोलविदों का इस ओर ध्यान दिलाने के लिए इस शोध-पत्र के माध्यम से प्रयास किया गया है। यह प्रेक्षित किया गया है कि भारत के पूर्वी एवं पश्चिमी तट तुलनीय नहीं हैं तथा वनस्पति के आधार पर एक दूसरे से भिन्नता व्यक्त करते हैं। पूर्वी तट पर सुन्दरबन, महानदी-ब्राह्मणी, गोदावरी एवं कावेरी डेल्टा तथा पश्चिमी तट पर कच्छ, महाराष्ट्र, गुजरात, केरल एवं कर्नाटक का अध्ययन किया गया। पुरावनस्पतिजातों की संरचना प्रस्तावित करने हेतु तथा विभिन्न घटनाओं की व्याख्या करने हेतु उपलब्ध परागाणविक आँकड़ों का संश्लेषण एवं समीक्षा की गई है साथ-साथ अतीत में मैंग्रोव पौधों के ह्रास के कारणों तथा तटीय भूमि को पुनः हरा-भरा करने पर भी विचार व्यक्त किये गये हैं।

SINCE early nineteenth century, a large number of botanists and ecologists undertook the study of coastal vegetation and contributed to the understanding of mangrove ecosystem. The origin of word 'mangrove' is perhaps from Malaysia. It refers to the vegetation "above the soil" with aerial roots and pneumatophores. This type of vegetation was also identified as 'forest on stilt roots' or 'moving forest'. Later, the word 'mangal' was substituted for 'mangrove community' (Macnae, 1968). Informally, the mangroves are defined as the tropical trees which are mostly confined to intertidal and adjacent zones in the estuarine complex. They can extensively encroach inland along the river banks where tides cause feeble influence. Mangroves are adaptive to coastal ecology mainly with various

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kinds of aerial roots, vivipary, salt regulating mechanism, etc.

The mangroves are distributed far and wide extending from tropic of Capricorn to tropic of Cancer. In India, varied range of mangrove taxa exist on the eastern and western coasts and the total extent of mangrove vegetation has been estimated to cover around 7,000 sq km (Siddhu, 1963). It is noticed that more than 60 per cent of the total mangrove cover is located in Bengal and 17 per cent in Andaman and Nicobar islands. The other thrust areas for mangroves are Mahanadi, Godavari and Cauvery deltas on the eastern coast and back waters on the western coast.

VEGETATION

Blasco (1975) advocated that the term mangrove forest can be used for any kind of vegetation, viz., arborescent, bushy, herbaceous or even growing on denuded coastland. Champion (1936) had considered the whole coastland vegetation as 'tidal swamp forest' and divided into four subtypes (i) low mangrove forest, (ii) tree mangrove forest, (iii) salt water *Heritiera* forest, and (iv) fresh water *Heritiera* forest. In the revised survey, Champion and Seth (1968) maintained almost the same title but added 'palm swamp'. Rao and Sastry (1974) grouped the estuarine vegetation into euestuarine and proestuarine. The proestuarine zone was further subdivided into tidal mangrove, euhaline and prohaline depending upon the magnitude of the tides and degree of salinity. Banerjee (1987) considered the adaptive features and fidelity of mangrove taxa for the division of ecozones into three groups in Mahanadi Delta: (a) zone of typical mangrove plants with stilt root and vivipary, (b) zone of less pronounced mangrove plants with pneumatophores and buttresses, and (c) zone of midland and upland plants with sudden change in habitat. Detailed study of mangrove taxa as regard to their global distribution, ecology, taxonomy, economic potential, etc. have been dealt with by Tomlinson (1986). He identified core mangroves on the basis of the following characteristics:

—Complete fidelity to mangrove environment
—Ability to form pure stands
—Morphological specialization
—Salt regulating mechanism
—Taxonomic isolation from their terrestrial relatives

The core mangrove taxa identified by Thanikaimoni (1987) are: *Aegialitis, Aegiceras, Avicennia, Bruguiera, Camptostemon, Ceriops, Conocarpus, Cynometra, Excoecaria, Heritiera, Kandelia, Laguncularia, Lumnitzera, Nypa, Osbornia, Pelliciera, Phoenix, Porteresia, Rhizophora, Scyphiphora, Sonneratia* and *Xylocarpus*.

