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PICHAVARAM ESTUARY AND ADJOINING WETLAND, TAMIL NADU, INDIA: POLLEN AND NON-POLLEN REMAINS IN THE SEDIMENT – A MODERN PALYNOFACIES ANALYSIS

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Variation in the preservation of biotic forms in the modern estuarine sediments between the Vellar and Coleroon river (Tamil Nadu), particularly, Pichavaram mangrove area has been studied in ecological perspective. Surface sediment (13 stations) and sub-surface core samples (8 stations) up to a depth of 65 cm were selected for the study. Organic matter are preserved in relatively silty to clayey sand sediments which constitute plant debris, pollen/spores, fresh water algal matter, fungal remains, dinoflagellate cysts, thecamoebians, foraminifera, tintinids and radiolarian lorica remains. The percentages of these vary during pre and post-monsoon periods and also in sub-surface shallow sediment cores indicating three distinct ecological zones. Palynological and thecamoebian evidences in surface sediments between Vellar and Coleroon coastal wetland reveal water runoff parallel to the shoreline. Increase in water salinity (~32 to 40 ppt) and 5–10 ppt in the aqueous soil solution particularly in the eastern seaward part of Pichavaram estuary as compared to the western and southern part was recorded. The sub-surface sediment up to 65 cm depth show an abundance of thecamoebians and other terrestrial palynomorphs indicating low salinity and more fresh water run off in the past. Increased salinity in the back waters and surface sediment is alarming which is likely to affect the true mangroves (*Rhizophoraceae*) giving way to salt-tolerant mono-specific plants like *Avicennia* and *Suaeda*.

Keywords: Biotic forms, sediment deposition, India, Mangroves, Pichavaram, Tamil Nadu.

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ИСПОЛЬЗОВАНИЕ СОВРЕМЕННОГО ПАЛИНОЛОГИЧЕСКОГО АНАЛИЗА ПРИ ИЗУЧЕНИИ ОСАДОЧНЫХ ОТЛОЖЕНИЙ В УСТЬЕ РЕКИ ПИЧАВАРАМ (ТАМИЛ НАДУ, ИНДИЯ) И ПРИЛЕГАЮЩИХ ЗАБОЛОЧЕННЫХ ТЕРРИТОРИЙ

В работе рассматривается вариант сохранения биотических форм в осадочных отложениях в дельте между реками Веллар и Колерун (Тамил Наду), в частности территории мангровых насаждений в устье реки Пичаварам. Для изучения были выбраны поверхностные осадочные породы (13 месторасположений) и подземные – на глубине 65 см (8 месторасположений). Органическое вещество сохранено в относительно заиленном, до степени глинистого песка, отложении, которое представлено обломками растений, пыльцой/спорами, веществом пресноводных водорослей, грибковыми остатками и др. Процентное содержание этих веществ отличается в период до муссона и после него, а также в зависимости от экологической зоны, которых в подземном мелководном осадочном слое выделяют три. Данные палинологических исследований поверхностных отложений между прибрежными зонами рек Веллар и Колерун указывают на сток воды к береговой линии. Было зарегистрировано увеличение солёности воды (32–40 ч. на тыс.) и 5–10 ч. на тыс. в водном почвенном растворе, в частности в восточной части устья Пичаварам. Подземные осадочные отложения, взятые на глубине 65 см, показали обильное содержание наземных палиноморфов, что указывает на низкую степень солености и больший сток пресной воды в прошлом.

Увеличение солености вод и поверхностных отложений вызывает опасения. Оно может повредить произрастающим здесь мангровым деревьям (*Rhizophoraceae*), которые будут заменены солеустойчивыми растениями, такими как *Avicennia* и *Suaeda*.

Ключевые слова: биотические формы, осадочные отложения, Индия, мангровые деревья, Пичаварам, Тамил Наду.

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ВИКОРИСТАННЯ СУЧАСНОГО ПАЛІНОЛОГІЧНОГО АНАЛІЗУ ПРИ ДОСЛІДЖЕННІ ОСАДОВИХ ВІДКЛАДІВ У ГИРЛІ РІЧКИ ПІЧАВАРАМ (ТАМІЛ НАДУ, ІНДІЯ) ТА ПРИЛЕГЛИХ ЗАБОЛОЧЕНИХ ТЕРИТОРІЙ

У роботі розглядається варіант збереження біотичних форм у осадових відкладах у гирлі між річками Веллар та Колерун (Таміл Наду), зокрема території мангрових насаджень у гирлі річки Пічаварам. Для дослідження були обрані поверхневі осадові породи (13 місцерозташувань) та підземні – на глибині 65 см (8 місцерозташувань). Органічна речовина збереглася у відносно замуленому, до ступеня глинистого піску, відкладі, яке представлене обломками рослин, пилком/спорами, речовиною прісноводних водоростей, грибковими залишками та ін. Відсотковий вміст цих речовин відрізняється від мусону та після, а також залежно від екологічної зони, яких у підземному мілководному осадовому шарі виділяють три. Данні палінологічних досліджень поверхневих відкладів між прибережними зонами рік Веллар та Колерун вказують на стік води до берегової лінії. Було зареєстровано збільшення вмісту солей у воді (32– 40 ч. на тис.) та 5–10 ч. на тис. у водному ґрунтовому розчині, зокрема у східній частині гирла Пічаварам. Підземні осадові відклади, взяті на глибині 65 см, показали значний вміст наземних паліноморфів, що вказує на низький вміст солей та великий стік прісної води у минулому. Збільшення вмісту солей та поверхневих відкладів викликає занепокоєння. Воно може пошкодити справжнім мангровим деревам Rhizophoraceae, які будуть заміщенні солестійкими рослинами, такими як *Avicennia* та *Suaeda*.

