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NEAR-SHORE FORAMINIFERA ALONG THE PALK STRAIT, SOUTHEAST COAST OF INDIA, TAMIL NADU

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ABSTRACT

Palk Strait forms a part of the prograding micro delta, and the benthic foraminifera assemblages are influenced both by the fresh and marine water influxes. To delineate the various benthic foraminifera species 40 sea bottom water and sediment samples at a water depth range of 0.5 to 6.5 m were collected during May 2015 from the near-shore environment to characterize the various benthic foraminifera. Environmental parameters such as water depth, pH, dissolved oxygen, salinity, $CaCO_3$, organic matter, sand, silt, and clay contents were determined. Benthic foraminifera separated from the sediment samples, yielded 92 species belonging to 47 genera, 25 families, 13 super-families, 21 sub-families, 5 sub-orders, and 5 orders. Out of the total population count of 12,587 specimens, 1044 were observed stained by Rose Bengal and these were living at the time of sample collection. *Ammonia beccarii* (Linnaeus, 1758) was observed to be the most abundant in the study area, followed by *Pararotalia nipponica* (Asano, 1936) and *Ammonia tepida* (Cushman, 1926). Species such as *Adelosina intricate, Spiroloculina robusta, Quinqueloculina venusta, Quinqueloculina schlumbergeri, Pseudotriloculina rotunda, Uvigerina senticosa, Fursenkoina pontoni, Elphidium delicatulum* and *Elphidium norvangi* were previously not reported in the study area.

Keywords: Foraminiferal distribution, ecology, textural study, Palk Strait, SE coast of India.

INTRODUCTION

Foraminifera are marine protoctists with the mineralized test, widely spread in sediments all over the world with more than 40,000 cited species (Loeblich and Tappan, 1987) owing to their abundance in the geological records from the Cambrian (>500 million of years) to the present time. They are commonly used by the micropaleontologists for reconstructing biostratigraphy, paleoclimate and stratigraphic correlations. Benthic foraminifera is increasingly used as environmental bio-indicators of pollution in coastal and marginal marine settings. Because of their high sensitivity to environmental conditions, they are increasingly used for ecological and paleoecological studies all over the world (Samir *et al*., 2003; Scott *et al*., 2005). Numerous studies have shown that the distribution of benthic foraminiferal assemblages can be related to several environmental and sedimentological conditions (Setty and Nigam, 1982; Khare *et al.*, 1995). The response of foraminifera to the changed environmental conditions is reflected in the variation in the abundance and morphology of the test. The foraminiferal test has high preservation potential, thus making these micro-organisms one of the most useful proxies for the long as well as short-term temporal variation in the amount and type of toxins in all kinds of marine environments, especially the near-shore coastal areas. Their community structure provides useful information on the general characteristics of the environment quality and as species are sensitive to specific environmental parameters (e.g., Alve, 1991, 1995; Yanko *et al*., 1994, 1999; Coccioni, 2000; Samir, 2000; Debenay *et al*., 2001, 2005; Geslin *et al*., 2002; Coccioni *et al*., 2003, 2005; Armynot du Châtelet *et al*., 2004; Coccioni and Marsili, 2005; Abbas and Achyuthan, 2011; Frontalini and Coccioni, 2008; Cherchi *et al*., 2009; Frontalini *et al*., 2009; Thilagavathi *et al*., 2012; Sundara Raja Reddy *et al*., 2012; Rajeshwara Rao *et al*., 2013; Tabita and Senthil Nathan, 2014; Jeyabal *et al*., 2015; Jeshma *et al*., 2016; Suresh Gandhi *et al*., 2017; Anbuselvan and Senthil Nathan, 2018).

Palk Strait is strategically an important channel in the East coast, Tamil Nadu. The coastal ecosystem of this strait is endangered by the shallowing nature of the bay because of sedimentation (Gandhi, 1999; Jena *et al*., 2001; Mohan *et al*., 2000; Kumar *et al*., 2000). Palk Strait is influenced by major drainage patterns, tributary of River Cauvery, which transports large amounts of terrigenous sediments into the shelf, producing coastal shoal and near the coast by marine tidal waters. The benthic foraminiferal distribution along the east coast Tamil Nadu has been reported by many workers (Bhalla and Kathal 1998; Kathal, 2002; Kumar and Manivannan, 2001; Suresh Gandhi *et al.,* 2002; Suresh Gandhi and Rajamanickam, 2004; Abbas and Achyuthan, 2011; Thilagavathi, 2012; Suresh Gandhi *et al.*, 2017). Moreover, to acquire a better knowledge of the past ecological conditions, it is essential to study the present ecology of the Recent benthic foraminifera and their species abundances. This is because assessing the distribution of Recent forms in the present-day settings helps to decipher the factors influencing their assemblages, structure and composition. The main purpose of this study is to delineate and understand the distribution pattern of benthic foraminifera and their dominant benthic groups in the study area.

STUDY AREA

The study area is located in southern part of Palk Strait (Fig.1) from Mandapam (9°16’43.83” N-79° 6’54.09”E) to Kottaipattinam (9°58’11.30”N- 79°11’58.40”E) connecting with Gulf of Mannar towards the south and Point Calimer and Bay of Bengal towards the north. It is bounded by Sri Lanka on

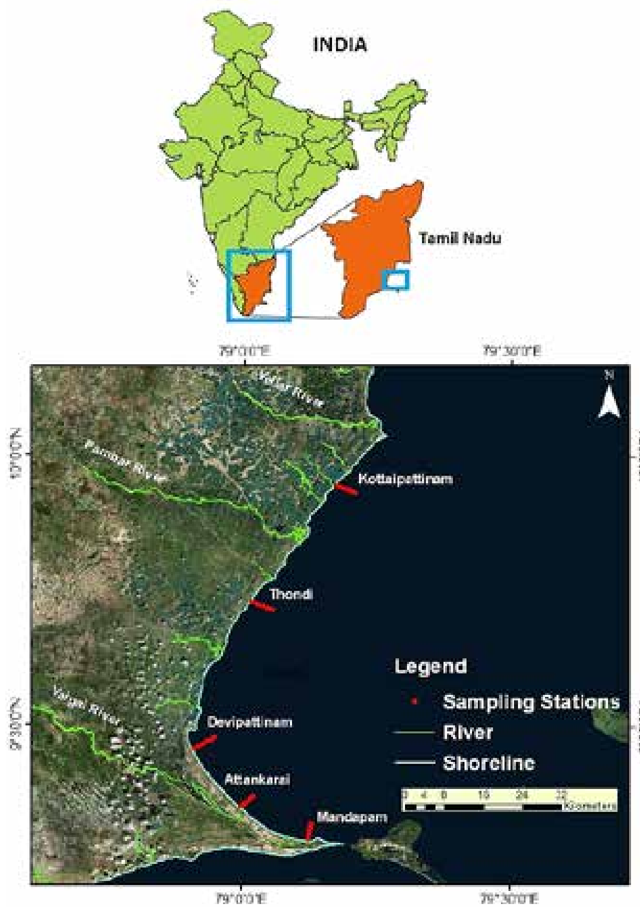


Fig. 1. Location map of the study area and sediment sample collection.

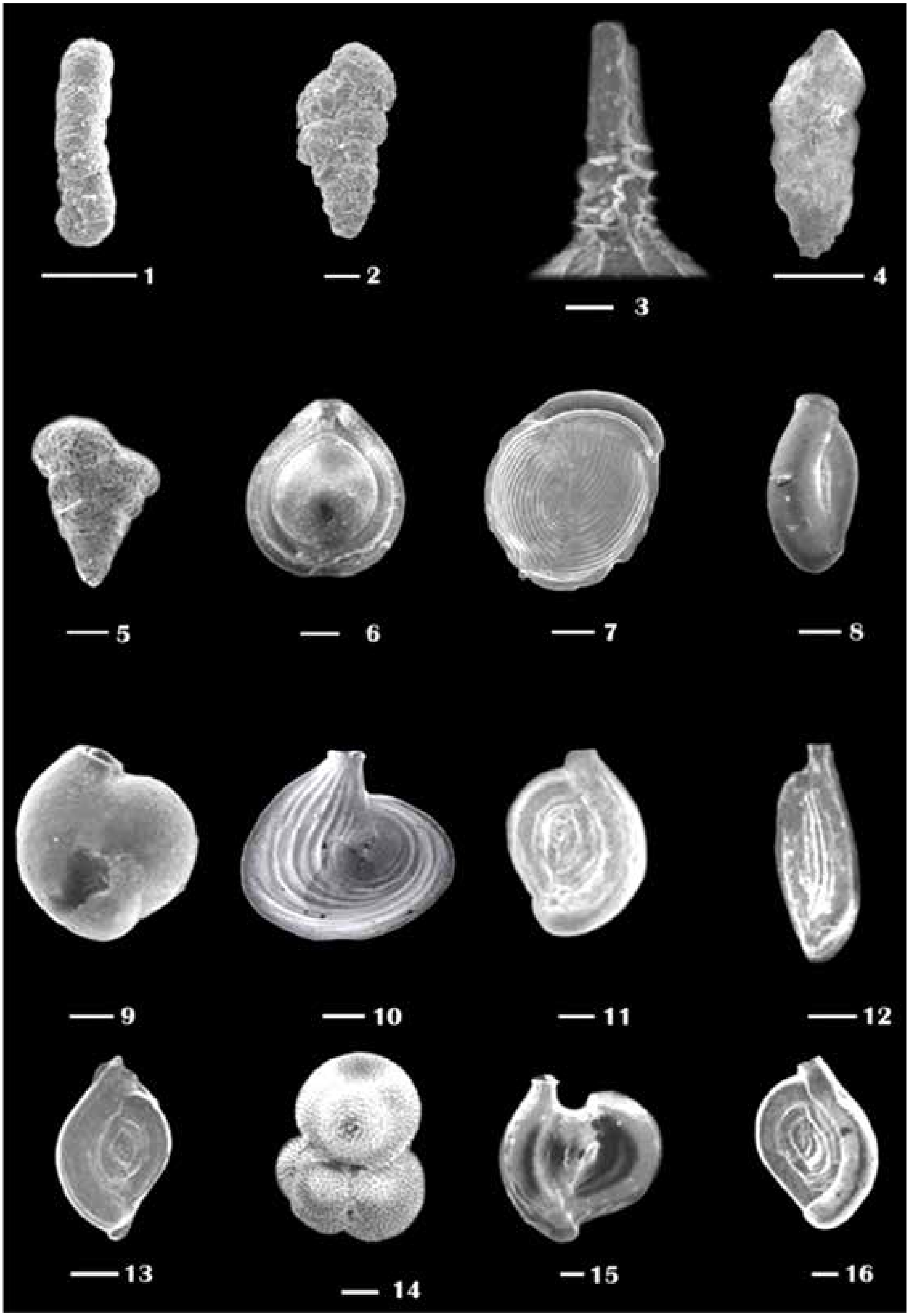
the east and coastal districts of Tamil Nadu State on the west. It is approximately 100 km coastal length and covers the coastal stretch of Ramanathapuram district. The maximum rainfall is received during the north-east monsoon period of October–November and summer showers are received during the month of April–May to the tune of 79–90 cm/year. The Ramanathapuram district the rainfall is erratic even during the monsoon season, the average rainfall in the district is 839.5 mm; the monthly average temperature is 24.6°C-29.1°C. The drainage system consists of Vagai and Pambar River and their tributaries flow in towards sea. Geologically the study area consists of an Archean basement overlain by Tertiary sediments. The sediments on the coastline are more often silty in nature. Prominent beach rocks along with cliffed coasts and Coral terraces have been observed around the Mandapam region. The coastal plain contains various coastal morpho-units like sand complexes, mud flats and backwaters, and Coastal dunes are widely distributed throughout the study area. Mandapam has a very calm protective environment with sandy substratum whereas Attankarai differs from others in getting freshwater influx and Devipattinam is found to be the meeting point of the monsoonal currents. Thondi is a minor harbor with less siltation and a dumping site of organic waste like fish. Kottaipattinam is the shadow zone of the spit, from Devipattinam to the Kottaipattinam region shows the drifting of lifeless seaweeds very commonly observed. Moreover, the monsoonal current surge is reported in Devipattinam and to certain extent in Thondi due to the wave action, which is kept under well-oxygenated conditions for the rich growth of seaweeds and algae.