The peripheral mangrove taxa can withstand wide range of salinity and are recorded as: *Acanthus, Acrostichum, Aglaia, Atriplex, Azima, Barringtonia, Brownlowia, Caesalpinia, Clerodendrum, Dalbergia, Dendropthoe, Derris, Dolichandrone, Flagellaria, Halosarcia, Hibiscus, Intsia, Ipomoea, Mauritina, Melaleuca, Myriostachya, Oncosperma, Pemphis, Prosopis, Salicornia, Salsola, Salvadora, Sesuvium, Solanum, Stenochlaena, Stictocardia, Suaeda, Symphonia*, etc. The transition between core and peripheral mangroves is usually abrupt and elements from upland vegetation are occasionally intermixed with the latter and are treated as peripheral mangroves. The other wet coastal communities which are distributed in river beds, beaches, salt marshes, coastal swamps, etc. constitute almost the same vegetal mosaic as it commonly occurs in peripheral mangroves.

Tomlinson (1986) has enumerated the taxonomic distribution of mangals both in eastern and western hemispheres and noticed floristic richness of taxa in the former. In India too, the vegetation in eastern coast is rich as compared to western coast. There are some species which are exclusively confined to eastern coast, viz., *Aegialitis rotundifolia, Heritiera fomes, H. littoralis, Lumnitzera littorea, Nypa fruticans, Rhizophora stylosa, Scyphiphora hydrophyllacea, Sonneratia griffithii* and *Xylocarpus mekongensis*. However, the recent study has recorded that the trees of *Heritiera fomes and Nypa fruticans* have disappeared from Sunderbans owing to ecological changes (Banerjee, 1987). At present, major part of coastland in India is transformed into the heathland/bareland. The mangrove vegetation, now-a-days, is present either in the form of degraded mosaic or has shrunk to a fraction and is mostly confined along the creeks and channels of protected estuaries, back waters, etc. The current awareness of mangrove potential on one hand and ruthless destruction on the other, has prompted Quaternary palynologists to undertake investigations of coastal sediments in order to rebuild the palaeofloristics and to understand the causes of mangrove degradation in time and space.

Palynological findings on eastern and western coasts of India have been dealt with separately in order to understand various aspects of mangrove development, palaeoclimate and depositional environment.

EASTERN COAST

Sunderban-Gangetic Delta

Palynological and palaeontological study of peat and associated layers to explore the palaeo-vegetation and palaeoenvironment of Bengal Basin have been made. Palynological investigations of recent sediments from a pond near Garia (Das, 1961) have revealed the presence of pollen and diatoms. Agarwal and Kusumagar (1967) have dated the wood recovered from Dum Dum area at a depth of 6.5 m, to 6175 ± 125 yrs B.P. Mallik (1969) investigated Calcutta peat and reported the total absence of mangrove taxa and inferred that there was no climatic change since Late Holocene in Bengal Basin. The wood samples collected from Salt lake and Bagerhat were radiocarbon 4,930 ± 120 yrs B.P. and 5080 ± 110 yrs B.P., respectively (Chanda & Mukherjee, 1969).

Several other soil profiles from Bagerhat, Belgachia, Salt lake and Baidyabati of contemporary age from Bengal Basin were pollen analysed (Mukherjee, 1972). He reported the existence of several arboreal taxa such as *Heritiera, Excoecaria, Rhizophora, Sonneratia, Barringtonia, Dipteracanthus, Terminalia, Anacardium*, etc. The nonarboreals were represented by Gramineae, Cyperaceae, Compositae, Umbelliferae, Malvaceae, Chenopodiaceae, *Acanthus, Lippia, Justicia, Plantago*, etc. Aquatics were represented by *Typha, Limnanthemum* and *Hydrocera*. Palynological results have revealed that climate of the recent past in Sunderbans was almost the same as today. Five wood and peat samples from Bengal Basin were also collected by Barui *et al.* (1986) and were radiometrically dated to 2,640 ± 150; 6,170 ± 140; 6,360 ± 120; 6,390 ± 130 and 7,030 ± 150 yrs B.P.

Gupta (1970) reported three saprophytic fungi namely *Anellophora, Entophlyctis* and *Tetraploa* from the Calcutta peat. Later, he noticed microbial attack over a few palynofossils (Gupta, 1978). Sankrail and Jangalpur soil profiles from West Bengal were palynologically investigated and palaeovegetation since Middle Holocene Epoch was reconstructed (Vishnu-Mittre & Gupta, 1972). Sankrail profiles I and II have been radiometrically dated to 4,925 ± 100 and 5,810 ± 120 yrs B.P., respectively. The high values of *Rhizophora* and *Heritiera* pollen have been recorded in the sediments. The other mangrove elements such as *Bruguiera, Sonneratia, Avicennia, Ceriops* and *Excoecaria* were sporadic. The overall picture of vegetation indicates the existence of fresh water *Heritiera* forest in the recent past. There was no apparent climatic change since 6,000 yrs B.P. Fresh water diatoms in the sediments supported the existence of fresh water depositional environment in Sankrail area (Gupta & Khandelwal, 1984). Gupta (1981) reconstructed the palaeofloristics from Kolara, Barrackpore, Namkhana and Chaltiya and found that metachroneity existed in the development of vegetation at all the four flanks of Bengal Basin. Furthermore, rate and time of peatification was found to be different in different areas. The maximum peatification was observed in the eastern and western parts of the basin which gradually reduced towards northern and southern regions. In Kolara region, the subsidence owing to the submergence of land has been exemplified by *in situ* vertical position of *Heritiera* wood stumps with intact knee roots.

