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Distribution of Benthic Foraminifera off Cuddalore, Bay of Bengal, Southeast Coast of India

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Abstract

Benthic foraminifera from both surface and core sediments collected along two transects in the offshore region of Cuddalore were studied in parallel to environmental variables and sediment characteristics. Altogether 95 species belonging to 47 genera and 6 orders were identified. Analysis revealed that species richness is high in the inner shelf while abundance increases seaward. Amphistegina, Quinqueloculina, Operculina and Elphidium are dominant in areas of coarser sediments and strong current activity. The outer shelf assemblage is characterised by muddy sediments rich in Uvigerina, Bulimina and Bolivina. Living specimens were rare though few numbers were found in the near shore region. The temperature, pH, dissolved oxygen and dissolved nitrogen content of the sample locations exhibited minimal changes except salinity. Strong currents, slight variations in the physicochemical parameters, mixing of cytoplasm during the development stages of tests would have resulted in test abnormalities. Four kinds of textures were identified: Sand, slightly sandy mud, slightly muddy sand, muddy sand. Statistical analysis showed that taxonomic richness never exceeded 13 per sample and they are more or less evenly distributed in all the stations.

Keywords: Benthic foraminifera, diversity, sediments, physicochemical parameters, statistical analysis, Bay of Bengal, India.

Introduction

Benthic foraminifera are single- celled microorganisms found ubiquitously in all the marine habitats[1]. They are easy to collect and have good fossilization potential offering vast scope to study them in detail. They are sensitive to pollution, changes in the sea level, environment and also provide excellent dataset for statistical analysis[2]. In the recent years a world wide application of benthic foraminifera as a bio - monitoring tool to investigate the changes in environmental parameters due to natural calamities and anthropogenic effect has been witnessed. Test abnormalities are noticed in naturally stressed environments exhibiting variations in pH, salinity and other parameters[3]; pollution[4] and also due to biological changes during the development stage[5]. The aim of this study is i. to examine the changes in the foraminiferal assemblages and know their distribution pattern both spatially and vertically using a multifaceted (micropaleontological, sedimentological and statistical) approach, ii. to deduce the response of foraminifera to environmental factors such as bathymetry, substrate, salinity, water currents etc.

Study Area: The area under investigation spans the continental shelf and the upper slope off Cuddalore where Ponnaiyar and Gadilam Rivers drain in to the Bay of Bengal. The river Ponnaiyar, with an estimated length of 430 km, is one of the largest interstate flowing eastern rivers. It originates from the eastern slope of Nandidurg Hills of Karnataka and flows through Karnataka and Tamil Nadu prior to joining the Bay of Bengal 3 miles north of Cuddalore. It has a catchment area of 16,019 km^2. It divides further into Ponnaiyar and Gadilam rivers below the Thirukovilur anicut. The river sediments provide an important source of building material[6]. Known for its significance since historic times, this river continues to play an indispensable role even today. People in Karnataka and Tamil Nadu states rely upon this water resources for drinking water, industrial and agricultural purposes. The Gadilam River covers a distance of 112 km as it streams through Villupuram and Cuddalore districts of Tamil Nadu and eventually drains into the Bay near Cuddalore. It has a drainage area of 900 km^2 and is bounded by Ponnaiyar and Vellar basins[7]. The climate in this region is subtropical with a maximum mean temperature of 26 °C. The average annual rainfall received is around 1040 mm[8]. The Cuddalore shelf is narrow and has an average width of 79 km. It is concave shaped with a gentle gradient up to 3000 m of water depth[9]. Two submarine canyons with steeply sloping, V-shaped walls are identified with their heads situated between 36 and 54 m depth[10].

Material and Methods

Sample collection: The collection of substrate sediment samples were carried out on a cruise in June 2012. Sediments were collected using van Veen grab sampler in two transects (figure 1) from different water depths ranging between ~ 10 and ~ 450 m. However, the sediments from beyond 100 m of water depth (transect –I) could not be retrieved owing to strong currents during the onset of SW monsoon. 50 g of sediment was

scraped from the top surface of the sediment and preserved in already cleansed vials containing Rose – Bengal solution (> 70% of ethanol and 2 g of stain /l)[11] for a fortnight[12]. Rose – Bengal solution is used to stain the living specimens and only brightly coloured foraminifera are counted as alive[13]. Physicochemical parameters like depth, temperature, pH, salinity, dissolved oxygen and dissolved nitrogen content were measured on board 'ROV - Sagar Paschimi' using SCUBA Submersible Fluorometer (table 1).

