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Research Article

ECOLOGICAL CHANGES IN PICHAVARAM ESTUARY DURING THE LAST 4 MILLENNIUM

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ABSTRACT
Analysis of sediment texture, thecamoebian assemblage and salinity of the sediment cores from three different sites in the Pichavaram Estuary has provided a palaeoecological record that covers the past 4000 yrs. Changes in sediment composition and salinity along with thecamoebian frequencies are assumed to represent variations in freshwater inflow to the estuary. Two major climatic periods are inferred in all the studied cores which include a basal lotic depositional environment due to occasional high tidal influx and freshwater input from land during the strengthened monsoon condition in the 3rd and 4th millennium and a relatively stable period with a lentic depositional environment responding to the weakening of monsoon since the 2nd millennium. The most recent period of high-salinity is primarily due to the upstream storage of water and diversion due to anthropogenic activities. The earlier high salinity condition is likely the result of reduced precipitation causing landward intrusion of sea water could be attributed to sedimentation pattern coupled with estuarine configurational changes influenced by fluctuations in climatic changes which affected the relative sea level.

Key Words: *Thecamoebians, Pichavaram, depositional environment, freshwater, India*

INTRODUCTION
Thecamoebians (testate amoeba) are a varied group of testate rhizopods existing in aquatic to moist environment and occur usually worldwide in a range of freshwater, slightly brackish environments and salt marshes (Medioli and Scott, 1988; Patterson and Kumar, 2002; Charman et al., 2002). Studies of testate amoebae are accounted from Canada, Europe, Africa and China etc. (Kumar and Dalby, 1998; Yang and Shen, 2005; Lahr and Lopes, 2006), South America (Vucetich, 1978), Brazil (Lansac-Toha et al., 2001). Ecological tolerances of these thecamoebians in different regions have been studied (Booth and Zygmunt, 2005). They are the potential proxies to examine the ecological fluctuations (Ellison, 1995; Patterson and Kumar, 2002; Lahr et al., 2006). The record of thecamoebians from Indian ecosystems is vivid in nature (Das and Chattopadhyay, 2003). Most of the studies have been centered on higher latitudes and a few records are from the tropical zone (Roe and Patterson, 2006). Farooqui and Gaur (2007) reported the palaeoclimatic and palaeosealevel data based on thecamoebians from the Harappan site in Porbander and Bet Dwarka in Gujarat. River mouths are subjected to recurrent salinity changes depending on the interaction of tidal influx and the fresh water input from land. The river systems in the east coast of India are basically monsoon driven and as such the sediments embedded in their deltas are measured as excellent repositories of past monsoon records to which the biotic forms have responded. Thus freshwater thecamoebians preserved in the sediment are suitable proxy for monitoring climate and ecological changes. There are records of intermittent relative sea level rise and fall during Late Holocene from Pulicat lagoon and other contemporary sites along the east coast (Banerjee, 2000; Farooqui and Vaz, 2000). But the data for Late Holocene relative sea level fluctuations from the Cauvery delta is still not adequate. The vertical and horizontal changes in the thecamoebian grouping in the sediments responding to environmental changes during Late Holocene brought on by external factors like relative sea level and climate was studied from the mouth of the Cauvery River. This work makes use of the potentials of fresh water thecamoebians as proxy for monitoring ecological changes in the river mouth in order to infer sea level and climatic fluctuations. The study also aspires in understanding the thecamoebian

Research Article

tolerance/susceptibility in the fluctuating sub-optimal estuarine ecosystem which is a significant input to the limited database from India.

Study Area

The Pichavaram mangrove wetland (11°25' N and 79° 47' E) which is spread irregularly in the Cauvery Delta, is a shallow estuarine complex sandwiched between two prominent estuaries, the Vellar estuary in the north and Coleroon estuary in the south with a total area of 1,400 ha (Tissot 1987). This mangrove forest is influenced by the sea water from the Bay of Bengal, brackish water from Vellar, Coleroon estuaries and fresh water from Uppanar and an irrigation canal called the Khan Sahib Canal. Pichavaram experiences a tropical monsoon climate and shows the dry period generally stretched over 6 months.