Ключові слова: біотичні форми, осадові відклади, Індія, мангрові дерева, Пічаварам, Таміл Наду.

Mangrove wetland is a multiple-use ecosystem, covering 8 % of the world's coast and 25 % of the tropical coastline. The interaction between marine and freshwater creates hydrodynamics unique to estuaries in which both the natural variation in freshwater inputs and the flood and ebb tidal flows are essential for maintaining estuarine health and mangroves in particular (Rao, 1974; Chapman, 1977). Mangrove forest with their unique ecological characteristics provide clue to ecological variability in the ecosystem (Ellison, 1989). These are intimately associated and influenced by the average sea level position and therefore indicate its variability through a time period. Frequent water runoffs in the estuary favor mangrove growth (Naskar, 1999) and therefore, are good indicators of monsoon intensity. The mangroves of India are recorded by number of workers (Naskar, 1999; Untawale, 1987). These respond opportunistically to habitat change induced by geomorphological processes that provide the basis for understanding the changes in the past and predict the possible trend in future.

Sands and muds in estuarine ecosystem are home to rich mangroves and abundant biota of prokaryotes like thecamoebians, ciliates, and various flagellates especially euglenids and dinoflagellates. Sedimentary records of biological communities are of great relevance in ecological studies since they provide the "key" to interpret past environmental conditions. Thus, the type of organic matter deposition and its preservation in an ecosystem provides a clue to ecological status that supports its biological fabric. The estuarine ecosystem which is conducive for the growth and proliferation of mangroves largely depends on the fresh water run off and the tidal influx. The shoreline demarcating the Pichavaram estuary in Tamil Nadu is wave dominated and the growth/ erosion of the sand spit running parallel to the shoreline shows seasonal opening and closing of the river mouths, thus affecting the ecological status of the estuary. This is one of the sites along the east coast of India that harbours rich mangrove diversity but the recent statistics shows many of the threatened and endangered mangrove species. In order to evaluate the recent

developments/changes in the Pichavaram ecosystem, this study elucidates the biotic assemblage in surface and sub-surface sediments supported by geochemical parameters. The study provides a modern analogue of organic matter facies in a set of known climate, geomorphology, ecology and vegetational set up in Pichavaram and adjoining estuarine ecosystem between the Vellar and Coleroon Rivers.

STUDY AREA

All along the coast of Cauvery delta, the dominant action of waves and coastal currents induce the formation of a sand bar (Ahmad, 1972). The Pichavaram mangroves located between latitude 11°22′N to 11°32′N and longitude 79°45′E to 79°49′E, constitute north-eastern part of Coleroon river delta and is about 15 km north of Chidambaram, Cuddalore District, Tamil Nadu. The southern part is an abandoned delta exhibiting a network of palaeochannels (Babu, 1991; Ramasamy, 1991). The eastern part of the Pichavaram estuary is separated from the Bay of Bengal by N-W trending sand barrier (Ramasamy, 1991). The estuary is aligned parallel to the shoreline in the NW-SE direction which is typical in wave dominated shoreline. The estuary connects the Vellar and Coleroon estuaries in the north and south, respectively by intricate waterways spreading over an area of about 1000 ha mangrove swamp consisting of 51 islets, ranging in size from 0.01 to 2 km^2 colonized by 13 species of mangrove. Pichavaram mangrove biotope is influenced by the mixing of neritic water from the Bay of Bengal, brackish water from the Vellar and Coleroon estuarine system and freshwater from the irrigation channel called the Khan-Sahib canal which links the Pichavaram estuary and mangroves. The constituents of the deltaic plain between the Vellar and the Coleroon river are fluvial channel sands and inter-distributory silts and muds and sand ridges alternating with silty flats, beach sands associated with estuarine muds and mud flats. The wetland is criss-crossed by hundreds of back water channels known as Killai back waters (Kil= narrow channels).The depth of the waterways ranges from about 0.1 m to 2 m which increases from 1 to 3.5 m during rainy season. The tide is micro and diurnal, and amplitude during the spring and the neap tide is about 42 and 20 cm, respectively. The area receives about 70 % of the average rainfall through north-east monsoon. The climate is sub-humid, warm summers (< 30°C) and annual average rainfall is 120 cm (~56 days yr^{-1}). It is one of the dominant features of the tropical coastline where salinity undergoes constant variation due to freshwater flow that is enhanced during monsoons and where the substratum is composed of accumulated deposits of sediments.

MATERIALS AND METHODS

In order to study the preservation of biotic forms in the modern sediments of Pichavaram mangrove area between the Vellar and Coleroon river (north-south adjoining areas) about 13 surface and 8 subsurface (Stations- St.C1 to St.C8 cores) sediments (Fig.1) were collected. The surface samples were collected twice in a year representing pre-monsoon (June, 2004) and post-monsoon (February, 2005) periods, which accidentally happens to be pre-tsunami and post-tsunami events. The core samples were collected from the mangrove area which was, further sub-sampled for analysis at intervals as shown in Fig. 3. Core samples have been collected through the routine and standard PVC pipe injection method.