The bottom sediments in zones I and II of Kolara profile were laid down around 7,000 yrs B.P. (665-540 cm) and their study has revealed warm, humid climate and fresh water environment with a little intermixing of brackish water. The main constituents of this zone were *Heritiera, Phoenix paludosa, Sonneratia*, ferns and Poaceae. The successive zone KO-III showed higher magnitude of tidal influx around 5,300 yrs B.P. (540-450 cm) which was witnessed by high frequency of core mangrove taxa like *Rhizophora, Ceriops, Sonneratia*, etc. In zone KO-IV around 5,000 yrs B.P. (450-350 cm) the tidal magnitude was reduced and high frequency of brackish water elements were recorded. In the succeeding phase gradual increase in the values of *Heritiera, Ceriops* and Leguminosae was encountered. It was suggested that around 1,700 yrs B.P. (350-250 cm) in zone KO-V, ponding environment prevailed in the basin providing congenial conditions for peatification.

At Namkhana, the southern flank of the Bengal Basin, the vegetation was dominated by high values of *Ceriops, Rhizophora*, Leguminosae, *Concentricystis rubinus*, etc. during zones NA-I, II and III (390-295 cm). This phase witnessed the high magnitude of tidal influx around 7,000 yrs B.P. In successive zone NA-IV (295-245 cm), *Pongamia, Ceriops, Bruguiera, Ruppia, Suaeda, Concentricystis rubinus*, etc. were encountered in high percentages. This phase around 4,500 yrs B.P. signified the admixture of both tidal mangroves and prohaline vegetation. In the upper zone NA-V (245-185 cm) around 3,000 yrs B.P., *Sonneratia, Acanthus ilicifolius, Nypa fruticans* and Leguminosae being salt tolerant fresh water constituents, were recorded in high percentages. This phase revealed that the tidal influx ceased to enable the salt tolerant fresh water taxa to flourish.

The rich assemblage of plant and animal

remains has been reported from Metro Railway Station in Calcutta (CV type section), Dum Dum, Barrackpore and Kolaghat in Bengal Basin (Sen & Banerjee, 1984, 1990). A few surface and subsurface samples have also been collected from Luthian and Prentice islands in Sunderbans (Banerjee *et al.*, 1989). Based upon bio-assemblage and environmental sequence six depositional phases have been recognised since 7,000 yrs B.P. (Sen & Banerjee, 1990).

The environmental conditions of deposition in Bengal Basin begin with arid barren zone composed of clay with 'Kankar' nodules in Phase-I. In Phase-II (7,000-6,650 ± 120 yrs B.P.), brackish mixed-fresh water environment prevailed which has been evidenced by pollen of *Heritiera, Avicennia, Bruguiera* and *Acrostichum aureum*. Inundation of land by sea water has been evidenced by the presence of *Ammonia*. In the succeeding Phase-III (6,650 ± 120-6,400120 yrs B.P.), swampy mangrove environment with regular inundation by the tidal water has been recognised. The high percentage of core mangrove taxa such as *Sonneratia, Avicennia,* Rhizophoraceae and *Ammonia* have been encountered. *Palaeocirrenalia*-fungal spore has also been identified from this phase.

In successive phase-IV (ca. 6,400-6,175 ± 125 yrs B.P.) swampy, deltaic environment with high precipitation has been recorded. The palynoassemblage of this phase includes *Ceriops, Bruguiera, Excoecaria, Avicennia, Sonneratia, Heritiera, Typha, Concentricystis*, etc. The presence of *Callimothallus* and fern spores has been considered as the indicator of high precipitation.

Phase-V (6,175 ± 125-5,000 yrs B.P.) recorded mixed brackish water/fresh water *Heritiera* forest with a few littoral elements. This change in the ecosystem has been evaluated by high values of *Heritiera*, Poaceae, Cheno/ams, etc. The mangrove taxa declined in this phase.

Phase-VI (ca. 5,000-2,000 yrs B.P.) representing the upper part of the profile depicts supratidal fresh water swampy condition in the area which has also been shown by high values of *Potamogeton* pollen, algal remains of *Gloeotrichia* and disappearance of mangrove elements except for *Heritiera*.

Overall palaeofloristic composition depicts transgression of sea between 7,000 and 6,175 yrs B.P. and regression after 6,175 yrs B.P. The supratidal fresh water swampy conditions prevailed during 5,000-2,000 yrs B.P. and are still continuing in the area.