MATERIAL AND METHODS

Forty surface sediment and bottom seawater samples at a depth ranging from 0.5 to 6.5 m were collected along the Mandapam to Kottaipattinam coastline during May 2015. The bottom water samples were collected manually with the help of local divers from the fishing hamlets and sediment samples were collected using a Van Veen grab sampler. The exact locations of the sampling sites were determined by using a global positioning system (GPS) (Fig.1). Seawater samples were preserved by adding a few ml of chloroform following the methods put forward by Newcombe *et al*. (1939). Sediment samples were preserved in a mixture of one part of buffered formalin in nine parts of water (4% solution) with a pinch of $CaCl_2$ to achieve neutrality (Walker *et al*., 1974), while pH of the water sampling was measured, using a pH meter. Salinity was estimated using the standard titration method and equation proposed by Knudsen (1901), while the dissolved oxygen (DO) content was determined using a UV-spectrophotometer (Duval *et al*., 1974).

Calcium carbonate and organic matter (OM) in the sediment samples were determined following Loring and Rantala (1992), and Gaudette *et al*. (1974), respectively. Sand, silt and clay percentages were computed from a combination of sieving and pipette procedures, the latter in accordance with Krumbein and Pettijohn (1938). A tri-plot was prepared and Sneed and Folk's (1958) textural nomenclature utilized for sediment type descriptions. The preserved sediment samples were subjected to the Rose Bengal staining technique, first described by Walton (1952), in order to differentiate "living" from dead foraminifera. In spite of its limitations, the Rose Bengal technique is still widely employed as it is not as cumbersome as other staining techniques (Murray, 1991); moreover, staining in tests of agglutinated species is easily recognized if Rose Bengal is used (Bernhard, 1988). The sediment samples that were preserved in a 4% solution of formalin were washed over an ASTM 230 sieve (mesh opening = 63 µm) to remove the mud content (silt + clay) and the sand fraction retained on the sieve was kept for 8 to 10 hours in a tray containing an aqueous solution of Rose Bengal (1 g dissolved in 1,000 ml of distilled water) ensuring that the residue on the sieve mesh was fully covered by the solution. The material was later washed thoroughly to remove the excess stain and subsequently oven-dried at 50° C. Each dried sediment sample was reduced to 25g after coning and quartering and then sub-divided into 5 fractions using ASTM 35, 60, 80, 120 and +120 sieves. The relatively coarser fractions retained on ASTM 35, 60 and 80 sieve pans were spread on picking trays and the benthic foraminifera tests were hand-picked using a .00 Windsor-Newton soft-bristled brush under a stereo zoom binocular microscope (EUROMEX-NOVEX). The relatively finer fractions were subjected to floatation using carbon tetrachloride (CCl_4) (Cushman, 1959) and the tests were separated from the filter paper to be mounted on 24-chambered micropaleontological slides. The residue after floatation was checked microscopically for tests that might have escaped floatation, and the separated tests subsequently hand-picked. The specimens were then mounted on card slides divided into numbered squares (usually 24 squares) with sliding glass covers.

Plate I



EXPLANATION OF PLATE I

Fig. 1. ***Ammobaculites exiguus*** (SV) 100µm, Fig. 2. ***Textularia agglutinans*** (SV) 50µm, Fig. 3. ***Lagena striata*** (AV) 50µm, Fig. 4. ***Textularia candeiana*** (SV) 200µm, Fig. 5. ***Textularia conica*** (SV) 100µm, Fig. 6. ***Fissurina marginata elegans*** 50µm, Fig. 7. ***Vertebralina striata*** (SV) 100µm, Fig. 8. ***Edentostomina cultrata*** (SV) 100µm, Fig. 9. ***Adelosina laevigata*** (SV) 100µm, Fig. 10. ***Adelosina intricata*** (SV) 100µm, Fig. 11. ***Spiroloculina planulata*** (SV) 100µm, Fig. 12. ***Spiroloculina affiixa*** (SV) 200µm, Fig. 13. ***Spiroloculina communis*** (SV) 200µm, Fig. 14. ***Globigerina bulloides*** (DV) 100µm, Fig. 15. ***Spiroloculina costifera*** (SV) 100µm, Fig. 16. ***Spiroloculina depressa*** (SV) 100µm.

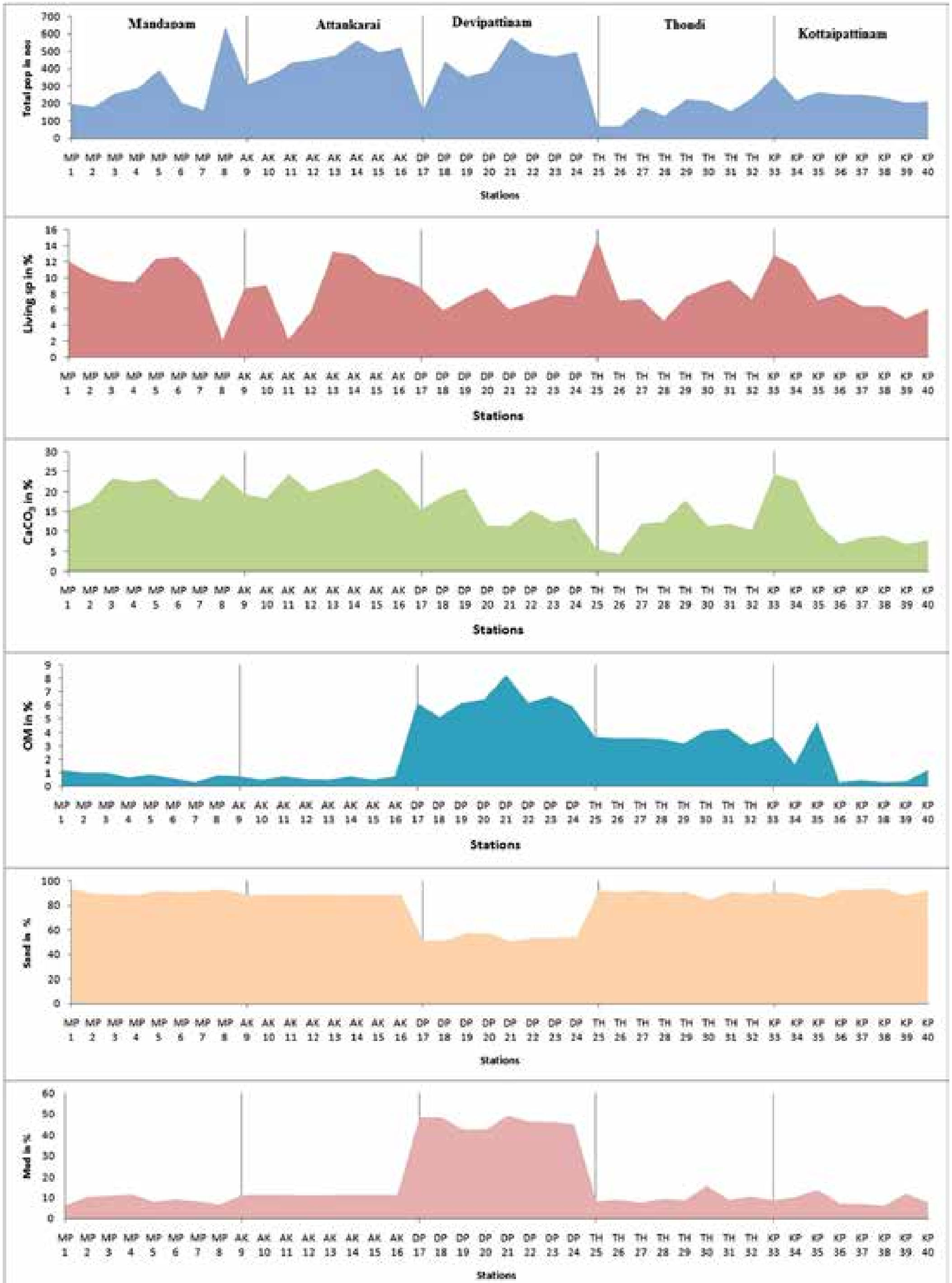


Fig. 2. Physiochemical parameters of the sea water and the sediments along the station sampled.

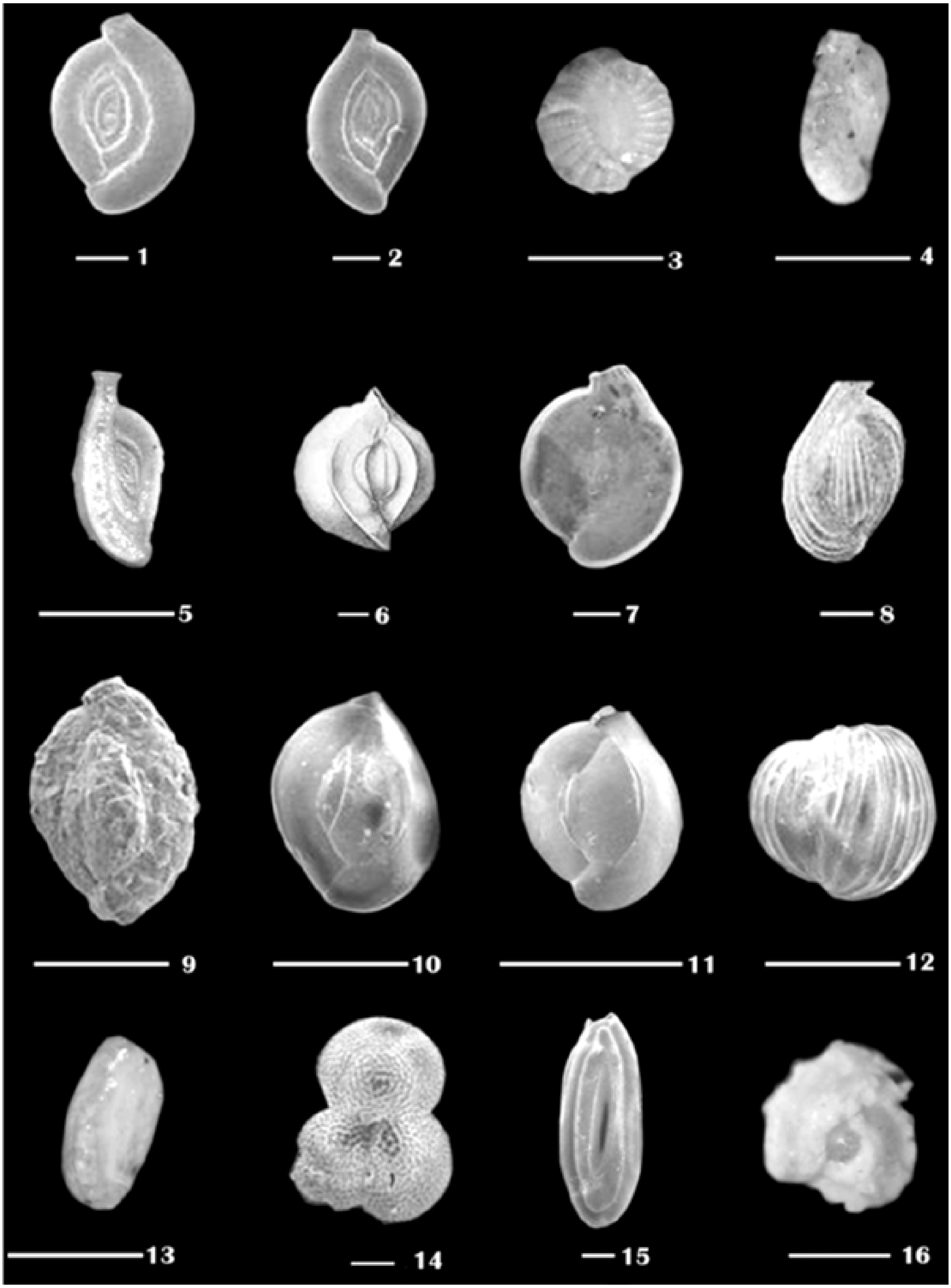
Gum tragacanth was used to mount the specimens on the slides according to the family, genus, and species, wherever possible. The different genera and species were identified and living and dead species of all the taxa were counted. Type specimens of each species were selected and transferred to single round punch micropaleontological slides with coverslips. All the hypotypes were duly indexed with numbers and are placed in the repository of the Department of Geology, University of Madras, Chennai 600 0025.