Ten-gram soil sample was treated with KOH followed by HF until the silica was dissolved. The residue was acetolysed following (Erdtman, 1943) and finally brought to 5ml volume. The residue obtained after passing through 600 mesh size (<15μm) was studied under high power light microscope (Olympus BX-52). The qualitative and quantitative study of pollen/spores, plant tissue, algal and fungal remains, dinoflagellate cysts, foraminifera linings and thecamoebians have been documented as percentage values of about more than 200 count. Sand, silt and clay fractions in the sediment were estimated by the pipette method (Krumbein, 1938; Trefethen, 1950) nomenclature has been used for soil texture. The salinity (ppt) and conductivity (mS cm^{-1}) was estimated using Thermo-Orion 5-star conductivity probe. The total organic matter (TOM) and total carbonate content (TCC) in soil was estimated by combustion method at 550°C and 950°C, respectively (Bergtsson, 1986).

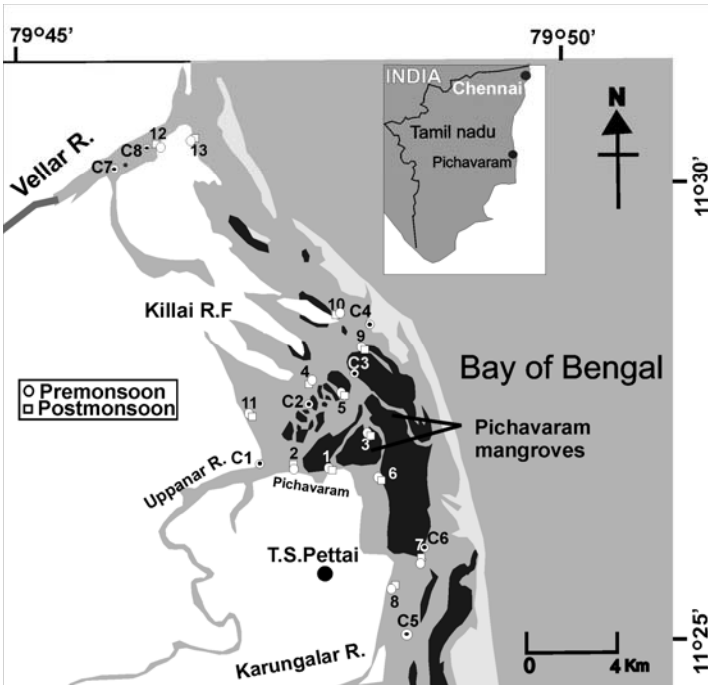

Fig. 1 – Location map of study area Pichavaram and adjoining areas

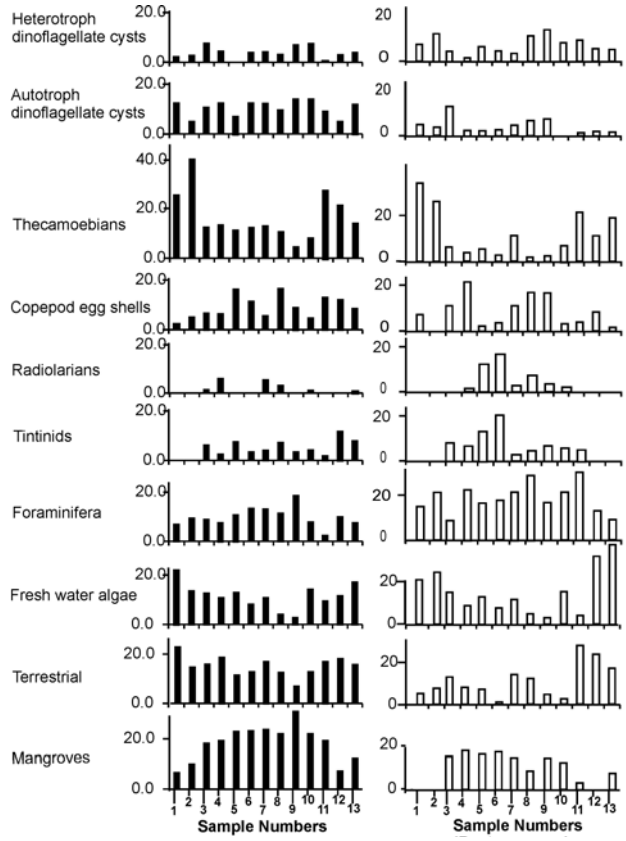

Fig. 2 – Percentage spectrum of pollen and non-pollen forms during premonsoon and post monsoon season in Pichavaram estuary and adjoining areas, Cauvery delta