The geomorphology of the ecosystem is typically covered by flood plain, sedimentary plain and beach sand. Most of the soil along the western part is alluvium whereas fluvial marine and beach sand rules in the eastern part. The climate is sub-humid and the ratio of precipitation to evapo-transpiration (P/Etp) ranges from 0.5-0.75 (Selvam, 2003) with maximum precipitation during the northeast monsoons. The annual temperature variation is 18.2-36ºC. The biogeochemical processes in this ecosystem are governed by a heavy input of sediments and anthropogenic releases from the Vellar and Coleroon River. Uppanar River and Khan Saheb Canal add the discharge during monsoon season. The main cause of the changed landscape in the recent past is perhaps the introduction of irrigation and hydrological works in the rivers of the Cauvery delta system, which caused the change in water supply. This resulted in a decrease in water discharge downstream in the river. Thus the recent environmental changes in this area were not due to natural climatic development, but can be attributed to human activities.

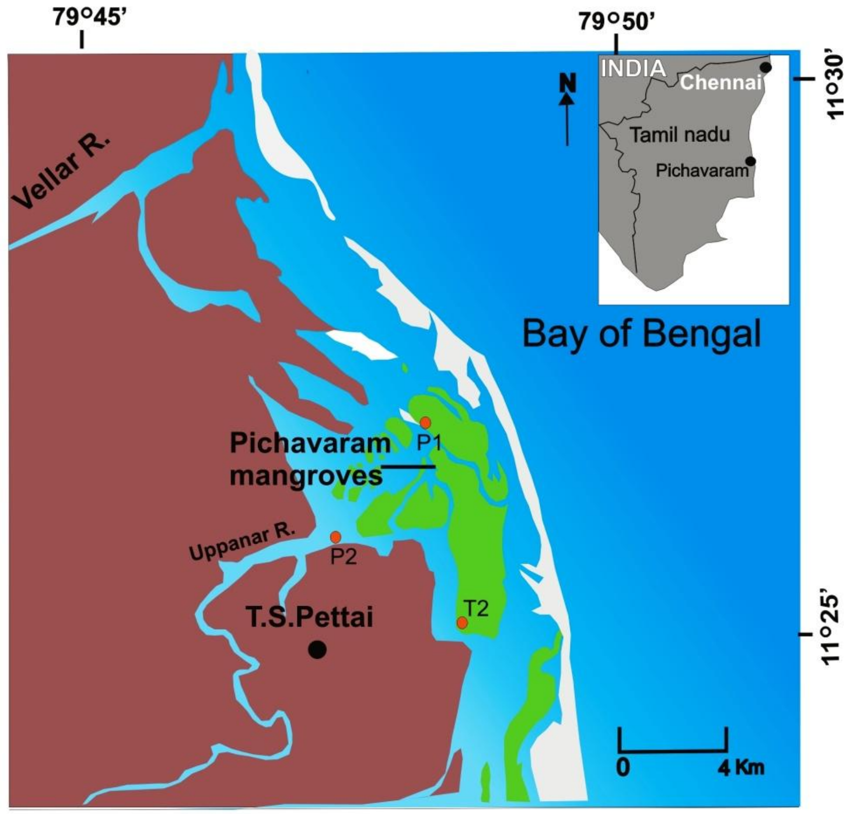

Fig 1. Map of the Pichavaram Mangrove (India) showing the sampling locations

MATERIALS AND METHODS

Three sediment cores located between Latitude 11°26'701" N to 11°24'728" N and Longitude 79°48'033" E to 79°48'280" E were collected and studied from the swampy area as well as from the