Mahanadi-Brahmani Delta

Six surface samples and two soil profiles, 70 cm and 90 cm deep, from Kalibhanja Dian Island and Talchua Village of Brahmani Delta, Orissa, respectively were palynologically investigated (*Caratini et al.*, 1980). The pollen spectra of surface samples show partial resemblance with the surrounding vegetation. The pollen composition from the profiles compares well with the present day vegetation mosaic of the area. However, high frequency of mangrove pollen in the bottom samples of Talchua profile has been recorded.

Eight surface samples and one 3 m deep profile from Paradip and Jambu islands in Mahanadi delta dated *ca* 500 yrs B.P. have been palynologically investigated (Gupta & Yadav, 1990). In and around Paradip, the mangrove vegetation today is represented by a few degraded patches of trees and shrubs such as *Avicennia alba, Excoecaria agallocha, Borassus* sp., *Phoenix paludosa, Acanthus ilicifolius, Acrostichum aureum*, etc.

In general, pollen spectra of almost all the surface samples match with the present day vegetation mosaic in Jambu and Paradip islands. However, Rhizophoraceae and *Sonneratia* were over represented. The pollen diagram constructed from Paradip profile revealed overall dominance of upland and midland vegetation, viz., *Terminalia, Adina, Emblica,* Fabaceae, Anacardiaceae, Sapotaceae, etc. The bottom samples of profile, deposited during 500 yrs B.P., recorded moderate occurrence of mangrove elements and witnessed the high magnitude of fresh water influx in deltaic complex. The fresh water swampy conditions continued till middle of the profile. The upper part of profile recorded the details of last few decades which showed overall dominance of mangrove taxa except at the extreme top of the diagram. The decline in the mangroves may be correlated with the construction of Paradip port in the year 1960 resulting in the denudation of land.

Palynological study of Mahanadi Delta sediments (Gupta & Khandelwal, 1990) has provided the basis for tracing vegetational history of mangroves. Fine resolution palynostratigraphy of Balugaon profile in Chilka Lake reveals the pattern of evolution of mangroves since 3,100 yrs B.P. In addition, soil, lake bottom mud and lake water samples were also pollen analysed to investigate the pollen/vegetation relationship in different depositional environments. The relative values of different palynodebris such as fungal spores, microforaminifera, *Concentricystis*, dinoflagellates, diatoms, fern spores and different categories of pollen in each sample were collectively plotted in the form of pollen deposition model. The model depicted the lack of uniformity in the values of

different organodebris in the samples in and around Chilka Lake which was attributed mainly due to the under water channels governing the movement of water both from sea and rivers into the lake. The analysis of all the samples has revealed the dominance of peripheral mangroves and codominance of core mangrove taxa. This pattern of pollen spectra is incoherent with the present day vegetation mosaic in and around Chilka Lake. The dispersed organic matter (D.O.M.) study of Balugaon profile has aided in determination and quantification of various stages of biodiagenesis which in turn has helped to confirm the deltaic depositional environment (Gupta & Khandelwal, MS).

A few air-catches at the bank of Chilka Lake near Barkul during the later half of march, 1988 depicted the total absence of core mangrove as well as peripheral mangrove pollen on exposed slides. Nevertheless, recorded arboreal pollen belong to *Morus, Ailanthus, Holoptelea,* Myrtaceae, Meliaceae, *Pandanus, Terminalia*, etc. These pollen are either drifted from hinterland zone or from the trees planted near the sampling site. In addition, a large number of fungal spores such as *Alternaria, Helminthosporium*, uredospores of *Puccinia, Cladosporium, Epicoccum, Nigrospora, Tetraploa,* etc. have been encountered.

Regarding the recent evolution of mangrove vegetation, a 5.50 m deep profile from Balugaon, Chilka Lake dated back to *ca.* 3,100 yrs B.P. was subjected to fine resolution palynostratigraphy. The pollen diagram constructed from this area has been phased into five zones, wherein six ecological grouping of plants have been made such as core mangrove, mangrove associate, hinterland, ubiquitous, aquatic and long distance drifted taxa.

Zone B-1 (5.50-4.40 m)—It covers a time span of about 700 yrs and enjoyed the luxuriant growth of core mangroves, especially in the lower half of this zone. However, mangrove associate and hinterland taxa remained inconsistent and sporadic throughout. Palaeofloristic picture depicts that the deltaic environment had prevailed in this phase and encouraged the spread of core mangrove taxa.

Zone B-II (4.39-3.60 m)—This zone spanned for about 500 yrs and recorded the overall supression in the values of Rhizophoraceae as compared to the preceding zone. However, the significant rise in *Excoecaria, Heritiera* and *Avicennia* pollen with simultaneous spurt in mangrove associate taxa suggests that this change over might have been due to the recession in the tidal magnitude and simultaneous increase in the fresh water discharge.