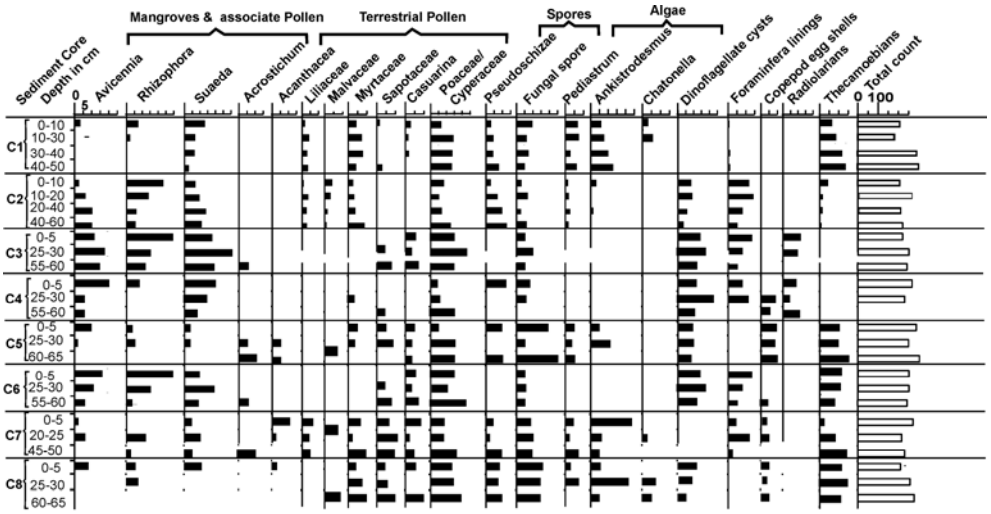

Fig. 3 – Pollen and non-pollen percentage spectrum in core sediments from Pichavaram estuary and adjoining areas (Each Div. 5 %)

Mangrove vegetation

The plant community-structure studies show that *Avicennia marina* (Forsk.) Vierh is monospecifically dominant seawards whereas, *A. officinalis* L. dominates the landward area. The back water channels are lined by luxurious thin line of *Rhizophora apiculata* Bl. and *R. mucronata* Lam., stray areas of *R. lamarckii* Montr. along with ground vegetation dominated by *Suaeda nudiflora* Moq. followed by *S. maritima* (L.) Dumort. and *S. monoica* Forssk.. Out of these *S. nudiflora* is adapted to highly saline substrate (Farooqui, 2009). Other plants recorded from this area are *Acanthus ilicifolius, Aegiceras corniculatum, Bruguiera cylindrica, Ceriops decandra, Excoecaria agallocha, Lumnitzera racemosa, Salicornia brachiata, Sesuvium portulacastrum, Sonneratia* spp. and *Xylocarpus granatum*.

Palynology

On the basis of palynological analysis three Zones could be demarcated (Z-I, Z-II & Z-III). Zone I (surface samples- 1 to 8 and sub-surface cores -C2, C3, C5, C6) constitutes main Pichavaram estuarine area where lush green true mangroves (Rhizophoraceae) occupy the fringes of backwater channels. Zone II (surface samples- 9, 10 and sub-surface core – C4) is the seaward eastern part of the estuary where the mangroves are less developed although seedlings of *Rhizophora* could be seen frequently because of ongoing reforestation programme. Patches of *Avicennia* and peripheral *Suaeda* bushes are common intermixed in between white salty patches. Zone III (surface samples- 11,12, 13 and sub-surface cores – C7, C8) is the landward estuary area.

Premonsoon (surface sediment)

Zone-I comprises of silty-sand sediment and the total organic carbon ranges from 2.2 % ± 0.2. The salinity ranged from 15-20 ppt in water. However, the aqueous solution of soil-water interface sediment shows salinity ranging from 3-4 ppt. An increased percentage of fresh water heterotrophs such as thecamoebians (13 to 40 %) like *Centropyxis aculeata, C. arcelloides, Arcella megastoma, A. vulgaris, A. excavata, Trigonopyxis arcuata, Trinema* species, *Cyclopyxis kahii* and *Nebela barbata* followed by low percentage (4 to 9 %) of foraminifera linings of *Ammonia* and *Elphidium* (Fig. 3). These samples also show moderate percentage of fresh water algae (10 to 17 %) like *Ankistrodesmus* and *Pediastrum*. Sediment from stations 5 and 8 show high percentage of brackish water-freshwater to marine heterotrophs like foraminifera (9–18 %) such as *Ammonia, Epistominella, Cribroelphidium, Trochammina, Valvulinaria, Cyclamina* and *Elphidium.*

The autotrophic dinoflagellate cysts like *Impagidinium*, *Lingulodinium and Spiniferites* show high frequency (5- 13.8 %) in Z-I at all the stations (Fig.2) as compared to heterotrophs (4 to 7.5 %) like *Protoperidinium* type and lorica remains of *Tintinopsis* and Radiolarians (1.5%). Results show thecamoebian abundance in the apex of the Pichavaram estuary (Z-I) fed by Uppanar and the Khan Saheb Canal. The similar forms of Foraminifera and dinoflagellate cysts were also recorded in Z-II at stations 9 & 10. High percentage of *Rhizophora, Avicennia* and *Suaeda* pollen (17%) followed by Poaceae, Cyperaceae, Liliaceae, Palmae, *Cocos, Acanthus*, *Clerodendron*, *Syzygium*, *Eucalyptus*, Malvaceae, *Mangifera, Madhuca, Casuarina,* Sapotaceae and Combretaceae (26%) were also recorded. Among the mangroves, although *Avicennia* is present in abundance but the pollen grain in the sediments is underrepresented (6%). However, the pollen grains of *Suaeda* are overrepresented (22%) followed by *Rhizophora* pollen (9%). Low percentage of *Pediastrum* and *Ankistrodesmus* (2%) were recorded in these samples. The sediment in Z-II is clayey sand to sandy silt in some places and the salinity ranged from 35 to 40 ppt in water samples and 5-10 ppt in aqueous soil solution of the sediment indicating increased salinity in the sea ward zone of Pichavaram estuary. Most of the barren patches are covered by white salts (Fig. 4) and the temperature here is unbearable to bare foot during daytime. The accretion of salt here is due to its translocation by capillary action during surface water

Fig. 4 – Pichavaram estuary and Adjoining Wetland, Tamil Nadu, India

evaporation. This indicates that the seaward land is exposed for longer duration allowing the salts to accumulate on the surface. Such a high salinity zone is vulnerable to true mangroves (Rhizophoraceae members). Increase in salinity would affect the reforestation programmes in and around Z-II. The high percentage of fresh water thecamoebians and low percentage of marine forms like foraminifera linings and dinoflagellate cysts were recorded in Z-III (fed by Vellar and Karungalar rivers).