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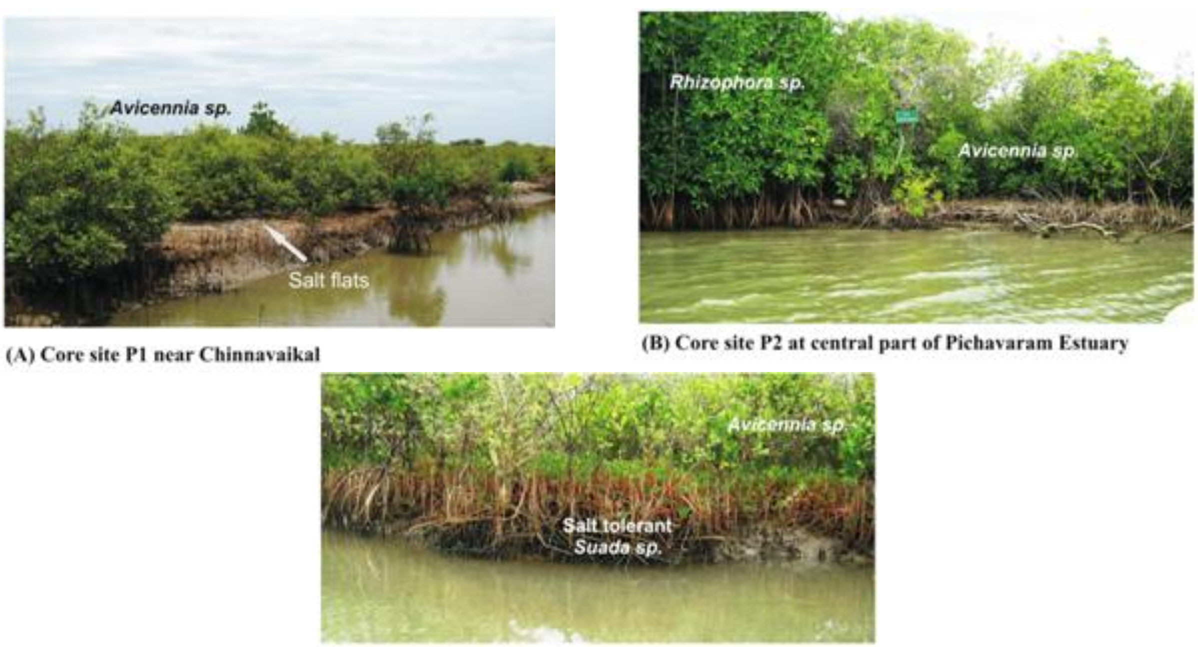
exposed land with an objective to understand the salinity pattern in both the environments which was visually distinguishable by the vegetative pattern. Core P1 is 200 cm deep obtained from the estuarine area at the mouth of the Uppanar River, close to Chinnavaikal. Core P2 is 250 cm deep located in the central part of Pichavaram estuary and is mainly inhabited by *Avicennia officinalis, A. marina and Suaeda sp.* with fringes of *Rhizophora sp*. along the backwater channel. T2 which is a 500 cm deep core located south of Pichavaram close to the village TS Pettai had a habitat alike as observed in P2 area. The sediment cores were retrieved using hand operated augur cum piston corer (Eijelkamp, Netherlands). Immediately, after collection the cores were sub-sampled at 2cm and 5cm interval, respectively. The samples were stored in air-tight polythene bags without any preservative. ^{14}C dates of the organic carbon were obtained from Birbal Sahni (BS) Institute of Palaeobotany, India and calibrated following Stuiver et al. (1998). In laboratory sediment color was known using Munsell color chart (Munsell and Farnum, 2004) and texture was analyzed on the basis of percentage of sand in the sediment following soil density method (USDA, 1992). Salinity was calculated in 10g of air dried soil sample dissolved in 100ml of deionized water. The samples were homogenized for 30 minutes before measuring the salinity using 'Orion-5 star (Thermo-Orion, Scientific Equipment, USA) at standardized 25ºC temperature. The thecamoebians were isolated from soil samples in laboratory. Samples were boiled in distilled water for 10 minutes and passed through 250 mesh size (175 µm). Thereafter, the samples were treated in a series with glacial and anhydrous acetic acid in order to reduce the opacity of the thecamoebians to study it under high power transmitted light microscope (Olympus BX-52). The material was subsequently caught in the 600 mesh size (10 µm) was stored in glycerol. Slides were prepared, and all testate amoebae were identified and counted in the processed 10 g samples. The thecamoebian spectra prepared is the percentage of total counts in the air dried 10 g sample.