RESULTS

Bottom seawater characteristics

The physicochemical parameters of the bottom waters such as temperature, pH, salinity and dissolved oxygen (DO) values at different depths are shown in table 1 and fig. 2. The measured values of the above parameters such as temperature, does not show much variation at different stations (29.6^{o}-31.1^{o}C). The pH variation does not exhibit a considerable change, although, the

Plate II



EXPLANATION OF PLATE II

Fig. 1. ***Spiroloculina henbesti*** (SV) 200μm, Fig. 2. ***Spiroloculina nitida*** (SV) 200μm, Fig. 3. ***Spiroloculina antillarum*** (SV) 100μm, Fig. 4. ***Spiroloculina indica*** (SV) 100μm, Fig. 5. ***Spiroloculina angulata*** (SV) 100μm, Fig. 6. ***Spiroloculina robusta*** (SV) 200μm, Fig. 7. ***Spiroloculina orbis*** (SV) 200μm, Fig. 8. ***Cycloforina sidebottoni*** (SV) 200μm, Fig. 9. ***Siphonaperta aqqlutinans*** (SV) 100μm, Fig. 10. ***Quinqueloculina seminulum*** (SV) 100μm, Fig. 11. ***Quinqueloculina bicostata*** (SV) 200μm, Fig. 12. ***Quinqueloculina costata*** (SV) 100μm, Fig. 13. ***Quinqueloculina elongata*** (SV) 100μm, Fig. 14. ***Globigerinella aequilateralis*** (DV) 100μm, Fig. 15. ***Quinqueloculina elegans*** (SV) 100μm, Fig. 16. ***Quinqueloculina parkeri*** (SV) 100μm.

Table 1. Physiochemical parameters measured at the sampling stations in the study area.

S.NO	Depth in m	Sand in %	Silt in %	Clay in %	Mean (Φ)	SD (ó)	Ski (Ski)	KG (KG)	$CaCO_3$ in %	Om in %	Substrate	Salinity in ppm	pH	DO mg/l	Dead.sp in %	Living.sp in %	Total population in nos
MP 1	1.5	93.670	0.33	6.00	3.322	0.651	-0.084	1.098	15.5	1.23	Very Fine Sand	31.20	8.0	3.7	87.94	12.06	199
MP 2	2.5	89.695	2.80	7.50	2.296	0.572	0.207	1.201	17.5	1.03	Fine Sand	30.60	8.1	3.5	89.50	10.50	181
MP 3	3	89.185	3.56	7.25	2.306	0.685	0.320	1.100	23.5	1.03	Fine Sand	32.41	8.2	4.0	90.38	9.62	260
MP 4	4.5	88.495	4.51	7.00	2.666	0.847	0.144	0.842	22.5	0.69	Fine Sand	30.40	8.0	3.6	90.59	9.41	287
MP 5	5	92.030	0.97	7.00	2.699	0.887	0.215	0.810	23.5	0.88	Fine Sand	32.15	8.3	3.7	87.59	12.41	395
MP 6	5.5	90.865	4.63	4.50	3.257	0.877	-0.162	0.804	19	0.64	Very Fine Sand	31.13	8.2	3.3	87.38	12.62	206
MP 7	6	91.835	1.41	6.75	3.271	0.821	-0.185	0.861	18	0.34	Very Fine Sand	30.51	8.1	3.6	90.00	10.00	160
MP 8	7	93.190	1.81	5.00	4.306	0.313	0.010	0.990	24.5	0.83	Very Coarse Silt	30.11	8.0	3.4	97.82	2.18	643
AK 1	1	88.88	3.875	7.25	2.897	0.470	0.070	1.065	19.5	0.77	Fine Sand	29.80	6.2	3.4	91.32	8.68	311
AK 2	2	88.75	4.250	7.00	2.626	0.467	-0.050	1.584	18.5	0.52	Fine Sand	29.50	6.3	3.2	90.99	9.01	355
AK 3	2.5	88.80	3.700	7.50	2.741	0.433	0.007	1.253	24.5	0.77	Fine Sand	30.12	7.1	3.6	97.69	2.31	433
AK 4	3.4	88.99	3.765	7.25	2.667	0.480	-0.076	1.271	20	0.57	Fine Sand	31.23	7.0	3.2	94.26	5.74	453
AK 5	4	88.85	3.905	7.25	2.601	0.404	-0.057	1.098	22	0.52	Fine Sand	33.21	7.3	3.4	86.79	13.21	477
AK 6	5.6	88.83	3.675	7.50	2.733	0.532	0.099	1.720	23.5	0.77	Fine Sand	30.23	7.2	3.7	87.21	12.79	563
AK 7	6	88.74	4.265	7.00	2.520	0.491	0.007	1.088	26	0.52	Fine Sand	32.35	7.0	3.5	89.49	10.51	495
AK 8	6.7	88.78	3.975	7.25	2.713	0.543	0.091	1.445	22	0.77	Fine Sand	31.15	7.0	3.5	90.06	9.94	523
DP 1	1.25	23.000	51.50	25.50	3.565	1.070	-0.510	1.016	15.5	6.18	Very Fine Sand	37.10	7.00	4.5	91.30	8.696	161
DP 2	2	22.530	51.47	26.00	3.568	1.056	-0.476	1.003	19	5.15	Very Fine Sand	37.20	7.10	4.7	94.10	5.896	441
DP 3	3.5	24.180	57.32	18.50	3.838	0.918	-0.527	1.037	21	6.18	Very Fine Sand	38.30	7.20	4.6	92.61	7.386	352
DP 4	4.4	23.720	57.28	19.00	3.615	1.080	-0.550	0.973	11.5	6.44	Very Fine Sand	38.10	7.00	5.2	91.24	8.763	388
DP 5	5	21.310	50.69	28.00	3.561	1.038	-0.466	1.088	11.5	8.24	Very Fine Sand	38.50	7.20	5.3	93.97	6.034	580
DP 6	6	27.370	53.63	19.00	3.570	1.059	-0.489	1.026	15.5	6.18	Very Fine Sand	38.60	7.30	4.5	93.09	6.911	492
DP 7	6.6	28.850	53.65	17.50	3.504	1.120	-0.474	1.029	12.5	6.70	Very Fine Sand	37.60	7.20	4.3	92.16	7.839	472
DP 8	7	22.700	54.80	22.50	3.611	1.060	-0.539	1.087	13.5	5.92	Very Fine Sand	37.80	7.10	4.9	92.35	7.646	497
TH 1	1.3	91.790	2.960	5.25	2.883	0.713	-0.206	1.137	5.5	3.68	Fine Sand	35.20	7.20	4.5	85.29	14.706	68
TH 2	2.5	91.075	2.425	6.50	3.001	0.729	-0.151	0.978	4.5	3.58	Very Fine Sand	36.60	7.10	4.7	92.86	7.143	70
TH 3	3	92.400	1.350	6.25	3.433	0.829	-0.251	1.021	12.0	3.58	Very Fine Sand	37.20	7.30	5.0	92.70	7.303	178
TH 4	4	90.695	3.305	6.00	3.860	0.729	-0.293	0.939	12.5	3.53	Very Fine Sand	37.30	7.20	4.8	95.38	4.615	130
TH 5	4.3	91.240	3.510	5.25	3.735	0.814	-0.251	0.987	18.0	3.19	Very Fine Sand	38.10	7.00	4.9	92.44	7.556	225
TH 6	5	84.355	8.895	6.75	3.362	0.914	-0.232	0.955	11.5	4.17	Very Fine Sand	35.50	7.10	4.6	91.16	8.837	215
TH 7	6	91.120	2.130	6.75	3.242	0.896	-0.092	0.806	12.0	4.27	Very Fine Sand	36.60	7.30	5.0	90.26	9.740	154
TH 8	7	89.595	3.905	6.50	3.592	0.748	-0.227	1.000	10.5	3.09	Very Fine Sand	38.20	7.10	4.5	92.70	7.296	233
KP 1	1.75	91.305	2.195	6.50	3.864	0.797	-0.386	1.092	24.5	3.68	Very Fine Sand	35.60	7.10	4.2	87.11	12.89	357
KP 2	2.25	89.840	3.910	6.25	3.777	0.876	-0.414	1.053	23	1.67	Very Fine Sand	35.80	7.20	3.5	88.58	11.42	219
KP 3	3	86.220	6.780	7.00	3.527	0.979	-0.246	1.004	12	4.81	Very Fine Sand	36.30	7.00	5.4	92.83	7.17	265
KP 4	4	92.775	0.725	6.50	3.939	0.685	-0.355	1.105	7.0	0.34	Very Fine Sand	36.50	7.10	3.2	92.03	7.97	251
KP 5	4.5	92.925	0.825	6.25	3.904	0.740	-0.344	1.001	8.5	0.49	Very Fine Sand	37.20	7.30	3.1	93.57	6.43	249
KP 6	5	93.940	2.060	4.00	4.050	0.636	-0.357	1.064	9.0	0.34	Very Coarse Silt	37.30	7.20	3.2	93.59	6.41	234
KP 7	6	88.195	4.805	7.00	3.896	0.725	-0.359	1.095	7.0	0.39	Very Fine Sand	35.70	7.00	3.3	95.15	4.85	206
KP 8	7	92.410	1.340	6.25	3.866	0.787	-0.386	0.967	8.0	1.23	Very Fine Sand	36.80	7.10	3.5	93.87	6.13	212
	Min	**21.310**	**0.33**	**4.00**	**2.296**	**0.313**	**-0.550**	**0.804**	**4.500**	**0.34**		**29.50**	**6.2**	**3.1**	**85.29**	**2.18**	**68**
	Max	93.940	**57.32**	**28.00**	**4.306**	**1.120**	**0.320**	**1.720**	**26.000**	**8.24**		**38.60**	**8.3**	**5.4**	**97.82**	**14.71**	**643**
	Ave	**76.151**	**14.06**	**9.90**	**3.309**	**0.760**	**-0.197**	**1.077**	**16.095**	**2.70**		34.60	7.3	4.1	91.49	8.51	**317**