Post monsoon (surface sediment)

As compared to pre-monsoon the ecosystem during post-monsoon period supported low foraminifera community (*Ammonia* and *Elphidium* species) and absence of *Tintinids* and *Radiolarian* remains in Z-I and Z-II. This could be due to increased turbidity and high seaward thrust of fresh water. Dominance of autotrophic dinoflagellate cysts of *Spiniferites mirabilis* and other *Spiniferitis* spp. were recorded in all the stations. Comparatively other autotrophs like *Impagidinium* and *Lingulodinium* were in low percentage. Thecamoebians like *Cyclopyxis kahlii* and *Arcella megastoma* were low in percentage at all the stations in Z-I but show high percentage in sediments from Z-II and Z-III. The percentage of mangrove pollen was comparatively low. *Suaeda* pollen over-represent in Z-I. Low percentage of mangrove pollen but high percentage of terrestrial pollen taxa were recorded in Z-III. A comparative account of variability during pre and post monsoon is given in Fig.2.

Palynology (Shallow cores)

Station C1 (0-50 cm)

Station C1, is at the mouth of the Pichavaram estuary where it meets with the Uppanar river and the Khan Sahab canal. The sediment is silty sand (50-70% sand) and presently devoid of mangroves but small seedlings of *Rhizophora* and *Avicennia* bushes could be encountered perhaps due to an effort of reforestation process. The average TOM is 2.2% and TCC is 3.2 % in the upper 0-20cm sediment but shows low TOM (1.4%) and high TCC (4.8 %) in 20-50 cm depth samples. The palynological study shows moderate percentage of *Rhizophora*, *Avicennia, Excoecaria* (2%) and comparatively high percentage of *Suaeda* (8%) and poaceae/cyperaceae pollen in the surface sediment (0-20 cm). Absence of mangrove pollen at lower depths (20-50) and moderate percentage of terrestrial pollen like *Acacia* spp. *Casuarina*, *Clerodendron*, Combretaceae, *Excoecaria*, Lamiaceae, Liliaceae, Meliaceae, Myrtaceae, Palmae, Sapotaceae, *Shorea* and Solanaceae, along with the fresh water algae like *Ankistrodesmus, Botryococcus* were recorded (Fig.3). The result reveals reduction in terrestrial pollen taxa along with the evidences of mangrove distribution near this station during the recent years. Thecamoebians like *Centropyxis aculeata, C. aerophila, Cyclopyxis kahlii, Arcella megastoma*, *A. vulgaris*, *Trigonopyxis arcula, Nebela barbata* and *N. militaris* were present throughout in the core which indicate low salinity and very fluctuating stressed environment.

The location of this core is in the middle of the Pichavaram estuary situated 4.5 km away from the sea mouth with large area covered by *Avicennia officinalis, Suaeda nudiflora* and *S. monoica* . But *Rhizophora apiculata, R. mucronata* occurred in scattered groups occupying fringes of back-water channels. Mangroves show luxuriant growth in this region. Besides *Aegiceras corniculatum, Ceriops decandra* and *Excoecaria agallocha* were also present. Palynological study reveals low percentage of *Rhizophora* but high percentage of *Avicennia* and *Suaeda* pollen in samples from 20-60 cm along with the high percentage of shallow water indicators like *psuedoschizae* (cysts of unknown lineage). Comparatively, foraminifera linings (*Ammonia* species) and dinoflagellate cysts (*Spiniferites spp.*) too show a reduction (Fig.3). The average TOM is 1.2% and TCC is 4.3 % at this depth. The upper 0-20cm sediment show high TOM (2.4%) and low TCC (1.8 %) along with the high percentage of *Rhizophora* and *Suaeda* species suggesting increase in *Rhizophora* plants during the recent years as compared to the recent past where salt tolerant *Avicennia* and *Suaeda* dominated in shallow saline ecosystem. High percentage of *Spiniferitis, Lingulodinium*, *Bitectodinium, Nebela barbata* and other *Nebela* species along with the presence of *Cyclopyxis kahlii* and few Centropyxids indicate eutrophic conditions and high organic matter productivity.