A short core was also collected using gravity corer from water depth of ~ 12.5 during a cruise on 'ORV – Sagar Manjusha' in February 2013. The top 5 cm of the core was sliced into 1-cm-thick samples, and 2-cm-thick layers were obtained from the remaining portion. Subsamples from every 5 cm interval were used for granulometric analyses.

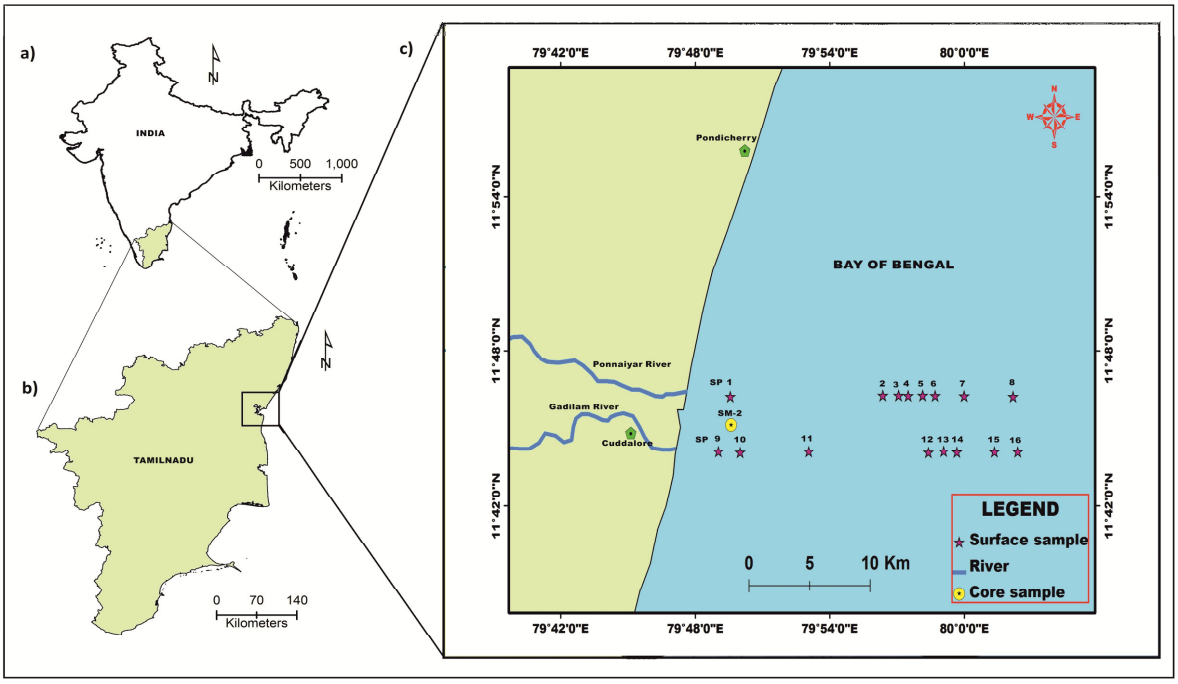


Figure-1
Study area showing sample locations

Table-1
Coordinates and physicochemical parameters of the study area

Sample Id	Latitude N	Longitude E	Depth (m)	T (°C)	pH	Salinity (psu)	DO (mg/l)	DN (ml/l)
SP-1	11.771452	79.826236	11	27.05	8.63	35.61	6.53	8.53
SP-2	11.772075	79.939649	32	27.26	8.77	35.71	6.62	8.62
SP-3	11.770849	79.951955	58	27.41	8.75	36.08	6.70	8.71
SP-4	11.771093	79.958250	74	27.91	8.80	37.29	6.76	8.77
SP-5	11.770603	79.969360	106	27.91	8.81	38.98	6.98	9.01
SP-6	11.771099	79.977993	139	27.84	8.82	39.83	7.22	9.28
SP-7	11.772358	79.999795	252	28.15	8.80	43.39	8.15	10.30
SP-8	11.773137	80.035980	411	28.35	8.81	43.09	8.68	10.95
SP-9	11.734540	79.817194	9	27.99	8.73	36.21	6.53	8.51
SP-10	11.734767	79.833419	15	28.06	8.95	36.64	6.56	8.54
SP-11	11.734709	79.884370	26	28.35	8.85	37.39	6.58	8.56
SP-12	11.732830	79.975230	75	28.62	8.84	38.41	6.78	8.79
SP-13	11.733510	79.984649	119	27.92	8.84	39.40	7.11	9.15
SP-14	11.733705	79.992583	161	28.15	8.82	41.16	7.60	9.71
SP-15	11.734279	80.024614	282	27.99	8.81	41.91	8.29	10.48
SP-16	11.736374	80.039914	404	27.95	8.80	41.52	8.73	11.01
SM-2	11.747205	79.832283	12.5	-	-	-	-	-