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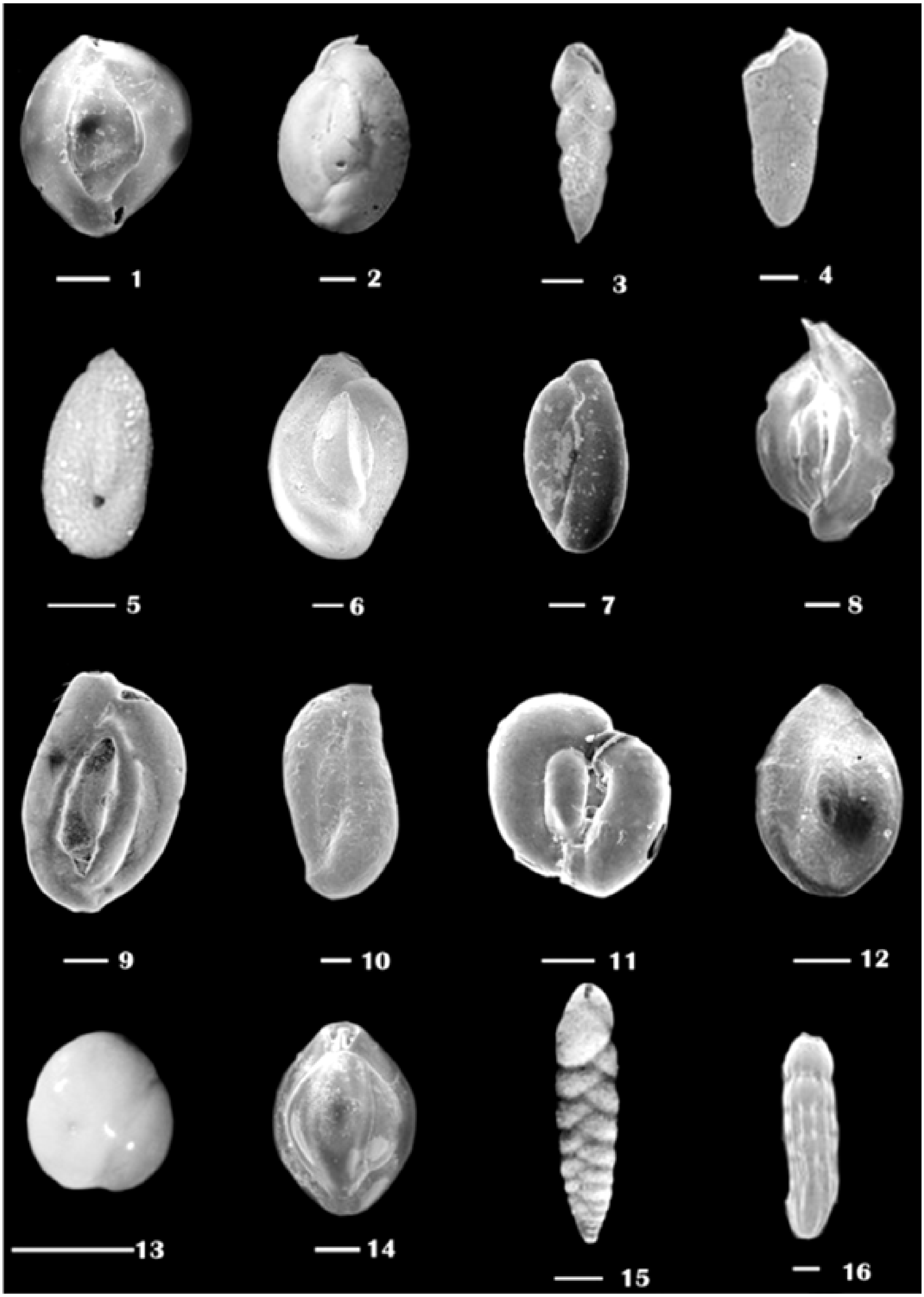
Plate III



EXPLANATION OF PLATE III

Fig. 1. ***Quinqueloculina lamarckiana*** (SV) 200µm, Fig. 2. ***Quinqueloculina tenagos*** (SV) 200µm, Fig. 3. ***Bolivina nobilis*** (SV) 100µm, Fig. 4. ***Bolivina ordinaria*** (SV) 50µm, Fig. 5. ***Quinqueloculina transversestriata*** (SV) 100µm, Fig. 6. ***Quinqueloculina polygona*** (SV) 100µm, Fig. 7. ***Quinqueloculina venusta*** (SV) 100µm, Fig. 8. ***Quinqueloculina sulcata*** (SV) 100µm, Fig. 9. ***Quinqueloculina schlumbergeri*** (SV) 100µm, Fig. 10. ***Quinqueloculina tropicalis*** (SV) 100µm, Fig. 11. ***Miliolinella circularis*** (AV) 100µm, Fig. 12. ***Miliolinella pyrgoformis*** (DV) 200µm, Fig. 13. ***Flintinoides labiosa*** (DV) 100µm, Fig. 14. ***Sigmamiliolinella australis*** (AV) 100µm, Fig. 15. ***Spiroloxostoma glabra*** (SV) 100µm, Fig. 16. ***Siphogenerina raphana*** (SV) 100µm.

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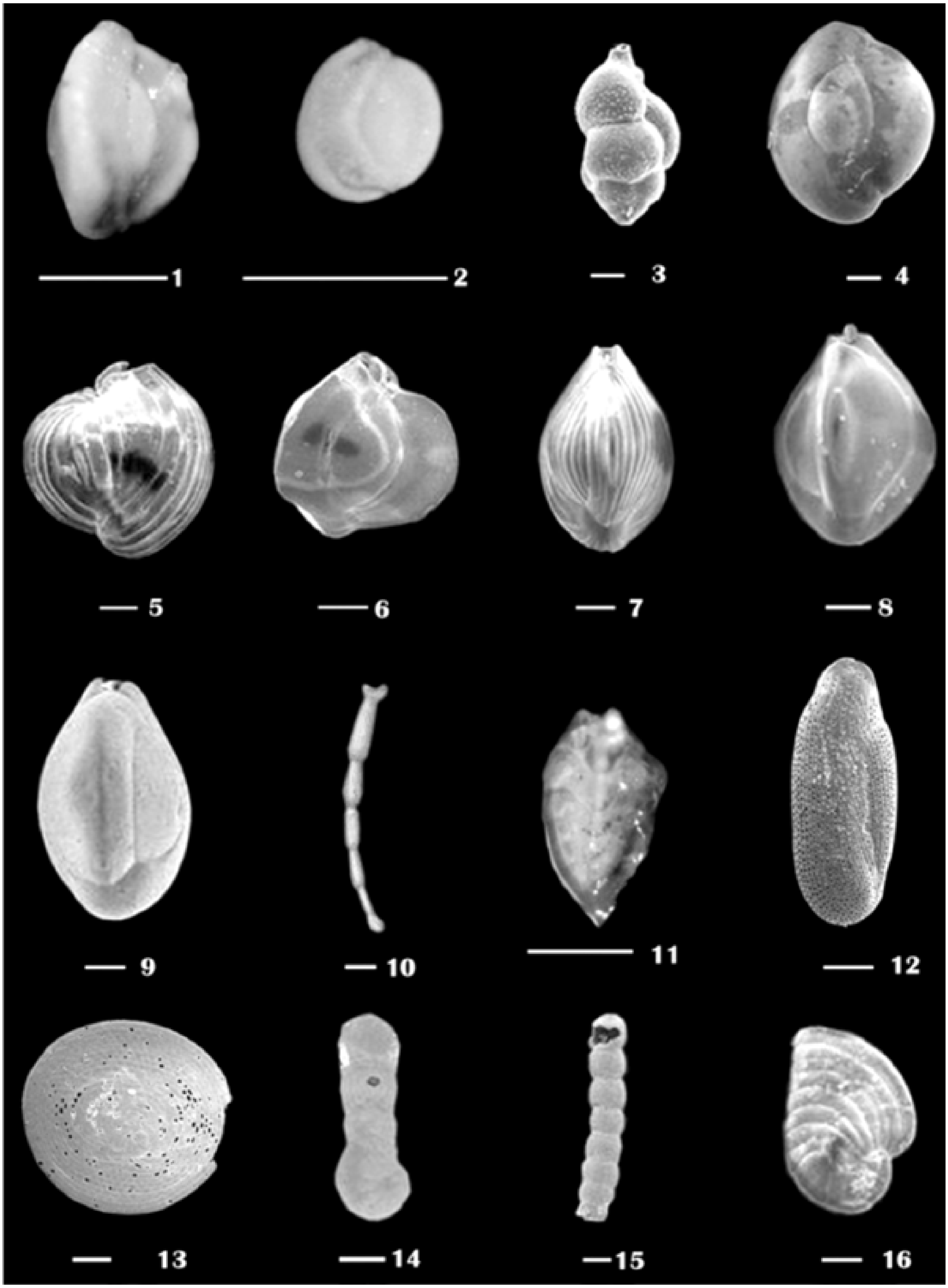
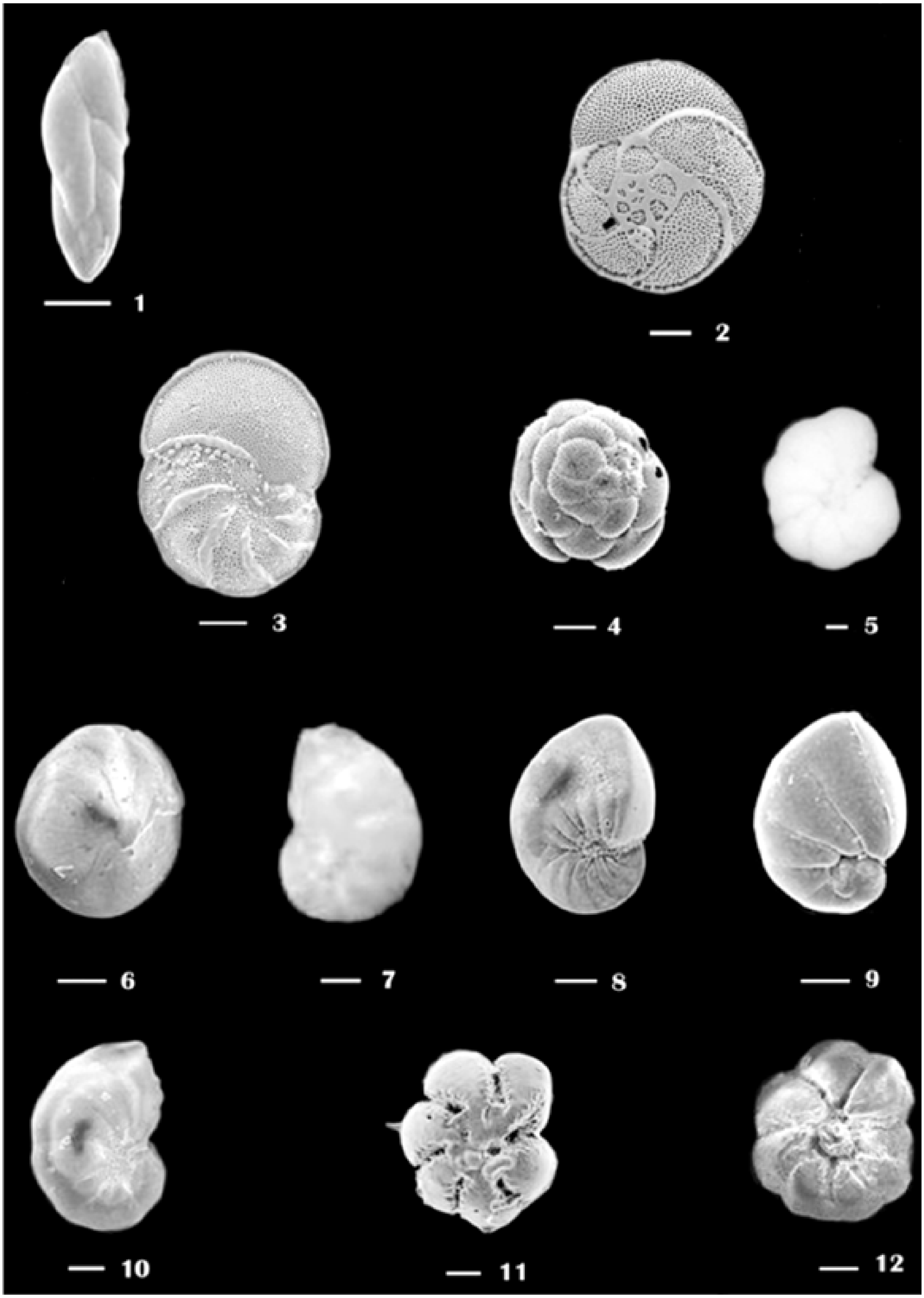
Plate IV