(A) Core site P1 near Chinnavaikal

(B) Core site P2 at central part of Pichavaram Estuary

(C) Core site T2 at TS pettai mangrove wetland

Fig. 2 Showing the vegetation at the Core sites

RESULTS

Lithology and Radiocarbon dates

The core P1 towards the mouth of the river comprises of sand (85.3%), silt (5.3%) and clay (6.1%) sediment with a Munsell color code of 5Y4/2 at the bottom from 200-120 cm depth. This sandy zone was overlaid by top 120 cm sandy clay having clay (74.3%), silt (4.9%) and sand (20.4%) with a Munsell color code of 5Y3/2 (Table 1). The sediment from 80-100 cm dates back to 2430 cal yrs BP and from 35-55 cm depth to 1760 cal yrs BP (Table 1). The heterogeneous type of sediment in the bottom zone of Core P2 (250-120 cm) is dominated by blackish to brown (5Y2/2) silty clay punctuated by four broad to thin bands of brownish (5Y4/2) fine sand (Fig. 3). The clayey bands constitute clay (85%), silt (10%) and sand (5%). The intermittent bands of sand constitute sand (60-85%) with low silt and clay content. The zone (120-85 cm) is of a short interval and the sediment is brownish (5Y4/2) fine to coarse sand constituting about 93.2 % sand. Fine blackish to brown (5Y3/2) sticky sediment in the top zone (85-0 cm) constitutes an average of clay (86%), silt (3.7%) and sand (10.4%). The Radiocarbon age at 250 cm depth is 3700 cal yrs BP and at 55-80 cm is 590 cal yrs BP. The core T2 bottom zone (500-220 cm) is dominated by brownish (5Y3/4) silty sand comprising of sand (79.8%), silt (5.0 %) and clay (15.2%), interspersed by six broad to thin bands of blackish to brown (5Y4/2) fine sticky clay. These intermittent bands of clay constitute clay (76%), sand (15%) followed by silt (9%). This zone is overlain by a blackish to brown (5Y3/2) sandy clay in the upper 220 cm sediment constituting clay (79.5%), silt (5.2%) and sand (15.2%). The Radiocarbon date at 240-260 cm is 3630 cal yrs BP, 95-100 cm is 2750 cal yrs BP and 20-25 cm is 1190 cal yrs BP.

Table 1. Soil Texture, color and Radiocarbon dates of the studied cores from Pichavaram Estuary

Core P-1			Core P-2			Core T-2		
Depth in cm	Clay Silt Sand Percentages	Color	Depth in cm	Clay Silt Sand Percentages	Color	Depth in cm	Clay Silt Sand Percentages	Color
0-120	74.3 4.9 20.4	5Y3/2	0-85	86 3.7 10.4	5Y3/2	0-220	79.5 5.2 15.2	5Y3/2
120-200	6.1 5.3 85.3	5Y4/2	85-120	Low Low 93.2	5Y4/2	220-500	15.2 5 79.8	5Y3/4
35-55	1760 (yrs BP) BS-3215		120-250	85 10 5 Low Low 60-85	5Y2/2 5Y4/2	20-25	1190 (yrs BP) BS-3191	
80-100	2430 (yrs BP) BS-3206		55-80	590 (yrs BP) BS-3200		95-100	2750 (yrs BP) BS-4016	
			250	3700 (yrs BP) BS-3199		240-260	3630 (yrs BP) BS-4014	

Thecamoebian Assemblage and salinity

On the basis of thecamoebian succession and salinity status, two major climatic phases were identified.

Core P1: The low percentage of fresh water thecamoebians such as *Arcella megastoma* (26.6%) and *Nebela* (5.1%) with an average salinity of 2 indicates a fresh water lotic depositional environment recorded prior to 2430 cal yrs BP (Phase I). An overall dominance of thecamoebian like *Centropyxis corona, Arcella vulgaris, A. artocrea* (48.7%) and *Nebela* (19.6%) that prefer lentic ecosystem indicate a shift from the lotic system in Phase II. The average salinity in Phase II (after 2430 cal yrs BP) is 3.4 particularly associated with a high percentage of clay deposited around 1760 cal yrs BP (Fig 3).

Core P2: Phase-I: Fig 3b shows a heterogenous type of sediment with a similar trend in the percentage of thecamoebians and salinity. The average salinity measured in this Phase (200-250 cm) is 3.5 with an average of 3 in the clayey fractions and 1.2 in the sandy bands. A good percentage of thecamoebians including *Centropyxis aculeata, C. corona, C. constricta* (48.7%), *Arcella megastoma, A. vulgaris* (8.7%) and *Nebela* (4.0%) were recorded (Fig. 4) in the fractions with lower salinity whereas absence/ decline of

Centropyxis spp. (6.3%) and *Arcella* (1.0%) in the sediment with higher salinity. The sediment in Phase II shows signatures of *Centropyxis spp.* (24.2%), *Arcella* (4.8%) and *Nebela* (2.3%) with an average salinity of 2.6 around 590 cal yrs BP.

Core T2: Phase-I: A low percentage of thecamoebians like *Centropyxis spp.* (21.8%) and *Arcella spp.* (13.0%) with an average salinity of 0.6 indicates a lotic condition in the estuary in Phase I around 4450 cal yrs BP (Fig.3c). A comparatively good percentage of *Centropyxis corona*, *Centropyxis aculeata* (40.3%), *Nebela* (11.8%) and *Arcella* (13.1%) in the clay-dominated Phase II with an average salinity of 1.5 show a lentic depositional environment after 3000 yrs BP.