Note: SP refers to surface samples and SM stands for core sample.

Sample processing: Sediments: The collected sediment samples were first air dried and then oven dried at 40°C overnight. 100 gm of weighed subsample is placed in a stack of ASTM sieves (2.0 mm = 1 Φ (phi), 1.0 mm = 0 Φ, 0.5 mm = 1 Φ, 0.25 mm = 2 Φ, 0.125 mm = 3 Φ and 0.63 mm = 4 Φ) and shaken for ten minutes. The grain size fractions are weighed for grain size distribution. The raw weight of each fraction is expressed as its weight percentage. Udden – Wentworth scale for grain size analysis is used to know the gravel, sand and mud content for each sample [14]. However, textural class is assigned based on the mud content after Reineck & Siefert [15], and Pejrup[16], modified by Fleming[17].

Foraminiferal analysis: At the lab, samples were wet sieved through 63and 125 µm sieves. Around 300 individuals were picked from > 125 µm fraction, mounted and identified from each sample[1]. Altogether 8168 benthic foraminifera were recognised from the surface and core sediments.

Diversity indices were calculated using the PAleontological STatistics (PAST) software, Version 2.17[18]: i. Taxonomic richness (S); S is the number of taxa per sample, ii. Dominance (D) is the percentage of the most common species and iii. Shannon Diversity Index (H) is determined from the total count of individuals (n) and the number of individuals (n_i) present in each taxon *i* using the equation $H(S) = \Sigma ((n_i /n) \text{ In } (n_i/n)$ [1, 19]. iv. Evenness [E] is quantified as the degree of evenness in distribution of species[20]. v. Margalef's richness index [(S-1) / ln (n)], (f) Equitability [J] and (g) Fisher-α index [S = α*ln (1 + n/ α)] is the relationship between the species count and the sum of individuals in an assemblage [21, 22].

Results and Discussion

Grain size distribution: The surficial sediments in the Cuddalore shelf are predominantly characterised by sand. High amount of sand in this region is correlated with the occurrence of high wave energy conditions which caused the winnowing of fine sediments[22], due to erosion[23] and presence of submarine canyons[10]. The coarser sediments are composed of gravel, mollusc shells and fragments of bryozoan colonies while carapaces and valves of ostracoda are found in medium sized fraction. In Transect - I, samples from shallow depths (< 75m) exhibit more content of sand (> 92%). Mud percentage is below 10 in all the sites. In the second transect, amount of sand is found to decrease gradually with depth but with a sudden decline at 282 m (~ 9%). Less than 20% of mud is found in all the sites except slightly higher quantity at 15 m (~ 39%) and more of mud in 282 m (~92%). Core sediments, showed an overall sandy mud pattern. However, high mud content is witnessed between 20 -25 cm depth (table 2).

Physicochemical parameters: In all the sampling stations, temperature varied between 27 – 29°C, dissolved oxygen and nitrogen content varied between 6.5 – 9 mg/l and 8.5 – 11 ml/l respectively. Salinity in northern part of the study area (35- 43 psu) differed slightly compared to that of the southern side (36 - 41 psu). The above parameters are observed to steadily increase with increasing depth. pH values were well within the normal range of seawater (7.5 – 8.84) except in two sites, SP- 10 &11 showing 8.95 and 8.85 (table 1).