EXPLANATION OF PLATE IV

Fig. 1. ***Massilina secans*** (SV) 100µm, Fig. 2. ***Pseudomassilina australis*** (SV) 100µm, Fig. 3. ***Uvigerina senticosa*** (SV) 50µm, Fig. 4. ***Pseudotriloculina rotunda*** (SV) 100µm, Fig. 5. ***Triloculina insignis*** (SV) 100µm, Fig. 6. ***Triloculina schreiberiana*** (AV) 100µm, Fig. 7. ***Triloculina terquemiana*** (AV) 100µm, Fig. 8. ***Triloculina tricarinata*** (AV) 100µm, Fig. 9. ***Triloculina trigonula*** (SV) 100µm, Fig. 10. ***Articulina mayori*** (SV) 200µm, Fig. 11. ***Fijiella simplex*** (SV) 100µm, Fig. 12. ***Rupertianella rupertiana*** (SV) 200µm, Fig. 13. ***Sorites marginalis*** (DV) 200µm, Fig. 14. ***Spirolina arietnus*** (SV) 100µm, Fig. 15. ***Monalysidium politum*** (SV) 200µm, Fig. 16. ***Peneroplis planatus*** (DV) 200µm.

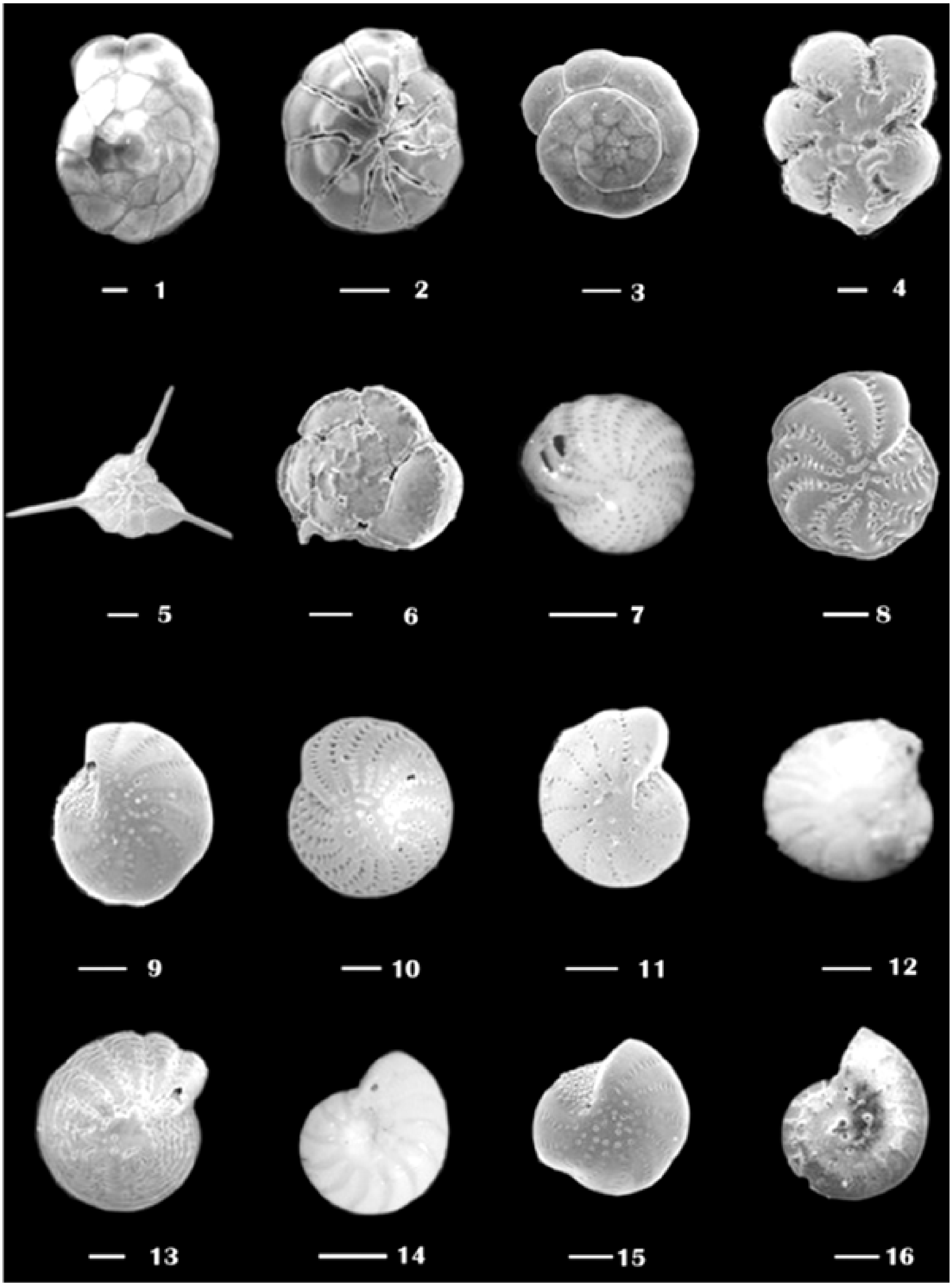
Plate V



EXPLANATION OF PLATE V

Fig. 1. ***Fursenkoina pontoni*** (SV) 100µm, Fig. 2. ***Rosalina globularis*** (DV) 100µm, Fig. 3. ***Discorbinella bertheloti*** (DV) 100µm, Fig. 4. ***Acervulina inharens*** (DV) 100µm, Fig. 5. ***Osangularia venusta*** (DV) 100µm, Fig. 6. ***Amphistegina radiata*** (DV) 200µm, Fig. 7. ***Nonion scaphum*** (DV) 100µm, Fig. 8. ***Nonionellina labradorica*** (AV) 100µm, Fig. 9. ***Nonionoides boueanum*** (AV) 50µm, Fig. 10. ***Nonionoides elongatum*** (DV) 100µm, Fig. 11. ***Neorotalia calcar*** (AV) 50µm, Fig. 12. ***Pararotalia nipponica*** (AV) 100µm.

Plate VI



EXPLANATION OF PLATE VI

Fig. 1. ***Ammonia beccarii*** (DV) 100µm, Fig. 2. ***Ammonia dentata*** (AV) 200µm, Fig. 3. ***Ammonia tepida*** (DV) 100µm, Fig. 4. ***Asterorotalia inflata*** (AV) 50µm, Fig. 5. ***Pulchella trispinosa*** (DV) 200µm, Fig. 6. ***Pseudorotalia schroeteriana*** (DV) 100µm, Fig. 7. ***Cribroelphidium incertum*** (DV) 100µm, Fig. 8. ***Elphidium advenum*** (DV) 100µm, Fig. 9. ***Elphidium craticulatum*** (DV) 100µm, Fig. 10. ***Elphidium crispum*** (DV) 100µm, Fig. 11. ***Elphidium discoidale*** (DV) 100µm, Fig. 12. ***Elphidium delicatulum*** (DV) 200µm, Fig. 13. ***Elphidium hispidulum*** (DV) 100µm, Fig. 14. ***Elphidium macellum*** (DV) 100µm, Fig. 15. ***Elphidium norvangi*** (DV)100µm, Fig. 16. ***Assilina ammonoides*** (DV) 200µm.

Table 2. Foraminifera species identified at various sampling stations.

Sl.No	Species Name	Mandapam	Attankarai	Devipattinam	Thondi	Kottaipattinam	Total
1	*Ammobaculites exiguus*	58	33	6	16	15	128
2	*Textularia agglutinans*	5	16	6	3	9	39
3	*Textularia candeiana*	-	-	16	-	-	16
4	*Textularia conica*	-	-	16	-	-	16
5	*Vertebralina striata*	7	14	12	-	15	48
6	*Edentostomina cultrata*	3	-	6	24	-	33
7	*Spiroloculina planulata*	-	-	21	-	-	21
8	*Spiroloculina affiixa*	-	30	-	-	-	30
9	*Spiroloculina communis*	84	72	41	2	-	199
10	*Spiroloculina costifera*	22	-	13	-	3	38
11	*Spiroloculina depressa*	-	-	86	24	43	153
12	*Spiroloculina henbesti*	-	-	4	1	18	23
13	*Spiroloculina nitida*	-	-	3	2	-	5
14	*Spiroloculina antillarum*	7	-	4	-	-	11
15	*Spiroloculina indica*	8	-	14	6	15	43
16	*Spiroloculina angulata*	14	-	19	12	28	73
17	*Spiroloculina robusta*	-	-	18	-	-	18
18	*Spiroloculina orbis*	26	-	9	1	4	40
19	*Siphonaperta aqqlutinans*	5	21	10	2	-	38
20	*Quinqueloculina seminulum*	114	86	73	13	69	355
21	*Quinqueloculina bicostata*	62	-	25	-	23	110
22	*Quinqueloculina costata*	20	-	-	-	26	46
23	*Quinqueloculina elongata*	45	14	7	14	48	128
24	*Quinqueloculina elegans*	-	-	-	7	-	7
25	*Quinqueloculina parkeri*	-	-	3	-	6	9
26	*Quinqueloculina lamarckiana*	92	-	41	8	53	194
27	*Quinqueloculina polygona*	78	-	32	2	38	150
28	*Quinqueloculina venusta*	-	-	17	1	-	18
29	*Quinqueloculina sulcata*	-	-	21	-	-	21
30	*Quinqueloculina schlumbergeri*	-	-	24	8	-	32
31	*Quinqueloculina tropicalis*	63	14	28	18	33	156
32	*Miliolinella circularis*	24	2	20	3	14	63
33	*Miliolinella pyrgoformis*	45	39	-	16	29	129
34	*Flintinoides labiosa*	-	-	21	1	-	22
35	*Sigmamiliolinella australis*	-	-	-	5	-	5
36	*Massilina secans*	-	-	7	-	5	12
37	*Pseudomassilina australis*	3	-	-	-	-	3
38	*Pseudotriloculina rotunda*	61	-	36	-	19	116
39	*Triloculina insignis*	9	-	5	-	23	37
40	*Triloculina terquemiana*	2	-	-	7	-	9
41	*Triloculina tricarinata*	14	26	15	17	5	77
42	*Triloculina trigonula*	24	84	21	14	12	155
43	*Articulina mayori*	1	8	3	-	-	12
44	*Rupertianella rupertiana*	43	3	4	-	16	66
45	*Sorites marginalis*	-	-	-	7	-	7
46	*Spirolina arietinus*	3	18	13	-	4	38
47	*Lagena striata*	-	7	-	-	-	7
48	*Globigerina bulloides*	17	-	10	-	10	37
49	*Globigerina aequilateralis*	-	-	-	-	16	16
50	*Bolivina nobilis*	26	144	6	-	5	181
51	*Bolivina ordinaria*	-	6	-	-	4	10
52	*Siphogenerina raphana*	-	20	-	-	-	20
53	*Uvigerina senticosa*	11	-	-	-	-	11
54	*Fursenkoina pontoni*	9	-	-	-	-	9
55	*Rosalina globularis*	-	30	279	10	51	370