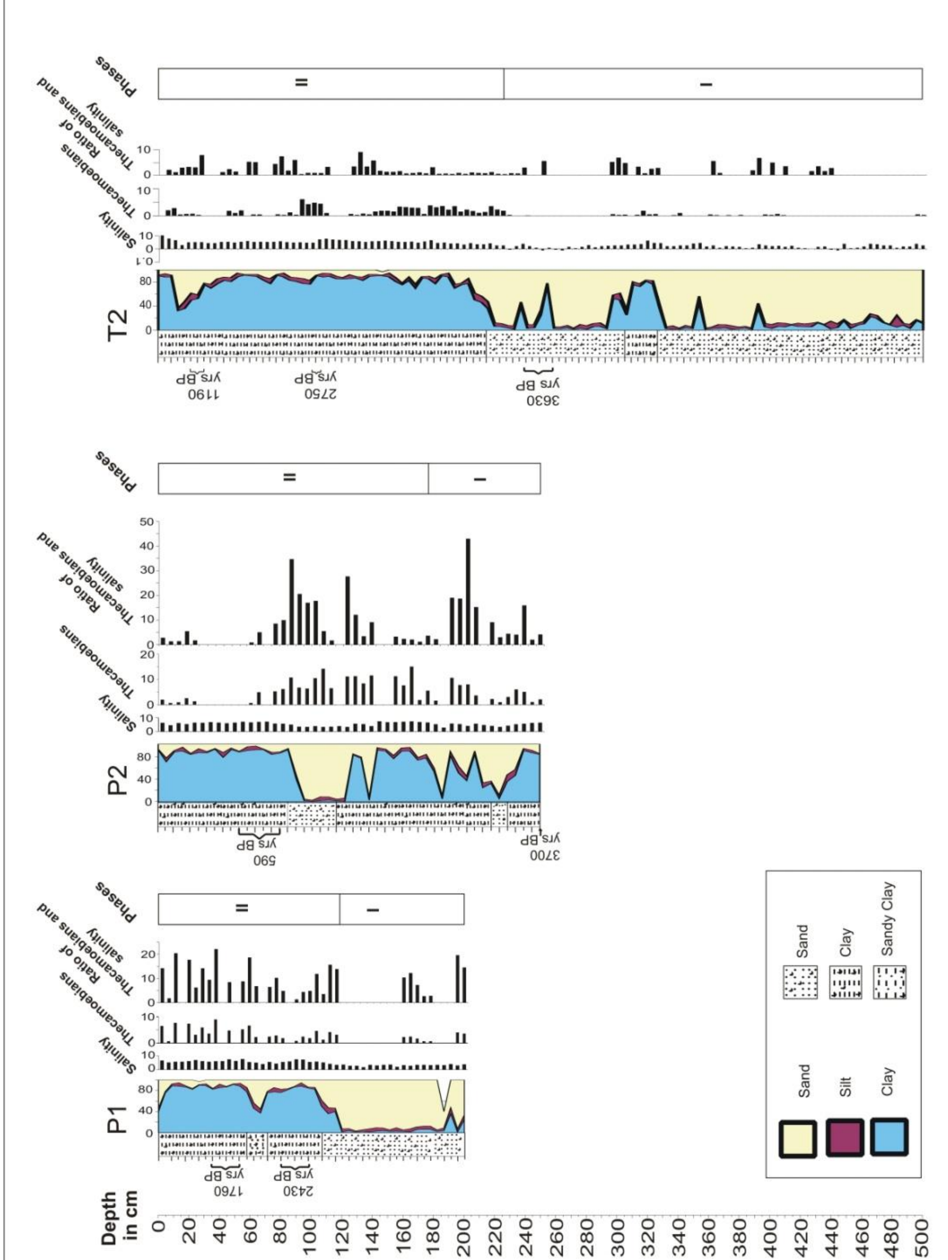


Fig. 3 Sediment Analysis, Salinity and percentage of Thecamoebians of the cores from Pichavaram Estuary