Table-2
Textural class based on mud content after Reineck and Siefert (1980), and Pejrup (1988), modified (Fleming, 2000)

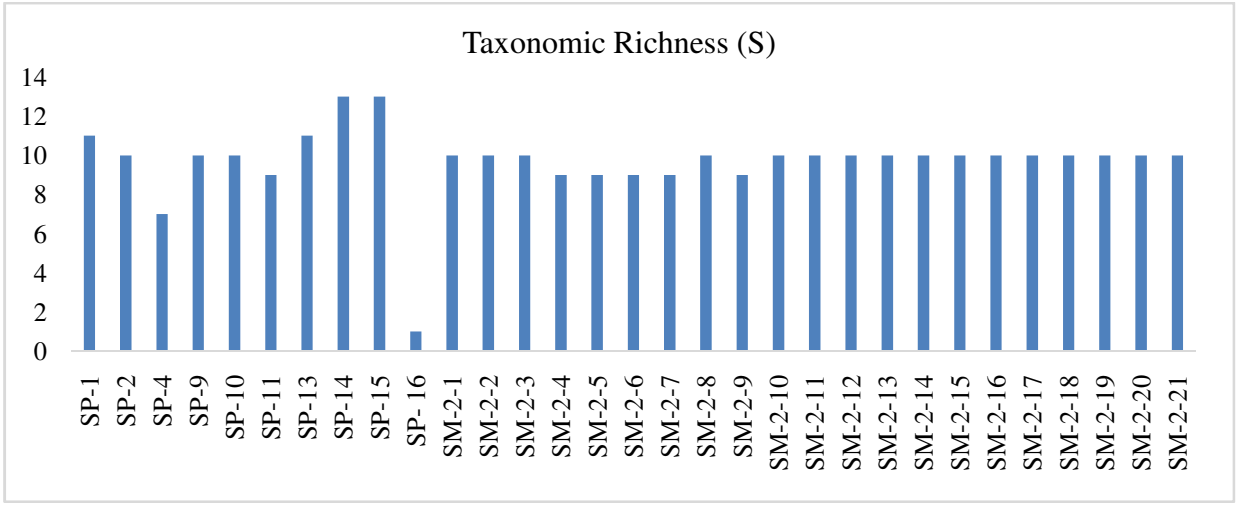
Sample Id	Sand %	Mud %	Textural Class
SP-1	92.09	7.91	Slightly muddy sand
SP-2	95.46	4.55	Sand
SP-4	94.25	5.75	Slightly muddy sand
SP-9	93.8	6.19	Slightly muddy sand
SP-10	61.60	38.405	Muddy sand
SP-11	85.94	14.06	Slightly muddy sand
SP-13	85.55	14.45	Slightly muddy sand
SP-14	80.14	19.84	Slightly muddy sand
SP-15	8.31	91.69	Slightly sandy mud
SM-2-1	83.02	25.27	Muddy sand
SM-2-2	64.51	35.47	Muddy sand
SM-2-3	57.37	42.59	Muddy sand
SM-2-4	38.45	57.05	Sandy mud
SM-2-5	32.57	67.42	Sandy mud
SM-2-6	37.94	62.05	Sandy mud
SM-2-7	39	61.48	Sandy mud

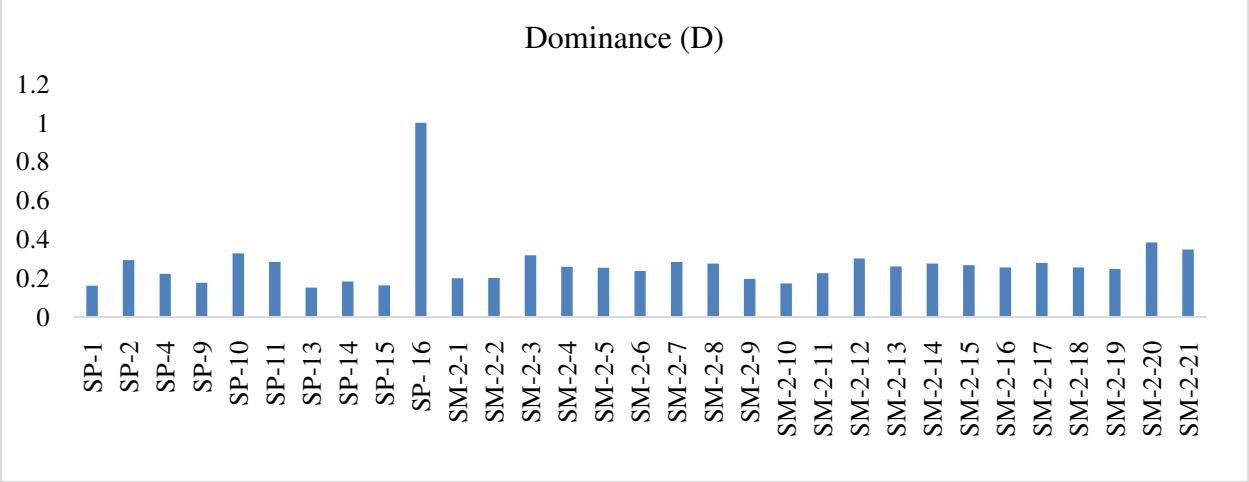
Foraminiferal analysis: 95 species have been identified out of which 59 were hyaline, perforate forms; 28 calcareous, imperforate forms, and 8 agglutinated forms. The recognised species are enlisted in table 3.