56	*Discorbinella bertheloti*	-	10	-	-	-	10
57	*Acervulina inhaerens*	5	18	-	-	-	23
58	*Osangularia venusta*	315	-	-	30	35	380
59	*Amphistegina radiata*	-	-	-	-	5	5
60	*Nonionella labradorica*	-	7	-	-	-	7
61	*Nonionoides boueanum*	20	-	-	-	-	20
62	*Neorotalia calcar*	45	152	26	1	45	269
63	*Pararotalia nipponica*	57	257	828	20	33	1195
64	*Ammonia beccarii*	458	813	1241	297	751	3560
65	*Ammonia dentata*	102	305	82	34	95	618
66	*Ammonia tepida*	110	202	82	376	265	1035
67	*Asterorotalia inflata*	7	-	-	-	5	12
68	*Pulchella trispinosa*	19	573	-	-	10	602
69	*Pseudorotalia schroeteriana*	-	-	-	16	-	16
70	*Cribroelphidium incertum*	15	54	3	11	5	88
71	*Elphidium advenum*	16	-	13	-	-	29
72	*Elphidium craticulatum*	16	-	-	9	-	25
73	*Elphidium crispum*	62	280	91	221	43	697
75	*Elphidium discoidale*	17	19	-	2	-	38
76	*Elphidium delicatulum*	-	10	-	-	-	10
77	*Elphidium hispidulum*	-	9	-	-	-	9
78	*Elphidium macellum*	22	182	-	6	37	247
79	*Elphidium norvangi*	-	11	-	-	-	11
80	*Assilina ammonoides*	22	14	-	-	-	36
	Total	2331	3610	3383	1273	1990	12587

Table 3. Coefficient correlation matrix of the various physicochemical parameters.

Correlation Matrix												
Parameters		Sand	Silt	Clay	$CaCO_3$	OM	Salinity	Ph	DO	Dead	Living	Total
	Sand	1.00										
	Silt	-1.00	1.00									
	Clay	-0.97	**0.94**	1.00								
	$CaCO_3$	0.08	-0.08	-0.06	1.00							
	OM	-0.82	**0.82**	**0.78**	-0.30	1.00						
Correlation	Salinity	-0.51	**0.52**	**0.46**	-0.61	**0.72**	1.00					
	Ph	0.18	-0.18	-0.18	0.24	-0.23	-0.29	1.00				
	DO	-0.52	**0.52**	**0.50**	-0.31	**0.87**	**0.65**	-0.16	1.00			
	Dead	-0.20	0.19	0.20	-0.22	0.15	0.26	-0.24	0.11	1.00		
	Living	0.20	-0.19	-0.20	0.22	-0.15	-0.26	0.24	-0.11	-1.00	1.00	
	Total	-0.38	**0.37**	**0.38**	**0.53**	0.10	-0.19	-0.09	-0.09	0.17	-0.17	1.00

Component Matrix			
Parameters	Component		
	Factor 1	Factor 2	Factor 3
Sand	-0.911	-0.348	0.006
Silt	0.908	0.339	0.002
Clay	0.883	0.359	-0.030
$CaCO_3$	-0.327	**0.769**	-0.289
OM	**0.926**	0.035	0.269
Salinity	**0.744**	-0.429	0.266
Ph	-0.333	0.272	0.175
DO	**0.735**	-0.149	0.365
Dead	0.384	-0.457	-0.778
Living	-0.384	0.457	**0.778**
Total	0.224	0.660	-0.553

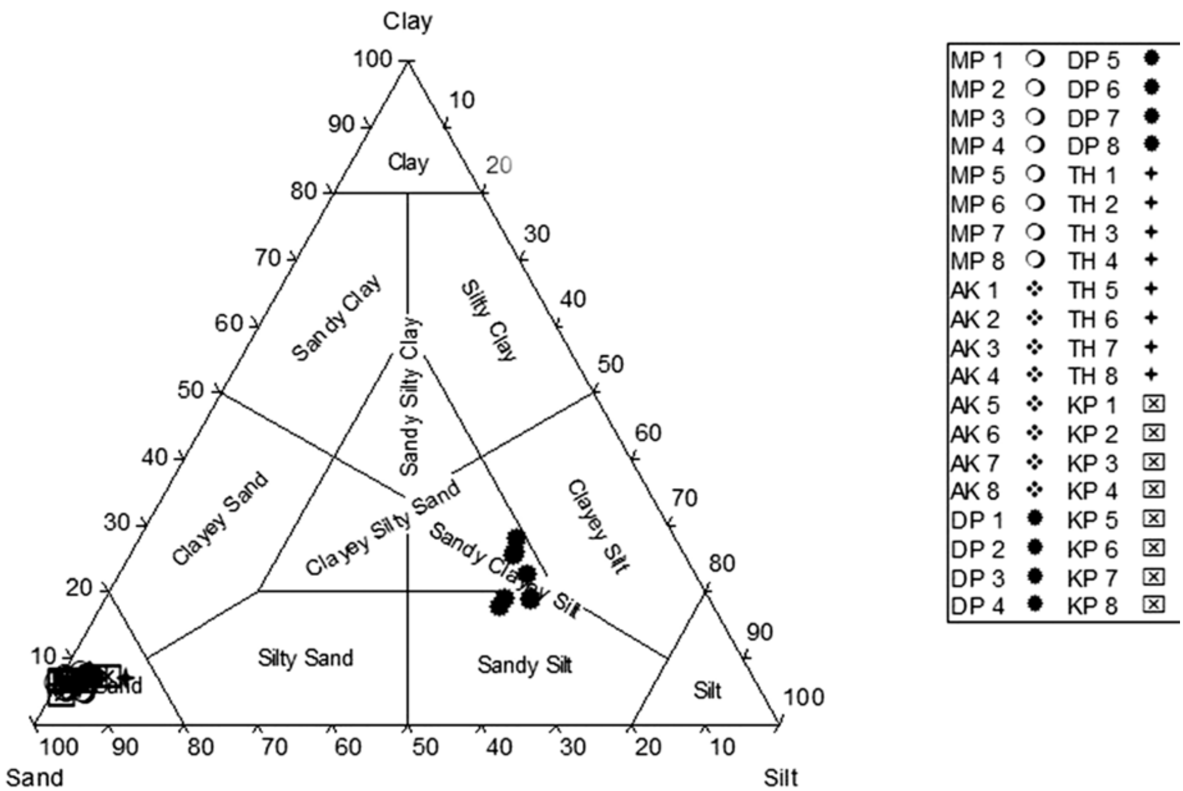


Fig. 3. Sediment texture represented in a triplot.

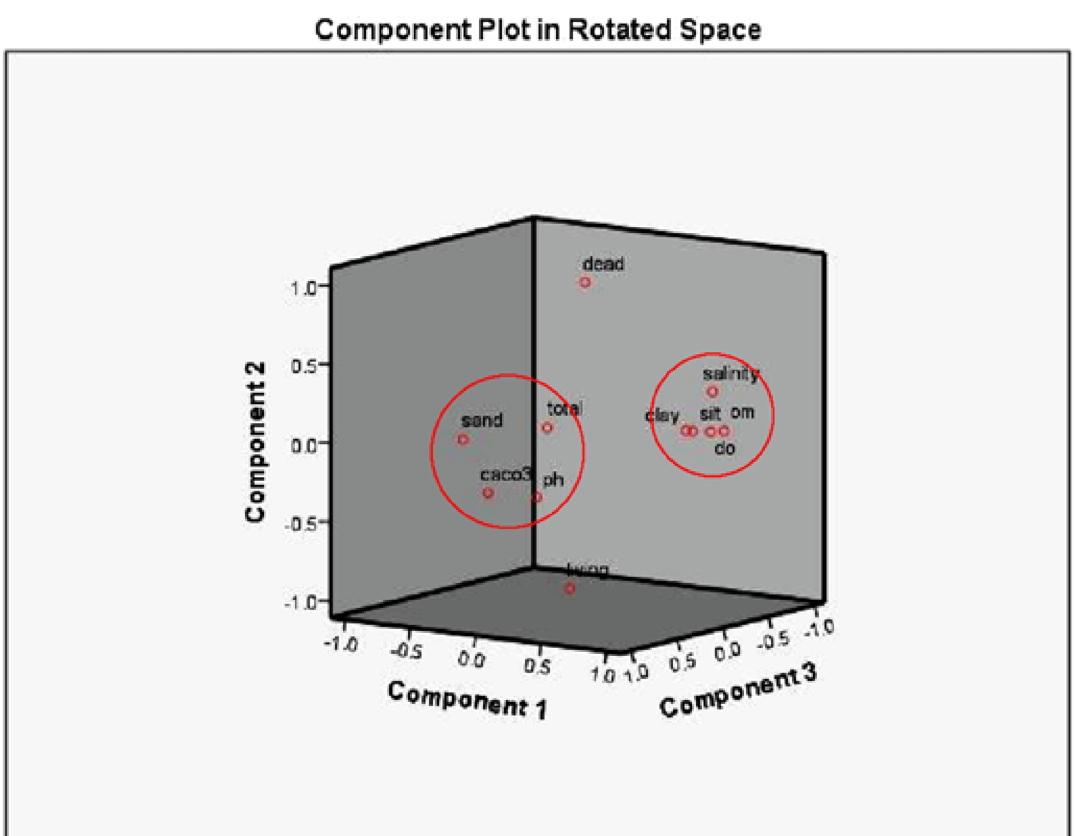


Fig. 4. Factor loading components of the parameters analysed.

pH values are changing in some stations range from 6.2-8.3, the average is 7.3. The overall salinity of the bottom water shows a negligible variation ranges from 29.50-38.60‰, the average concentration is 34.60. The highest salinity was observed in Devipattinam, Thondi, and Kottaipattinam whereas the lowest salinity was observed in Mandapam and Attankarai in the study area. The distribution of dissolved oxygen (DO) overall ranges between 3.1 - 5.4 ml/l, the average is 4.1ml/l. However, Devipattinam and Thondi stations show the highest DO in the study area.

Sediment characteristics

The relative abundance of sand, silt and clay % in the surface sediment shows the mean values range from 2.296-4.306, standard deviation ranges from 0.313-1.120. Skewness ranges from -0.550-0.320 and kurtosis ranges from 0.804-1.720 has been estimated in the study area (Table 1). The ternary diagram for sand-silt-clay analysis shows most of the samples falling under sand category except Devipattinam (Fig.3) where Devipattinam stations show very fine sand (silt and clay are dominant). Overall, the sediment type of the area consists of fine sand, very fine sand and very coarse silt nature of the substratum.

Calcium Carbonate ($CaCO_3$) and Organic matter (OM)

The $CaCO_3$% in the sediments ranges from 4.5-26.0%, the average concentration is 16.095%. The higher amount of $CaCO_3$ has observed at station nos AK7 (26.0%), AK3 (24.5%), MP8 (24.5%) and KP1 (24.5%). The organic matter ranges from 0.34-8.24%, the average concentration is 2.70%, the higher amount organic matter has observed at station nos DP5 (8.24%), DP7 (6.70%) and DP4 (6.44%). However, the entire station does show appreciable variation in both $CaCO_3$ and organic matter.