Zone B-III (3.59-2.40 m)—It covered a time span of 800 yrs and witnessed the total disappearance of Rhizophoraceae and *Avicennia.* However, corresponding rise in *Nypa fruticans, Heritiera* and *Sonneratia* suggests that probably there was cessation in tidal magnitude which helped in progradation of delta and thus the exposed land was flooded with fresh water influx.

Zone B-IV (2.39-1.35 m)—This zone spanned for about 500 yrs and witnessed the reappearance of Rhizophoraceae together with high values of Acanthaceae and Chenopodiaceae. The palaeofloristic picture suggests that deltaic conditions were restored, which provided congenial conditions for mangrove taxa to thrive.

Zone B-V (1.34-0.0 m)—It covers a time span of about 600-700 yrs and the palynological assemblage indicates perceptible decrease in mangrove vegetation, particularly in the last phase of this zone. The decrease in mangrove taxa had been attributed to the immense biotic, particularly human, pressure on the landscape resulting in total extermination of mangrove vegetation.

Godavari Delta

Two sites namely, Balsudippa situated in close proximity to sea coast and Bairavapalayam, a little farther from sea coast have been palynologically investigated (Caratini *et al.*, 1980). The presence of dinoflagellates, microforaminifera and high frequency of mangrove taxa have been recorded in 1.30 m deep profile of Balsudippa. The bioassemblage of profile reveals its proximity to the sea and presence of *Casuarina* pollen right from the bottom of profile suggests the age to be around 50 yrs only.

The palynological assemblage of 115 cm deep profile from Bairavapalayam showed high frequency of Chenopodiaceae, relatively low values of mangrove taxa, scanty presence of dinoflagellate and microforaminifera. The bioassemblage has revealed that the site of investigation was far off from the sea coast and was not under direct influence of sea.

Cauvery Delta

In order to know the modern pollen/vegetation relationship, the surface samples from three different zones of Pichavaram mangrove complex (mouth of Cauvery Delta) have been palynologically investigated (Caratini *et al.*, 1973). The palynological assemblage exhibited almost the same vegetational mosaic as is present in Pichavaram area today. However, over representation of Rhizophoraceae and *Sonneratia* pollen and under representation of *Avicennia* and *Excoecaria* have been highlighted.

To evaluate the causes of mangrove degradation, two profiles each from southern (Muthupet) and northern (Pichavaram) regions of Cauvery Delta, dated to about 2,000 yrs B.P., were pollen analysed (Tissot, 1980, 1987). From Muthupet two profiles, 1.50 m and 6 m deep and about 3 km away from the coastline were analysed. Depending upon the frequency of pollen of mangroves, back mangroves and marine elements such as microforaminifera and dinoflagellates, four periods have been recognised. Period 'A' revealed poor occurrence of mangrove taxa but bottom sediments indicate the clear and constant marine influence. In Period 'B' both mangroves and marine elements showed enhanced values. Period 'C' recorded maximum growth and development of mangroves but the marine elements declined in this phase. In Period 'D'—uppermost part of the profile, disappearance of both mangrove and marine elements was noticed and they were eventually succeeded by herbaceous halophytes. The gradual decline and extermination of mangroves has been largely assigned to the geomorphological changes resulting in heavy sedimentation and prograding the delta.

Two profiles, one 3.90 m deep from *Avicennia* forest and another 6.90 m deep from stand of *Rhizophora, Bruguiera* and *Ceriops* in Pichavaram, were palynologically analysed and three phases have been recognised in the palynological evolution of mangrove vegetation. In Phase 'A' the mangrove vegetation was established and extended further in Phase 'B' recording high values of *Rhizophora, Sonneratia* and *Excoecaria*. In successive Phase 'C', pollen of *Sonneratia* declined while Rhizophoraceae, *Excoecaria, Avicennia*, etc. remained static. It has been recorded that the erection of a dam in hinterland zone had enchanced hypersalinity in the Cauvery Delta, which adversely affected the growth and development of mangroves.

WESTERN COAST

Several attempts have been made to study the western coast sediments but it was found that either they were devoid of pollen or contained feeble number of pollen which were not enough for percentage calculation. However, the mycological records are enumerable.

Gujarat

In Arabian coastal sediments, fungal spores belonging to families Microthyriaceae, Asterinaceae, Parmulariaceae and Trichothyriaceae have been identified from nine samples (Ratan & Chandra, 1982). Thirty five grab samples collected along the continental shelf off-Bombay and Gulf of Kutch have also revealed a variety of fungal spores (Ratan & Chandra, 1983). The identifiable ones belong to *Curvularia, Cladosporium, Leptosphaeria, Bispora, Brachisporiella, Helminthosporium, Alternaria, Tetraploa, Brachidesmiella*, etc. It has been found that variety and concentration of fungi was higher near the sea coast rather than away from the coast.