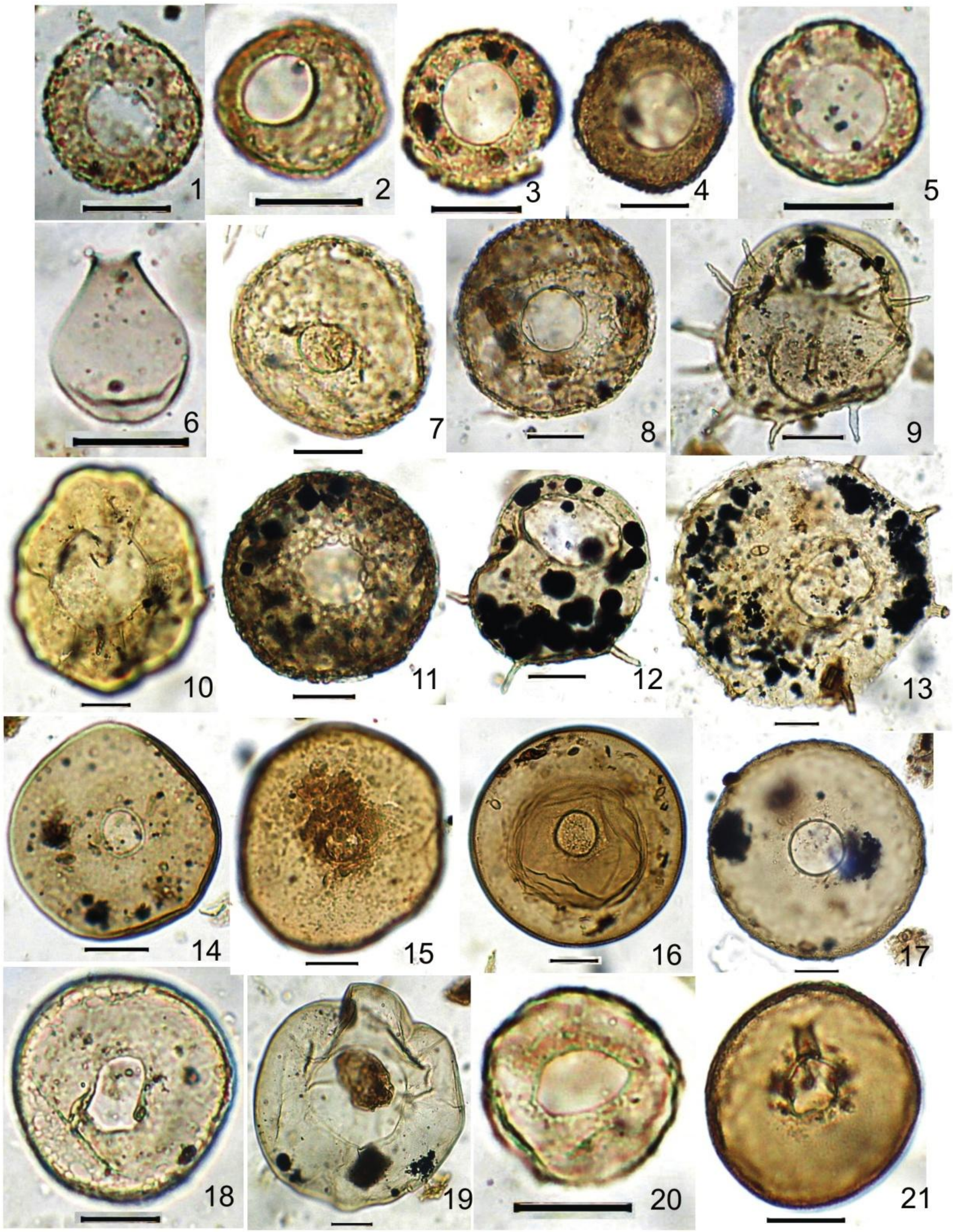


Figure 4.- 1,2,3,4,5.*Arcella megastoma*; 6.*Nebela*; 7,8.*Arcella spp*.; 9,13.*Centropyxis aculeata*; 10.*Arcella spp*.; 11.*Centropyxis corona*; 12.*Centropyxis constricta*; 14,15,16,17.*Arcella artocrea*; 18,19.*Arcella vulgaris*; 20,21.Unidentified species. Scale=10 microns Legends: Light Microscopic photographs of thecamoebians.