Foraminiferal characteristics

The study area is in a shallow coastal setting, the living/dead and total individuals of the foraminifera were studied, in which Rose Bengal staining technique was used to differentiate between "living" and dead species. All the 40 stations put together, the total foraminifera were counted as 12,587, out of which 1044 tests were stained, implying that they were living at the time of collection. Living species, therefore, constitutes 8.06% of the total benthic foraminifera in the near-shore region. The sediment sample collected off Attankarai yielded the highest total foraminiferal numbers of 3610, out of which 334 were found to be stained and hence living at the time of sediment collection. Mandapam and Devipattinam stations were represented higher diversity and foraminiferal abundance in the study area. However, the Thondi and Kottaipattinam stations show the lower abundance and less diversity in the study area.

STATISTICAL STUDIES

The statistical analysis results confirming the association and relationship between foraminiferal assemblages and environmental parameters (Table. 3).

Correlation matrix: A significant correlation has been observed between ecological and textural parameters such as clay (0.94) that strongly correlated with silt; organic matter strongly correlated with silt (0.82), clay (0.78); salinity strongly correlated with the organic matter (0.72) and moderately correlated with silt (0.52), clay (0.46); DO strongly correlated with organic matter (0.87), salinity (0.65) and moderately correlated with silt (0.52), clay (0.50), finally the total population showed a low correlation with silt (0.37) and clay (0.38) and moderately correlated with $CaCO_3$ (0.53). Factor1: silt (0.908), clay (0.883), organic matter (0.926), salinity (0.744) and dissolved oxygen (0.735) were high loading factor in the study area. It indicates increased preservation of the organic carbon-rich environment in the presence of a high amount of finer fraction. Factor2 shows $CaCO_3$ (0.769) and the total population (0.660) are the secondary dominating factor. Factor3 reveals the living species (0.778) are the tertiary dominant factor. Figure 4 shows two groups of associations that have been observed; all the parameters show a inverse relationship with the living and dead species. Sand, $CaCO_3$, total population and pH are associated with one group which indicates and depicts the source of calcium carbonate. Salinity, clay, silt, OM and DO have associated with other groups that indicate the source of organic matter. However, factor analysis and correlation matrix results show that there is no significant relationship between foraminiferal assemblages and environmental parameters.

DISCUSSION

The following environmental parameters were determined in the 40 near-shore water and sediment samples which include water depth, pH, dissolved oxygen (DO) and salinity with regard to water samples, and calcium carbonate ($CaCO_3$), organic matter, sand, silt and clay contents in the sediment samples (Table 1 and Fig. 2). From the table 1, it is evident that the temperature shows little variations, as all the samples were collected within a near shore water depth range of 0.5 to 6.5m, but changes in some parameters such as pH, dissolved oxygen, salinity and sediment texture in the study area were also observed. Mandapam and Attankarai stations show the lower salinity when compared to other stations as both are located in the protected wave shadow zone of the respective spit of Dhanuskodi, where the wave churning action is more with lack of evaporation and mixing of freshwater influx. Further, Attankarai being the confluence zone of the River Vaigai, the fresh water mixing is found to be in appreciable amount for variation of salinity (Rao *et al.*, 1979; Reddy and Rao, 1984). Moreover, Devipattinam, Thondi and Kottaipattinam stations show the highest salinity content due to the circular motion of littoral current and the intensity of churning action taking place inside the Palk Strait and the freshwater inflow (Rao *et al.*, 1987). The higher salinity aids the fast deposition of fine tails, which in turn decreases the values of skewness (Rao *et al.*, 1988). The pH values of the bottom water show a negligible variation, although, the pH values in some stations vary and the reduced pH is generally associated with low abundance and diversity of foraminifera (Boltovskoy and Wright, 1976). Mandapam station shows higher species diversity (pH is found to vary from 8.0- 8.3) compare to other stations. The concentration of dissolved oxygen overall ranges between 3.2-5.4 ml/l in the study area; Devipattinam and Thondi stations show higher concentration of DO compared to other stations which may be due to the presence of dense extensive patches of benthic algae in shallow and near shore environment. These have significantly contributed high order of dissolved oxygen content (Alleem,1949; Rasheed and Ragothaman, 1978).

From Table 1 and Fig. 3, it is evident that among the 40 sediment samples collected and analyzed, almost 80% of them fall in the category of sand as per the textural classification proposed by Sneed and Folk (1958). Generally, sediment texture becomes finer as the depth of the water column increases;

near-shore sediments are invariably coarse-grained, mainly a consequence of winnowing, a process active on accreting beaches. The study area is prograding zone and wave action contributes in depositing relatively coarser clasts on the beach and in the near-shore region as a result of reduced wave velocity as it recedes and carries back the relatively finer clasts (Rao *et al*., 2014). The presence of sediment textures is probably an indication of variable hydrodynamics in the near-shore region of the study area. The Palk Strait coastal sands are clean, fine in grain size, well sorted to poorly sorted, very coarsely skewed to fine skewed and leptokurtic to platykurtic in nature. The higher amount of calcium carbonate observed in Mandapam and Attankarai stations is mainly due to shell fragments and the coral reef environment. The higher amount of organic matter observed in Devipattinam and Thondi stations is due to influenc of seaweeds and sea grass (Murray, 1973). Based on the generic classification by Loeblich and Tappan (1987; 1992) and other modified classifications, 92 benthic foraminiferal species were identified (Table 2), composed of five Orders, although, the orders LITUOLIDA and LAGENIDA are poorly represented. This is typical of a near-shore benthic foraminiferal assemblage, as the hydrodynamics of such an environment favors only those species that can withstand the energy impact. The dominance of *Ammonia beccarii* followed by *Pararotalia nipponica* and *Ammonia tepida*, *Ammonia beccarii* is due to cosmopolitan nature of the species which are environment-tolerant to a significantly higher level in the near-shore region. The following species namely *Adelosina intricate, Quinqueloculina tenagos, Adelosina laevigata, Cycloforina sidebottoni, Adelosina intricate, Quinqueloculina transversestriata, Triloculina schreiberiana, Monalysidium politum, Peneroplis planatus, Fissurina marginata elegans, Spiroloxostoma glabra, Fijiella simplex, Nonion scaphum,* and *Nonionoides elongatum* are very rare in occurrence. Rose Bengal staining technique was used to differentiate between "living" and dead species. All the 40 stations put together, the total population was counted as 12,587, out of which 1044 tests were stained, implying that they were living at the time of collection. Living species, therefore, constitutes 8.06% of the total benthic foraminifera in the near-shore region. The sediment sample collected off Attankarai yielded the highest total population of 3610 specimens, out of which 334 were found to be stained. Further, both living and dead foraminifera are not properly correlated with any of the ecological and textural parameters determined. Species diversity was found to be the highest in Mandapam and Devipattinam stations, Mandapam stretch is found to be sand, silty sand, in a coral reef environment, whereas, Devipattinam station shows high salinity, high organic matter and seaweed accumulation which favored more species diversity in the study area (Sundararaj and Venkataswamy, 1989; Kannan and Kannan, 1996). Attankarai stations show the mouth of the Vagai River, where the ocean easily has a large amount of nutrient availability. Thondi and Kottaipattinam have much shallow depth which must have inhibited the diversity.

CONCLUSIONS

In the present study, the benthic foraminifera along the near-shore region of Palk Strait yielded 92 species belonging to 47 genera, 25 families, 13 super-families, 21 sub-families, 5 sub-orders, and 5 orders and these have been illustrated. Out of the total population count of 12,587 specimens, 1044 were Rose Bengal-stained and were living at the time of sample collection. The most abundant species was observed to be *Ammonia beccarii* (Linnaeus, 1758). It is a more cosmopolitan species, followed by *Pararotalia nipponica* (Asano, 1936) and *Ammonia tepida* (Cushman, 1926). The majority of the species were in dead condition while the living were less abundant in the study area. Devipattinam region reflected a higher concentration of organic matter owing to its backwater like environment, the occurrence of seaweeds and seagrass and very fine substratum has stored organic matter competently. Mandapam and Attankarai stations revealed high calcium carbonate content because of the extensive patches of shell fragments and coral reef, those are favored for more species diversity. Beside this, *Adelosina intricate, Spiroloculina robusta, Quinqueloculina venusta, Quinqueloculina schlumbergeri, Pseudotriloculina rotunda, Uvigerina senticosa, Fursenkoina pontoni, Elphidium delicatulum* and *Elphidium norvangi* species were not reported earlier studies in this region.

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REFERENCES

Abbas, H. and Achyuthan, H. 2011. Benthic foraminiferal assemblages from the estuary and tidal zones along the east coast of Tamilnadu, India: Deciphering Holocene sea-level change. *Journal of the Paleontological Society of India*, **56**(2):195-200.

Anbuselvan, N. and Senthil Nathan, D. 2018. Benthic foraminiferal distribution and biofacies in the shelf part of Bay of Bengal, east coast of India. https://doi.org/10.1007/s12526-018-0845-1.

Aleem, A. A. 1949. Distribution and ecology of marine littoral diatoms. *Bot. Notiser*, **4** : 414-440.

Alve, E. 1991. Foraminifera, climatic change and pollution: A study of Late Holocene sediments in Drammensfjord, SE Norway. The Holocene, **1**: 243-261.

Alve, E. 1995. Benthic foraminiferal responses to estuarine pollution: a review. *Journal of Foraminiferal Research*, **25**: 190–203.

Armynot du Châtelet, E., Debenay, J. P. and Saulard, R. 2004. Foraminiferal proxies for pollution monitoring in moderately polluted harbors. *Environmental Pollution*, **127**: 27–40.

Bernhard, J. M. 1988. Postmortem vital staining in benthic foraminifera: duration and importance in population and distribution studies. *Journal of Foraminiferal Research*, **18**:143-146.

Bhalla, S. N. and Kathal, P. K. 1998. Recent foraminiferal thanatocoenose from Gulf of Mannar *N. Jb. Geol. Paläon*., Mh., **207** (3): 419-431.

Boltovskoy, E. and Wright, R. 1976. Recent foraminifera. The Hague, Dr. W. Junk B.V., Publishers, pp. 515.

Cherchi, A., Da Pelo, S., Ibba, A., Mana, D., Buosi, C. and Floris, N. 2009. Benthic foraminifera response and geochemical characterization of the coastal environment surrounding the polluted industrial area of Portovesme (South-Western Sardinia, Italy). *Marine Pollution Bulletin*, **59**: 281-296.

Coccioni, R. and Marsili, A. 2005. Monitoring in polluted transitional marine environments using foraminifera as bioindicators: a case study from the Venice Lagoon (Italy), pp. 250–256, In: Lagoons and Coastal Wetlands in the Global Change Context: Impacts and Management Issues. (Eds. Lasserre, P., Viaroli, P., Campostrini, P.). Proceedings of the International Conference Venice, 26–28 April 2004, IOC Integrated Coastal Area Management (ICAM), Dossier No. 3. UNESCO.

Coccioni, R., Marsili, A. and Venturati, A. 2003. Foraminiferi e stress ambientale, pp. 99-118. In: Verso la gestione integrata della costa del

Monte S. Bartolo: risultati di un progetto pilota. (Ed. Coccioni, R.). Quaderni del Centro di Geobiologia Università degli Studi di Urbino, **1**: 99–118.

Coccioni, R., Marsili, A., Frontalini, F. and Troiani, F. 2005. Foraminiferi bentonici e metallic in traccia: implicazioni ambientali, pp. 57–92. In: La dinamica evolutiva della fascia costiera tra le foci del fiume Foglia e Metauro: verso la gestione integrata di una costa di elevato pregio ambientale. (Ed. Coccioni, R.). Quaderni del Centro di Geobiologia Università degli Studi di Urbino, **1**.