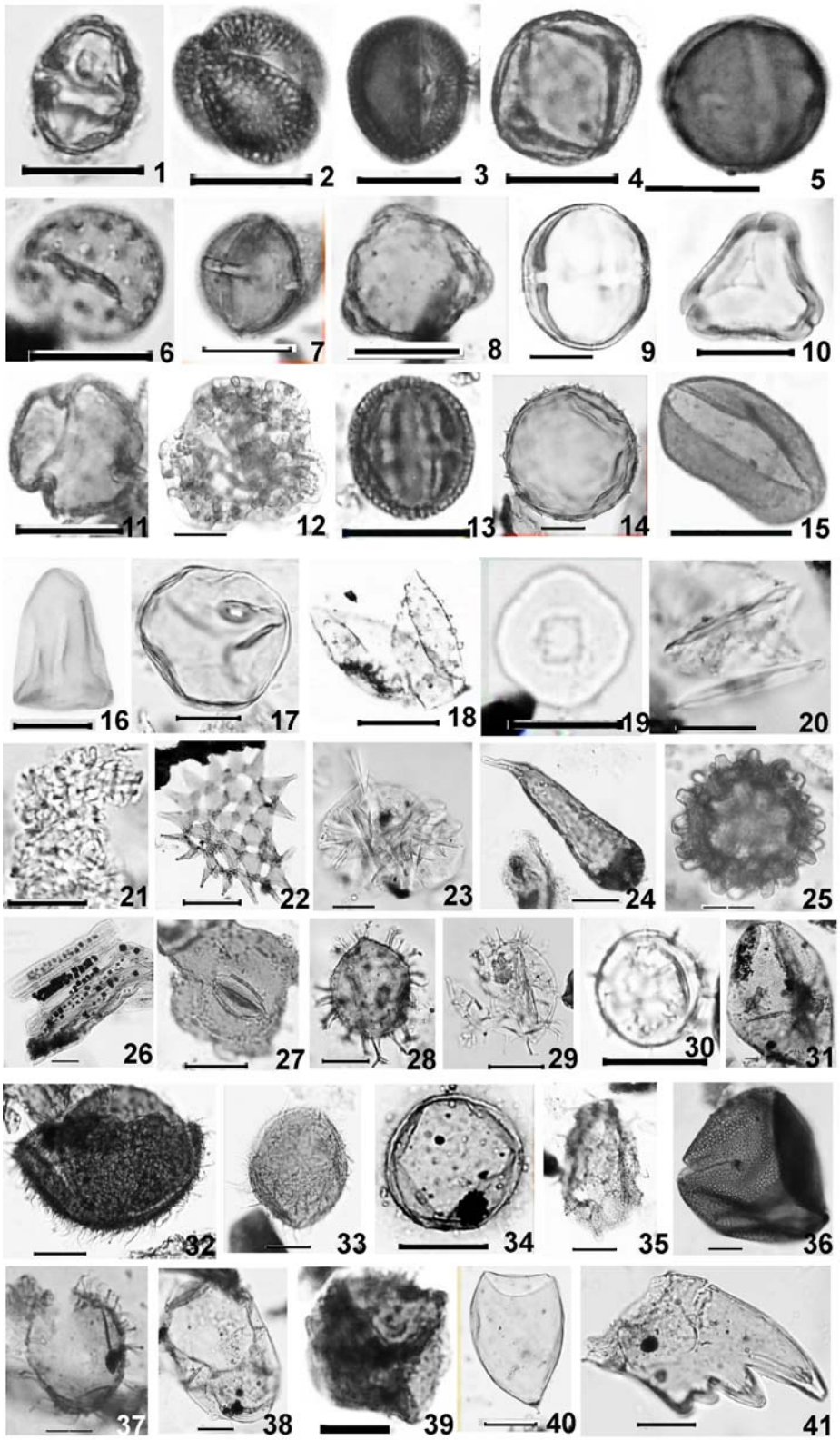

Fig. 5. Palynology

Station C2 (0-60 cm)

Core No. – C3 (0-60 cm)

Dense mangrove cover is found in this region. Besides *Avicennia officinalis*, *A. marina, R. apiculata, R. mucronata, R. lamarckii, Ceriops decandra, Aegiceras corniculatum, Excoecaria agallocha, Suaeda monoica, Suaeda maritima* and *S. nudiflora* were also present. Palynological study of the sediment reveals high percentage of *Suaeda* and *Avicennia* pollen at the lower depth as compared to high *Rhizophora* pollen in the surface sediment indicating favourable conditons for the growth of *Rhizophora* in the present day state of ecology. Increase in Rhizophoraceae pollen preserved in the surface sediment could be attributed to recent conservation and extensive efforts of afforestation programmes in Pichavaram estuary. However, pollen grains of *Aegiceras, Excoecaria* and *Sonneratia* were not recorded in the sediments despite the occurrence of its plants in Pichavaram estuary. The TOM in the entire core ranged from 2.1 to 2.6 % and TCC ranged from 0.5 to 0.9 %. Presence of foraminifera linings mainly *Ammonia* type, Radiolarian remains and dinoflagellate cysts such as *Impagidinium*, *Spiniferites* and *Bitectodinium* represent the surface samples. However absence of fresh water algae like *Ankistrodesmus, Botryococcus* and thecamoebians like *Centropyxis* & *Arcella* species (Fig. 3) indicate more tidal flushing and seaward saline ecosystem.

Core No. –C4 (0-60 cm)

The sediment in this station is silty sand with poor mangroves although plantation of small seedlings of *Rhizophora* could be seen. Pockets of *Avicennia* and *Suaeda* plants were encountered in slightly raised surface of sandy land along the water channels. Patches of salty surface, devoid of vegetation is common in this part (Fig.3). Deposition of salts on the surface reveals that the substrate is generally exposed for longer duration facilitating high rate of water evaporation leaving behind the salts that have accumulated due to capillary action. Palynological study in the sediments from this station shows high percentage of Poaceae/Cyperaceae, fungal spores at the lower depth and dinoflagellate cysts like *Spiniferites mirabilis*, *Impagidinium aculeatum, Bitectodinium spongium, B. tepikiensis* and *Lingulodinium* species in the surface sediment indicating more marine influence (seaward zone) and low fresh water runoff. High per cent of salt tolerant *Suaeda* followed by *Avicennia* pollen in the surface sediment reveal high salinity zone.