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DISCUSSION

The present study reveals a low percentage of thecamoebians in the heterogenous sediment constituting coarser sand embedded with occasional bands of fine sticky clay indicating a lotic unstable depositional environment perhaps due to occasional high tidal influx and freshwater input from land during the strengthened monsoon condition in the early part of Late Holocene in Phase I (~3500 yrs BP). A low salinity in the aqueous soil solution is also attributed to the strong fluvial activity during this phase which led to the deposition of coarse sand, having larger pore sizes between soil particles causing downward leaching of salts with low accumulation of salts and less preservation of organic matter including thecamoebians. On the other hand a high percentage of thecamoebians in the fine clay-dominated sediment in Phase II (during and after 2000 yrs BP) indicates a lentic fresh water depositional environment. Thecamoebians are known to be associated with aquatic vegetation and algae (Medioli and Scott, 1983) in lentic ecosystem. High salinity during the phase is attributed to the deposition of fine clay sediment with smaller pore sizes between the soil particles and an affinity for salts due to the development of strong aggregates which do not allow significant leaching of salt particles. This increase in salinity of the soil is alarming and is caused by the ingress of sea water and accumulation of capillary driven salts probably either by percolation from surface inundation or through translocation from stratified water columns in the backwater channels (Farooqui, 2010). The regular high peaks of thecamoebians shows monsoonal variability with rhythmic climatic changes in the span of 100 years. The thecamoebians proliferated during the time of monsoonal recharge when the salinity also got diluted and during the tidal influx the cysts of these thecamoebians remained preserved in the fine clay sediment. Therefore it is inferred that the fluvial process in the river system was weak perhaps responding to weakening of monsoon and drier climate. Several records through different proxies from Asia and Africa show a severe and long-lasting drought throughout Middle-Late Holocene (Booth et al. 2005; Kaniewski et al. 2008). A gradual weakening in the Asian summer monsoon between 3700 cal yrs BP and 1500 cal yrs BP have been reported from low and mid latitudes in India and China (Selvaraj et al. 2008; Liu et al. 2009), and is generally interpreted as a response to decreasing summer insolation (Overpeck et al. 1996). High seasonality leading to an increase in the number of dry months also causes an increased salinity condition which is attributed to the lentic ecosystem during most of the time in the year whereas during the monsoonal recharge the salinity gets diluted resulting into the growth of thecamoebians. Any change in salinity or related abiotic factors is reflected by the variability/extinction of these thecamoebians indicating palaeoecological changes (Patterson and Kumar, 2002). The sediment characterized by dominance of fresh water thecamoebians suggests a fresh water depositional environment and the salinity in the aqueous soil solution ranging from 1-2 (Farooqui and Naidu, 2010). However, salinity up to 3 in the aqueous soil solution shows comparatively lower percentage of thecamoebians. Therefore, it is inferred from the present study that the thecamoebians show sensitivity to salinity exceeding 3.

Conclusions

The thecamoebian succession and salinity status in the sediments from the Pichavaram Estuary disclose the depositional environment during Late Holocene since 4000 yrs BP. The river remained an active channel between ~4000 to 3000 yrs BP, responding to the strengthened monsoon during which there was wide fluctuation in the presence of thecamoebians along with salinity due to a lotic ecosystem indicating an unstable depositional environment. After this period the fresh water thecamoebians dominated indicating lentic/shallow ecosystem with a stable estuarine condition. The salinity status during the past millennium indicates fluvio-marine sediment deposition suggesting recent landward intrusion of sea water. Thecamoebians here show sensitivity to high salinity in the aqueous soil solution exceeding 3. These thecamoebians are short lived and readily tend to preserve its thecate body in salinity up to 4. Its dominance and absence in the sediments from the river mouth/estuaries serve as suitable proxy for monitoring short-term high resolution palaeoecological fluctuations particularly in coastal ecosystems.