Coccioni, R. 2000. Benthic foraminifera as bioindicators of heavy metal pollution – a case study from the Goro Lagoon (Italy), pp. 71–103. In: Environmental Micropaleontology: The Application of Microfossils to Environmental Geology (Ed. Martin, R.E.), Kluwer Academic/Plenum Publishers, New York.

Cushman, J. A. 1959. Foraminifera, Their Classification and Economic Use, 4th Ed., with an Illustrated Key to the Genera, Harvard University Press, Massachusetts, p. 588.

Debenay, J. P., Tsakiridis, E., Soulard, R. and Grossel, H. 2001. Factors determining the distribution of foraminiferal assemblages in Port Joinville Harbor (Ile d'Yeu, France): the influence of pollution. *Marine Micropaleontology*, **43**:75–118.

Debenay, J. P., Millet, M. and Angelidis, M. 2005. Relationships between foraminiferal assemblages and hydrodynamics in the Gulf of Kalloni (Greece). *Journal of Foraminiferal Research*, **35**: 327–343.

Duval, W. S., Brockington, P. J., von Melville, M. S. and Geen, G. H. 1974. Spectrophotometric determination of dissolved oxygen concentration in water. *Journal of the Fisheries Research Board of Canada*, **31**: 1529-1530.

Frontalini, F. and Coccioni, R. 2008. Benthic foraminifera for heavy metal pollution monitoring: a case study from the central Adriatic Sea coast of Italy. Estuarine, *Coastal and Shelf Science*, **76**: 404–417.

Frontalini, F., Buosi, C., Da Pelo, S., Coccioni, R., Cherchi, A. and Bucci, C. 2009. Benthic foraminifera as bio-indicators of trace element pollution in the heavily contaminated Santa Gilla lagoon (Cagliari, Italy). *Marine Pollution Bulletin*, **58**: 858-877.

Gaudette, H. E., Flight, W. R., Toner, L. and Folger, D. W. 1974. An inexpensive titration method for determination of organic carbon in Recent sediments. *Journal of Sedimentary Petrology*, **44**: 249-253.

Geslin, E., Debenay, J. P., Duleba, W. and Bonetti, C. 2002. Morphological abnormalities of foraminiferal tests in Brazilian environments: comparison between polluted and non-polluted areas. *Marine Micropaleontology*, **45**: 151–168.

Jena, B. K., Chandramohan, P. and Sanil Kumar, V. 2001. Long shore transport based on directional waves along north Tamil Nadu coast. India. *Journal of Coast Research*, **17**: 322-327.

Jeyabal, G., Muralidharan, S., Ramasamy, S., Rajeshwara Rao, N., Krishna Kumar, S. and Parthasarathy, P. 2015. Vertical distribution of foraminifera species and palaeo-ecology of the Pichavaram mangrove ecosystem, Southeast coast of India. *Journal of Coastal Science*, **3**: 1-7.

Kathal, P. K. 2002. Taxonomy, distributional patterns and ecology of Recent foraminifera of the east coast of India. *N. Jb. Geol. Paläon. Abh.* **(1)**:115-160.

Kannan, R. and Kannan, L. G. 1996. Physico-chemical characteristics of sea weed beds of the Palk Bay, southeast coast of India. *Indian Journal of Marine Science*, **25**: 358-362.

Kumar, V. and Manivannan, V. 2001. Benthic foraminifera responses to bottom water characteristics in the Palk Bay, off Rameshwaram, southeast coast of India. *Indian Journal of Marine Science*, **30**: 173-179.

Knudsen, M. 1901. Hydrographical Tables, G.M. Mfg. Co., New York, p. 63.

Krumbein, W. C. and Pettijohn, F. J. 1938. Manual of Sedimentary Petrography, D. Appleton Century Co. Inc., New York, p. 549.

Khare, N., Sinha, R., Raj, A. K. and Nigam, R. 1995. Distributional pattern of benthic foraminiferal morpho-groups in the shelf region off Mangalore: Environmental implications. *Indian Journal of Marine Science*, **24**: 162-165.

Loeblich, A. R. and Tappan, H. 1987. Foraminiferal genera and their classification, Von Nostrand Reinhold, New York, p. 970.

Loeblich, A. R. and Tappan, H. 1992. Present Status of Foraminiferal Classification, pp. 93-101. In: Studies in Benthic Foraminifera, Proceedings, 4th International Symposium on Benthic Foraminifera, Sendai, 1990. (Eds. Takayanagi, Y. and Saito, T.) Tokai University Press, Japan.

Loring, D. H. and Nota, D. J. G. 1973. Morphology and sediments of Gulf of St. Lawrence. *Bulletin of the Fisheries Resources Board of Canada*, **182**: 1-147.

Loring, D. H. and Rantala, R. T. T. 1992. Manual for the geochemical analyses of marine sediments and suspended particulate matter. *Earth Science Reviews*, **32**: 235-283.

Loveson, V. J., Rajamanickam, G.V. and Anbarasu, A. 1990. Remote Sensing application in the study of sea level variation along Tamil Nadu coast, India, pp.179-195. In: Sea Level Variation and its Impact on Coastal Environment. (Ed. G.V. Rajamanickam), Tamil University Press, Thanjavur.

Mohan, P. M., Shephard, K., Angusamy, N., Suresh Gandhi, M. and Rajamanickam, G. V. 2000. Evolution of Quaternary sediments along the coast between Vedaranyam and Rameswaram. *Journal of Geological Society India*, **56**: 271-283.

Murray, J. W. 1991. Paleoecology of Benthic Foraminifera, Longman Group, London, p. 397.

Murray, J. W. 1973. Distribution and ecology of living benthonic foraminiferids. Heinemann Educational Books Ltd., London, p. 274.

Newcombe, C. L., Horne, W. A. and Shepherd, B. B. 1939. Studies on the physics and chemistry of estuarine water in Chesapeake Bay. *Journal of Marine Research*, **11**: 87-116.

Rasheed, D. A. and Ragothaman, V. 1978. Ecology and distribution of Recent foraminifera from the Bay of Bengal off Porto Novo, Tamil Nadu state, India. Proc VII Indian Coll Micropal Strut, 263–298.

Rao, M. S., Vedantam, D. and Nageswara Rao, J. 1979. Distribution and ecology of benthic foraminifera in the sediments of the Visakhapatnam shelf. *Paleogeography, Palaeoclimatology, Palaeoecology,* **27**: 349-369.

Reddy, K. R. and Rao, R. J. 1984. Foraminifera-Salinity relationship in the Pennar estuary, *Jour.Foram.Res.,* **14**. 115-119.

Rao, K. K., Sivadas, P., Narayanan, B., Jayalakshmy, K. V. and Krishnan Kutty, M. 1987. Distribution of foraminifera in the lagoons of certain islands of the Lakshadweep Archipelago, Arabian Sea. *Indian Journal Marine Science,* **16**, 161-178.

Rao, K. K., Jayalakshmy, K. V., Pannikar, B. M. and Krishna Kutty, M. 1988. Living planktonic foraminifera of the Wedge bank, Nothern Indian Ocean. *Ind. Jour. Mar. Sci.,* **17**: 67-70.

Rajeshwara Rao, N., Jayaprakash, J. and Velmurugan, P. M. 2013. The Ecology Of Asterorotalia Trispinosa (Thalmann, 1933) — New Insights From Muthupet Lagoon, Southeast Coast of India. *Journal of Foraminiferal Research*, **43**: 14–20.

Rajeshwara Rao, N., Saubhagya Ranjan, M., Anbalagan, S. and Pasupathi, R. 2014. Near-shore benthic foraminifera from the Nizampatanam Bay, east coast of India. *Int. J. Environ. Sci.* **4**(5): 906-9188.

Samir, A. M., Abdou, H. F., Zazou, S. M. and El-Menhawey, W. H. 2003. Cluster analysis of recent benthic foraminifera from the northwestern Mediterranean coast of Egypt. *Revue de Micropaleontologie*, **46**: 111–130.

Samir, A. M. 2000. The response of benthic foraminifera and ostracods to various pollution sources: a study from two lagoons in Egypt. *Journal of Foraminiferal Research*, **30**: 83–98.

Scott, D. B., Tobin, R., Williamson, M., Medioli, F. S., Latimer, J. S., Boothman, W. A., Asioli, A. and Henry, V. 2005. Pollution monitoring in two North American estuaries: historical reconstructions using benthic foraminifera. *Journal of Foraminiferal Research*, **35**: 65–82.

Setty, M. G. A. P. and Nigam, R. 1982. Foraminiferal assemblages and organic carbon relationships in benthic marine ecosystems of western Indian continental shelf. *Indian Journal of Marine Science*, **2**: 225-232.

Sneed, E. D. and Folk, R. L. 1958. Pebbles in the lower Colorado River, Texas – A study of particle morphogenesis. *Journal of Geology*, **66**: 114-150.

Suresh Gandhi, M., Rajamanickam, G. V. and Nigam, R. 2002. Taxonomy and distribution of benthic foraminifera from the sediments off Palk Strait, Tamil Nadu, east coast of India. *Journal of the Palaeontological Society of India*, **47**: 47-64.

Suresh Gandhi, M. and Rajamanickam, G. V. 2004. Distribution of certain ecological parameters and foraminiferal distribution in the depositional environment of Palk Strait, east coast of India. *Indian Journal of Marine Sciences*, **33**: 287-295.

Suresh Gandhi, M., Kasilingam, K., Arumugam, T., Lalthansangi and Rajeswara Rao, N. 2017. Distribution of benthic foraminifera, sediment characteristics, and its environmental conditions in and around Manalmelkudi Spit, Palk Strait, Tamil Nadu, East coast of India. *Indian Journal of Geo-Marine Sciences*, **46**: 519-533.

Sundararaj, V. and Venkatasamy, M. 1989. Seaweeds (in Tamil). Star Publications, Madras, p. 187.

Sundararajan, M. and Usha, N. 2010. Environmental Significance in recent sediments along Bay of Bengal and Palk Strait, East coast of India: A Geochemical approach. *International Journal of Environmental Research*, **4**(1): 99-120.

Sundara Raja Reddy, B., Jayaraju, N. and Reddy, K. R. 2012. Anthropogenic Impact on the Pulicat Lagoon Monitoring with Foraminifera, East coast of India. *Marine Science*, **2**(5): 66-76.

Tabita, S. and Senthil Nathan, D. 2014. Distribution of benthic foraminifera off Cuddalore, Bay of Bengal, southeast coast of India. *Int Res J Environ Sci* **3**(9): 5–13.

Thilagavathi, B., Varadharajan, D., Manoharan, J., Vijayalakshmi, S. and Balasubramanian, T. 2012. Taxonomy and Distribution of Benthic Foraminifera from the Sediment of Palk Strait, South East Coast of India. International Journal of Pharmaceutical & Biological Archives, **3**(5): 1129-1136.

Walker, D. A., Linton, A. E. and Schafer, C. T. 1974. Sudan Black B: a superior stain to rose Bengal for distinguishing living and non-living foraminifera. *Journal of Foraminiferal Research*, **4**: 205-215.

Walton, W. R. 1952. Techniques for recognition of living foraminifera, Contributions from the Cushman Foundation for Foraminiferal Research, **3**: 56-60.

Yanko, V., Kronfeld, J. and Flexer, A. 1994. Response of benthic foraminifera to various pollution sources: implications for pollution monitoring. *Journal of Foraminiferal Research*, **24**: 1–17.

Yanko, V., Arnold, A. J. and Parker, W. C. 1999. Effects of marine pollution on benthic foraminifera, pp. 217–235. In: Modern Foraminifera (Ed. Sen Gupta, B.K.). Kluwer Academic Publisher, Dordrecht.

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