The pollen analysis of a 2 m deep profile collected from Navlakhi, the eastern part of Gulf of Kutch (Caratini, 1980) has exhibited different phases of evolution of mangrove vegetation. The abundance of Chenopodiaceae and stray occurrence of Rhizophoraceae, *Avicennia*, etc. were noticed in bottom samples. The middle of the core showed high frequency of *Avicennia* pollen which subsequently reduced in the upper part of profile. The gradual decline of mangrove taxa from the sediments, tending to disappear from Kutch may be accounted due to local inhabitants destroying the mangrove vegetation to meet their daily requirement.

The result of pollen analysis of 13 surface samples collected from Gulf of Kutch (Ratan & Chandra, 1983) matched well with the existing vegetation of the area. The palynological assemblage showed good amount of pollen of *Avicennia*, Chenopodiaceae, Poaceae, Cyperaceae, etc. The other significant taxa recorded are *Bauhinia, Artemisia, Salvadora, Acanthus, Acacia, Dalbergia, Prosopis*, etc. Like fungal spores, the pollen grains also concentrated at the mouth rather than in the head region of the gulf.

The pollen diagram constructed from Ox-bow Lake at Malvan, Surat (Vishnu-Mittre & Sharma, 1975) revealed the abundance of nonarboreal vegetation belonging to families Gramineae, Cyperaceae, Urticaceae, Asteraceae, Chenopodiaceae, Amaranthaceae, *Artemesia*, etc. The arboreal taxa belonging to families Leguminosae, Myrtaceae and *Holoptelea* have also been encountered. The presence of microforaminifera, exhibiting the estuarine condition, has been noticed throughout in the profile. The fungal spores belonging to genera like *Tetraploa, Helminthosporium, Alternaria, Curvularia, Puccinia, Torula*, etc. have been recovered from the same site (Sharma, 1976). It is inferred that good frequency of *Helminthosporium* and *Tetraploa* in combination with the pollen of grasses and sedges is suggestive of cultivation of food crops in and around the site.

Palynological investigation of another six metre deep profile dated back to about 7,000 yrs B.P. from Nal Lake, about 60 km south-west of Ahmedabad was

done (Vishnu Mittre & Sharma, 1979). The palynological assemblage records grassland-chenopod-savanah type vegetation in the area. The pollen of *Holoptelea* might have been transported from the nearby riverain, dry, deciduous forests. Based on the frequency of microforaminifera, three phases of estuarine conditions were demarcated at different levels, viz., 7,000 yrs B.P., between 6,000 to 3,500 yrs B.P., and around 160 yrs B.P.

Kerala and Karnataka

Poilen analysis of bore-core samples dated back to *ca.* 22,000 yrs B.P. and located 10° N offshore Kerala and 15°N offshore Karnataka was carried out (Van Campo, 1983). In the bottom samples (22,000-18,000 yrs B.P.) a few mangrove elements were recorded at offshore Kerala Coast depicting dry climatic conditions. In successive phase 11,000 yrs B.P. good frequency of mangrove taxa was recorded witnessing humid climatic conditions. In the next phase, after 6,000 yrs B.P. the mangroves began to decline and thereafter, they almost vanished from top of the core. This decline in mangrove vegetation is largely assigned to biotic influence.

A 4.25 m deep bore-core from Kandavara in Coondapur, about 7 km from Karnataka Coast, has been palynologically investigated (Tissot, 1990). The study has revealed the presence of well-developed mangrove forest in near past comprising *Avicennia, Sonneratia* and *Kandelia.* The back mangrove taxa like *Calophyllum, Excoecaria, Sesuvium, Heliotropium*, etc. have also been encountered in moderate quantities. On the basis of frequency and continental/marine microfossils ratio it is concluded that the sea level remained unchanged since 6,000 yrs B.P. and the deposition of sediments in the area was laid down under lagoonal condition.

Pollen analysis of Kanara Coast, Karnataka dated *Ca.* 40,000 yrs B.P. has been carried out (Caratini *et al.*, 1990). The organic clay samples, ranging from 3.5 to 7 m thick, in different wells namely Handabi, Varambali, Shaligram, Navunda and Shirali have been palynologically investigated. The overall composition of pollen assemblage revealed that *Rhizophora, Ceriops* and *Bruguiera* were collectively present to the tune of 90 per cent, whereas *Avicennia* and *Aegiceras* were feebly present. The back mangroves such as *Acanthus ilicifolius, Calophyllum, Excoecaria* and *Heliotropium* were poorly represented. It was suggested that the deposition had taken place in mangrove environment. The climate and flora deduced from present investigation were comparable with palaeoclimate and palaeovegetation existed during the last interglacial (Eemian). It also matched well with Holocene mangrove ecosystem of Coondapur, Karnataka.