Core No. – C5 (0-65 cm)

The sediment in this station is sandy silt and rich in TOM (2.7%). The TCC was low (0.9%). Absence of mangrove pollen at lower depths and moderate percentage of terrestrial pollen like *Casuarina*, Myrtaceae, *Excoecaria*, Sapotaceae, Meliaceae, Solanaceae, Combretaceae, Liliaceae and Palmae along with the fresh water algae like *Ankistrodesmus, Botryococcus* and Thecamoebians like *Centropyxis aculeata, Arcella megastoma*, *A. vulgaris*, *Trigonopyxis* and *Nebela* species all indicate very fluctuating stressed environment. The top sediments show high percentage of Rhizophoraceae pollen followed by *Excoecaria, Avicennia* and *Suaeda* with rare occurrence of other mangrove associates. The *Excoecaria* and terrestrial pollen taxa show a decrease in surface sediment.

Core No. – C6 (0-65 cm)

The sandy silt sediment from 0-5cm depth shows high percentage of both *Rhizophora* and *Avicennia* pollen along with *Suaeda* but at lower depth these are reduced (Fig.3). Foraminifera linings of *Ammonia* spp. indicate brackish water ecology at this depth and, fresh water algae like *Pediastrum* and *Botryococcus* show fresh water input. Species of *Centropyxis, Cyclopyxis* and *Arcella* were recorded throughout in the core suggesting regular influx of fresh water that diffused the salinity favouring thecamoebians (Fig.3). Terrestrial pollen show low percentage. The average TOM in 0-5cm depth is high (2.4%) as compared to deeper sediment from 20-60cm depth. The average TCC in the entire core is 0.7 %.

Core No. – C7 (0-50 cm)

The sediment in the entire 0-50cm core is clayey sand. The TOM was low (1.1 %) and TCC was high (1.4%). High percentage of terrestrial pollen and very low percentage of Rhizophoraceae pollen followed by Chenopodiaceae were recorded along with fungal and

algal spores throughout in the core. Fresh water algal forms like *Pediastrum,* abundant *Ankistrodesmus* and thecamoebians comprising of *Arcella megastoma, A. vulgaris, Centropyxis aculeata, Trinema* and *Trigonopyxis* species were recorded but shows absence of dinoflagellate cysts both in surface and sub-surface sediment. Results indicate a depositional environment influenced by fresh water influx. Although occurrences of copepod egg shells along with the increase in mangrove pollen and *Suaeda* species at 20-25 cm depth points to a shorter span of increased marine depositional environment. High percentage of copepod egg shells, stray foraminifera linings of *Epistominella, Cribroelphidium* and *Trochammina* along with the Dinoflagellate cysts of *Bitectodinium* at 45-50 cm indicate estuarine to marginal marine forms which could have been transported landwards during the 2004 Tsunami and survived due to increased salinity after the event.

Core No. – C8 (0-65 cm)

The sediment is clayey sand and the TOM ranges from 1.1 to 1.4% in the entire core. The TCC ranges from 0.5 to 0.8 %. The deeper sediment (25-30 cm) show high percentage of Sapotaceae, Myrtaceae, Malvaceae pollen taxa along with the fresh water algal matter (Fig.4). Foraminifera linings, dinoflagellate cysts and few radiolarian remains were present in this core at 60-65 cm depth similar to as in Core C7. However foraminifera linings and dinoflagellate cysts decrease in percentage in upper 0-30 cm samples. These surface core samples show increase in mangrove pollen and reduction in terrestrial pollen.

DISCUSSION

Abiotic variability in the ecosystem during pre and post monsoon is suggested to disrupt biological controls (Bakun, 2003) that allow drastic changes in phytoplankton community structure and the mangrove zonation. Besides the tidal influence, the fresh water influx during the monsoon period from August to October plays a major role responsible for ecological fluctuations in the Pichavaram estuarine ecosystem. Results show high percentage of autrotrophic and heterotrophic dinoflagellate cysts, foraminfera and thecamoebians indicating a considerable input of nutrients through precipitation and terrigenous sources during the monsoon period. The central part of the study area comprised of Pichavaram reserve mangrove forest (Z-I) is a stabilized ecosystem exhibiting a similarity in mangrove zonation favouring true mangroves like *Rhizophora* species in the permanently inundated lowlying areas fringing the back water channels followed by *Avicennia* and *Suaeda* species in highland (30-50 cm height) areas. The surface sediment in this zone reveal under representation of pollen grains of *Avicennia* followed by *Suaeda* and *Rhizophora* pollen. However, the highlands in Z-II are exposed to evaporation for most of the time during the year whereby, the salinity increases due to upward translocation of salts through capillary action. This zone constitutes salt-tolerant *Avicennia-Suaeda* community interspersed by white patches of salt-covered barren land. The pollen grains of *Suaeda nudiflora* characterized by suaedoid type of anatomy dominate here as compared to *S. maritima* and *S. monoica* characterized by austrobassioid type of anatomy (Fisher, 1997).