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REFERENCES
Banerjee P K (2000) Holocene and Late Pleistocene relative sea level fluctuations along the east coast of India; *Marine Geology* **167** 243-260.
Booth R and Zygmunt J (2005) Biogeography and comparative ecology of testate amoebae inhabiting *Sphagnum* dominated peatlands in the Great Lakes and Rocky Mountain regions of North America; *Diversity Distributions* **11** 577-590.
Booth R K, Jackson S T, Forman S L, Kutzbach J E, Bettis E A, Kreig J and Wright D K (2005) A severe centennial- scale drought in mid-continental North America 4200 years ago and global linkages; *The Holocene* **15** 321-328.
Charman D, Roe H M and Gehrels W R (2002) Modern distribution of saltmarsh testate amoba: regional variability of zonation and response to environmental variables; *Journal of Quaternary Science* **17**(5-6) 387-409.
Das A K and Chattopadhyay P (2003) Morphology, Morphometry, and Ecology of Moss Dwelling Testate Amoebae (Protozoa: Rhizopoda) of North and North-East India: Rhizopoda) of North and North-East India; *Memoirs of* the *Zoological* Survey *of India* **vii** 530.
Ellison R (1995) Palaeolimnological analysis of Ullswater using testate amoebae; *Journal of Palaeolimnology* **13** 51-63.
Farooqui A (2010) Salt water intrusion, metal accumulation and mangroves along the Pednapatnam, Machlipatnam coastline, Andhra Pradesh, India; *Journal of Applied Geochemistry* **12**(1) 126-138.
Farooqui A and Gaur A S (2007) Arcellaceans and pollen/spores of a late Harappan settlement near Porbandar, west coast of India: Implications for palaeoecology and environmental monitoring; *Current Science* **92**(7) 992-998.
Farooqui A and Naidu T Y (2010) Thecamoebians and Palynological assemblage in Gautami- Godavari River mouth, India: Environment and sea level since 3000 years; *Journal of Geological society of India* **75** (June) 841-850.
Farooqui A and Vaz G G (2000) Holocene sea- level and climate fluctuations: Pulicat lagoon- A case study; *Current Science* **79**(10) 1484-1488.
Kaniewski D, Paulissen E, Van Campo E, Al-Maqdissi M, Bretschneider J and Lerberghe K V (2008) Middle East coastal ecosystem response to middle-to-late Holocene abrupt climatic changes; *PNAS* **105**(37) 13941-13946.
Kumar A and Dalby A P (1998) Identification key for Holocene lacustrine Arcellacean (thecamoebian) taxa; *Palaeontologia Electronica* 1-39.
Lahr D J G, Sônia G B C and Lopes S G B C (2006) Morphology, Bimetry, Ecology and Biogeography of Five Species of Difflugia Leclerc, 1815 (Arcellinida: Difflugiidae), from Tiete River, Brazil; *Acta Protozoologica* **45** 77-90.
Lansac-Tôha F A, Velho L F M, Zimmermann-Callegari M C, Bonecker C C and Takahashi E M (2001) On the occurrence of testate amoebae (Protozoa, Amoebozoa, Rhizopoda) in Brazillian inland waters. III. Family Difflugiidae: Genus *Difflugia*; *Acta Scientiarum* **23** 305-321.
Liu X, Dong H, Yang X, Herzschuh U, Zhang E, Stuut, Jan-Berend W and Wang Y (2009) Late Holocene forcing of the Asian winter and summer monsoon as evidenced by proxy records from the northern Qinghai-Tibetan Plateau Earth Plant; *Science Letters* **280**(1-4) 15 April 276-284.
Medioli F and Scott D (1988) Lacustrine thecamoebians (mainly Arcellaceans) as potential tools for paleolimnological interpretations; *Palaeogeography, Palaeoclimatology, Palaeoecology* **62** 361-386.

Medioli F S and Scott D B (1983) Holocene Arcellacea (Thecamoebians) from eastern Canada; *Cushman Foundation For Foraminiferal Research Special Publication* **21**.
Munsell A H and Farnum R B (2004) A color notation: An illustrated system defining all colors and their relations 1941. *Kessinger Publishing*.
Overpeck J, Anderson D, Trumbore S and Prell W (1996) The southwest Indian monsoon over the last 18,000 years; *Climate dynamics* **12** 213-225.
Patterson R T and Kumar A (2002) A review of current testate rhizopod (thecamoebian) research in Canada; *Palaeogeography, Palaeoclimatology, Palaeoecology* **180** 225-251.
Roe H M and Patterson R T (2006) Distribution of thecamoebians (testate amoebae) in small lakes and ponds. Barbados, West Indies; *Journal of Foraminiferal Research* **36**(2) 116-134.
Selvam V (2003) Environmental classification of mangrove wetlands of India; *Current Science* **84** 757–765. CSA
Selvaraj K, Chen C T A. and Lou J Y (2008) Holocene East Asian monsoon variability: links to solar and tropical Pacific forcing; *Climate of the Past Discussions* **4** 929-953.
Stuiver M, Reirner P J and Braziunas T F (1998) High-precision radiocarbon age calibration for terrestrial and marine samples; *Radiocarbon* **40** 1127-1151.
USDA (1992) Soil Conservation Service; *Soil Survey Laboratory Methods Manual. United States Dept. of Agriculture, Soil Survey Investigation* Report. No. **42**. Washington DC.
Vucetich M C (1978) Nuevos aportes al conocimiento de los tecamebianos del dominio subtropical; *Neotropica* **24** 79-90.
Yang J and Shen Y (2005) Morphology, biometry and distribution of *Difflugia biwae* Kawamura, 1918 (Protozoa: Rhizopoda); *Acta Protozoologica* **4.**