Maharashtra

The palynological investigations of coastal region in Bombay (Vishnu-Mittre & Guzder, 1975) recorded sporadicity in mangrove and other allied taxa such as *Acanthus ilicifolius, Avicennia* type, *Carallia* sp., Chenopodiaceae, *Excoecaria agallocha, Sonneratia acida, S. apetala,* Leguminosae, Myrtaceae, *Phyllanthus*, etc. Pollen analysis of 270 cm deep profile near Thana, Bombay (Caratini *et al.*, 1980) revealed poor representation of mangrove elements and abundance of Gramineae pollen. The presence of *Casuarina* pollen right from the base of profile suggests the recent age of the sediments.

The study of pollen and spores from the recent sediments of the continental shelf off Bombay has been carried out by Ratan and Chandra (1984). They observed that all the 22 grab samples have yielded pollen belonging to mangrove, tropical evergreen and mixed deciduous type of forest. The herbaceous and pteridophytic spores were predominant and the quantitative abundance of taxa have been noticed in the samples collected from near the coast.

DISCUSSION AND CONCLUSION

Eastern and western coasts in India are the two main important areas where palynology has been instrumental to trace out the history of mangrove vegetation during Holocene Epoch. Since two areas differ greatly in geomorphology, ecology and vegetation characteristics, it is deemed necessary to deal with them separately.

Eastern Coast

Several deltaic zones such as Sunderban-Gangetic Delta, Mahanadi-Brahmani Delta, and Godavari and Cauvery deltas have been palynologically studied. Amongst all, Sunderban—Gangetic Delta, has been thoroughly investigated covering all the four flanks of Bengal Basin. The palynological sequence in Bengal is consistent and therefore it has been taken as a base to define all other possible events and episodes which occurred since 7,000 yrs B.P. High biomass accumulation and rich palynological assemblage are the common factors amongst all the profiles of the basin. But, the anomaly exists in number, position and thickness of peat bands throughout the basin. The vegetation is metachronous at all the four flanks of Bengal Basin. Therefore, the palaeopalynology of east, west and south of Bengal Basin has been dealt separately so as

to achieve precision in the interpretation of depositional environment. To facilitate the translation of vegetational shifts in terms of events and episodes, the whole vegetation system from east and west of the basin has been classified into six phases.

Bottom sediments at Kolaghat and Calcutta (CV type section) largely comprise kankar nodules and there is no record of biota. The sediments were laid down under arid conditions and this event has been extrapolated before 7,000 yrs B.P.

Phase I (ca. *7,000-6,700 yrs B.P.*)—The pollen assemblage of this zone portrays the existence of brackish water and mixed *Heritiera* forest with sporadic occurrence of *Sonneratia.*

Phase II (ca. *6,700-5,600 yrs B.P.*)—During this period sea regressed and fresh water discharge increased. Thus as a result fresh water *Heritiera* forest thrived and mangrove taxa disappeared.

Phase III (ca. *5,600-5,300 yrs B.P.*)—The general pattern of this phase has revealed that there was complete cessation in the sea tide and the land was frequently inundated by river water. As a result, no mangrove taxon thrived during this period except for the poor occurrence of fresh water *Heritiera* trees.

Phase IV (ca. 5,300-4,900 yrs B.P.)—The vegetational pattern of this phase indicates that inflow of river water was substantially reduced which resulted in more of saline conditions. It encouraged the development of salt tolerant fresh water plants such as *Sonneratia, Acanthus ilicifolius, Suaeda,* etc.

Phase V (ca. *4,900-3,000 yrs B.P.*)—The overall picture of this zone depicts the existence of quiet conditions encouraging peat formation in ponding environment. The curves for all taxa in this phase showed coherence with the ecological conditions except for *Ceriops* which was misfit in the fresh water plant community.

Phase VI (ca. *3,000-1,710 yrs B.P.*)—This phase does not significantly differ from the preceding phase both lithologically and palynologically except for high biotic pressure over the landscape. The top sediments covering a period of about 1,500 years are mostly unconsolidated silty sand which is mostly aeolian in nature and does not hold any biota.