The increase in *Spiniferites mirabilis* during postmonsoon in most of the studied samples may be linked to an increase in anthropogenic eutrophication of coastal waters and increased load of nutrient concentrations of phosphate, and nitrate which has been documented earlier (Harland, 1983; Turon, 1984). A gradual increase in nitrate concentration and simultaneously decrease in dissolved oxygen (Anderson, 2002) often lead to dysoxic or anoxic depositional environment. Such a condition in the studied area perhaps favoured good preservation of organic matter in muddy, clayey/silty sediment. Study reveals that Z-I is sheltered and stable estuarine area fed by intermittent fresh water. While ecology in Z-II is more influenced by high salinity due to restricted fresh water influx, Z-III are influenced by intermittent mixing of fresh water and tidal water exhibiting fluctuating ecology that often creates stressed conditions for biotic forms particularly indicated by thecamoebians (Centropyxids).

Thecamoebians that dwell in fresh water ecosystem are highly sensitive to frequent changes in salinity in river mouths/estuarine areas (Patterson, 2002). Thecamoebian abundances increase with nutrient level and low salinity in the estuary, as observed in the Z-I and ZIII in the studied area. Therefore, it is evident that at present the water runoff between Vellar and Coleroon wetland is almost lateral running parallel to the shoreline favouring true mangroves in brackish water ecosystem. The Z-II in the Pichavaram estuary shows salinity more than 35 ppt (max. 39 ppt) in water and more than 10 ppt in the sediment soil solution suggesting low water runoff in the area. The luxuriant growth of mangroves is observed in water salinity ~22 ppt (Kathiresan, 2002) bestowed with either high annual direct precipitation and/or high surface water runoff from upland watersheds (Kathiresan, 1996).

At present no fresh water is discharged from the Vellar River into the Pichavaram mangrove wetland (Selvam, 2003) but it is the major source of saline water incursion into the mangroves. High percentage of foraminifers, tintinnids, radiolarians and dinoflagellate cysts recorded in Z-III do indicate sea water influx. It is inferred that due to the growing sand spit parallel to the coastline, the closure of river mouth during most of the time in the year near Chinnavaikal is restricting the water runoff in the eastern part of Pichavaram estuary inducing highly saline conditions (39 ppt) which in future may not be beneficial for true mangroves. At present monospecific patchy growth of *Avicennia* species lined by *Suaeda nudiflora* in its periphery is observed among barren patchy salty dry substrate with highest salinity (~35-39 ppt) unsuitable for any type of vegetation. Results from deeper sub-surface core samples reveal high percentage of terrestrial pollen taxa at lower depths indicating terrigenous input from open type of sparse hinterland vegetation. However, a gradual decrease in thecamoebians and terrestrial pollen grains in the surface samples as compared to the deeper sediments indicate reduction in fresh water input inducing increase in salinity.

Thecamoebian abundances reveal that the sub-rivers like Uppanar and Karungalar rivers along with the Khan Saheb canal drain fresh water in Z-1 and Z-III particularly during monsoons. As compared to the surface sediment, the sub-surface core samples show high percentage of fresh water thecamoebians indicating more fresh water input in the near past which has reduced in the recent years. Mangrove degradation in recent years have been reported earlier (MoEF, 1987) attributing it to diminishing fresh water inflow and increasing salinity. The water sample collected from most of the back water channels constituting Pichavaram mangroves show salinity greater than 32 ppt (parts per thousand) which reaches to about 39 ppt in Z-II. The beach area is under erosion in many places and spits are observed near Coleroon and Uppanar mouth. Mudflats are observed in between mangrove vegetation in the hightidal, intertidal and subtidal zone (Krishnamoorthy, 1997). These are associated with less wave energy zones and constitute salt-tolerant *Avicennia-Suaeda* plants. Sparse stunted and degraded mangroves are present on these mudflats near mouth of Vellar river, bank of Uppanar and Near Coleroon riverbank which are gradually increasing in area indicating reduced water runoff. As a result nearly 5.93 sq. km, of this wetland are occupied by halophytic vegetation like *Suaeda nudiflora*, 2.63 sq. km by barren mud flats and 12.38 sq. km by barren high saline soil. Of this, the mangrove wetland occupies only 11.00 sq.km., comprising the entire mangrove vegetation located in the middle portion of the Vellar-Pichavaram-Coleroon wetland which has been declared a reserved forest by the Department of Forest, Government of Tamil Nadu. Dominance of salt-tolerant vegetation (*Avicennia-Suaeda*) interspersed between barren salty substrate all along the east coast is an alarming situation.

CONCLUSIONS

1. Fresh water thecamoebians dominate in the landward Z-I and Z-III suggesting water runoff parallel to coastline.

2. The brackish water-freshwater ecology suitable for mangroves is in Z-I and Z-III which constitute the Pichavaram mangroves. However, the salinity of water samples is

greater than 32 ppt. attributed to restricted fresh water discharge and also closure of sea water inlet during most of the time in the year.

3. Highly saline Z-II is seawards near the mouth indicating restricted fresh water flow through the present river mouths due to growth of the sand spit parallel to the shoreline. Salt pans are fast developing in this zone intermixed with *Avicennia- Suaeda* scrubs.

4. Palynological study reveals underrepresentaion of *Avicennia* pollen in the surface sediment despite the abundance of these plants in the area. *Suaeda* pollen is overrepresented followed by *Rhizophora* pollen. *Excoecaria* pollen was comparable to its present day cover. Other mangrove pollens are absent despite its presence in the area.

5. The geomorphology of the river mouth and sedimentation process accompanied by fresh water discharge in the coastal wetland play a vital role in mangrove protection and conservation.

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