Namkhana, a site on southern flank of the basin, records entirely different vegetation from the rest of the profiles in eastern and western flanks of the basin. The total vegetation sequence has been phased under following five heads:

1. ca. *7,000-6,500 yrs B.P.*—The overall picture of this phase strongly suggests the existence of tidal mangrove forest and the area was constantly under the influence of sea.
2. ca. *6,500-5,800 yrs B.P.*—During this phase characteristic tidal mangrove elements either withered or reduced to fraction and were succeeded by salt tolerant fresh water plants indicating recession in the tidal magnitude.
3. ca. *5,800-5,000 yrs B.P.*—This phase signifies the reversal of core mangrove taxa indicating that the area was again inundated by the tidal water.
4. ca. *5,000-4,000 yrs B.P.*—This phase is marked by rich pollen assemblage having an admixture of tidal mangrove and prohaline taxa. This phase, more or less, is a continuation of the preceding phase wherein the tidal influx was quite prevalent. But certain plants which could not directly withstand tidal currents, preferred to grow on dry nitches bordering the estuarine water.
5. ca. *4,000-3,170 yrs B.P.*—The overall vegetational picture of this phase has revealed that either the sea regressed or else tidal magnitude was much reduced encouraging the salt resistant fresh water elements to colonize.

Thus the Holocene vegetation of Bengal Basin is summarised as follows:

1. The sea arm did not encroach the eastern and western flanks of the basin.
2. The southern flank was frequently under the influence of sea tides. The short term transgression of sea was recorded between 7,000-6,500 yrs B.P. and 5,800-5,000 yrs B.P.
3. The peatification is not uniform in time and distance. The formation of peat is recorded between 5,000-2,000 yrs B.P. and was restricted to western and eastern flanks of the basin only.
4. The palynological records from 3,000 yrs B.P. onward are not preserved owing to the mounting biotic pressure over the landscape. As a result the land which festooned once with the colossal growth of mangrove taxa, was transformed into the heathland. This resulted in heavy loss in the coastal ecosystem, disbalancing the biosphere, inviting the typhoon-sand cyclones and thus taking heavy tolls.

In Mahanadi-Brahmani Delta the studies are confined to Chilka Lake and Paradip island. The vegetation sequence at Chilka Lake, covers a time span of 3,100 yrs B.P., while at Paradip it is only 500 yrs old sequence. During first phase between 3,100-2,500 yrs B.P. there was splendid growth of core mangroves but in the succeeding phase between 2,500-2,000 yrs B.P. the core mangrove taxa diffused and were later succeeded by peripheral mangroves.

This change-over suggests that the tidal influence ceased and fresh water discharge increased so much that in Phase III between 2,000-1,200 yrs B.P. the mangroves almost vanished. Phase IV, between 1,200-700 yrs B.P., has witnessed the rejuvenation of mangrove forest. In all probabilities, the depressed sea during preceding phase was restored or else storm surges, hurricanes produced high water levels creating congenial conditions for core mangrove to expand and recolonize. Phase V between 700-till now is the period when the mangrove forest was periodically threatened by immense human pressure. This pressure is multifaceted such as agriculture, urbanization and industrialization, etc. The combined impact of human greed has almost resulted in the extermination of mangrove taxa in and around Chilka Lake and Paradip Island. The palynological investigations in Godavari and Cauvery basins are very meagre and only fragmentary information is available.

Western Coast

The oldest sediments along the Western Coast have been found in Kanara Coast, Karnataka. The organic clay layer from different wells, at the depth ranging from 1.5 to 7 m thick, have been radiometrically dated to 40,000 yrs B.P. The palynological assemblage exhibited the dominance of Rhizophoraceae members and stray occurrence of *Avicennia* and *Aegiceras*. It is presumed that the sediments were laid down in mangrove environment. The vegetation and climate around 40,000 yrs B.P. in Kanara Coast, as suggested by Caratini *et al.* (1990), were not different from that of last interglacial (Eemian). It also matched well with Holocene mangrove ecosystem of Coondapur, Karnataka. Furthermore, offshore sediments from Kerala and Karnataka have been palynologically investigated and radiometrically dated to 22,000 yrs B.P. (Van Campo, 1983). The palynology of Kerala sediments has depicted the poor occurrence of mangroves between 22,000 to 18,000 yrs B.P. However, around 11,000 yrs B.P. luxuriant growth of mangrove vegetation is recorded denoting deltaic environment. Thereafter, 6,000 yrs onwards the mangroves declined showing irregularity in their development and the conditions they have experienced could be equated with the existing mangrove ecosystem of Kerala.

Nevertheless, the degradational mosaic of mangrove vegetation in recent and subrecent samples around 2,000 yrs B.P. and onwards on both eastern and western coasts have been largely influenced by biotic pressure for increasing demand of agricultural practices, urbanization and industrialization. The mounting human population and their domestic animals have caused immense and irreparable loss to the mangrove forests converting the Indian coastland into bareland. The pernicious damage to mangrove taxa has resulted into changed biosphere and ecosystem encouraging unwarranted cyclones, typhoons and tidal surges, etc. causing heavy losses to human life and wealth. Since information is available about the vegetational development in time and space of different Indian estuaries, it is proposed that the afforestation scheme may be implemented for restoration of mangrove vegetation.

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