Surface samples: The total (living + dead) assemblage in the Cuddalore shelf sediments were dominated by Amphistegina (30%). Miliolids comprised (25%) of the foraminiferal population in the first transect and (20%) in the second. Species diversity is higher in the near shore and inner shelf than in the deeper substrate sediments. *Cibicides wuellerstorfi*, *Lobatula* (22%) and *Quinqueloculina spp*. (21%) were found in sandy sediments and in areas of active currents. Higher species dominance found beyond 100 m of water depths is attributed to the availability of more nutrients and organic content. *Uvigerina spp*., *Bulimina marginata* and *Bolivina spathulata* were found in > 250 m of water depth (SP -16) characterised by higher mud content and lower current velocity. This assemblage indicates the presence of hypoxic - anoxic microhabitat in the sediments contrary to the well oxygenated conditions of the overlying water column. Very few living species were encountered in the samples such as *Amphistegina radiata*, *Ammonia papillosa* and *Elphidium spp*. The lesser number is probably owing to the higher current velocity[25]. Shannon Index (H) values are > 1.5 in sites with above 80 % of sand. In stations with slightly higher mud content, these values are less. Higher number of dominance in sample no. SP -16 shows low diversity values and represented by very few species. The Margalef's Index shows > 2 values for three sites SP-1, 14 and 15 (figure 2). More relict specimens stained with ferric ion and broken tests were observed in water depth < 50 m. The assemblage includes *Triloculina trigonula*, *Triloculina insignis*, *Rotalia annectens* and *Quinqueloculina agglutinans* etc. in the order of increasing abundance. Presence of relict forms denotes low rate of deposition in the area of interest.

Core samples: *Nonion*, *Ammonia*, *Elphidium*, *Cibicides* and *Triloculina* are the dominant genera with more than 5% abundance in all the samples. *Nonion elongatum*, *Nonion fabum*, *Nonion scaphum*, *Nonionella labradorica*, *Nonionella turgida*, *Nonionella grateloupi*, *Nonionella stella* contributed to nearly half (45.3%) of the entire benthic population. Living foraminiferal assemblage are composed of *Nonion*, *Elphidium* and *Spiroloculina.* They are found in more numbers in the top three centimetres and decreased in the rest of the core. The down - core increase in mud content are correlated with the decrease in diversity and equitability values. Taxonomic Richness (S) ranges between 9 and 10 in the entire core. Shannon diversity values (H) are < 2 and equitability values (J) are < 0.82 (figure 2). Deformed tests constituted only 6.43% of the entire population picked from the samples. *Nonion fabum* and *Nonion elongatum* (~ 60%) are the major contributors while *Elphidium advenum*, *Elphidium crispum*, *Elphidium discoidale* made up nearly 20 % of the total deformed population. SEM images of few deformed species are shown in figure 1. The types of deformation observed include twisted or distorted shape, protuberances of the final chamber, overdeveloped chambers of the last whorl, reduction in size of the last chamber, twin and quadruplet forms. Developmental accidents[26], sharing of the same reproduction cyst, current action[5], change in pH, and salinity etc.[3] could be few factors that are responsible for twin and quadruplet formation in benthic foraminifera. It is also noted that high numbers of deformed tests occur only under polluted conditions[4]. However, less percentage of deformed forms suggest that these test abnormalities may be due to environmental and biological changes.

Overall, the distribution pattern in the study area reveals that the environment is more or less stable with only slight changes in the physicochemical parameters. Living foraminiferal assemblage majorly comprised of calcareous forms in the surface sediments and hyaline forms in the core. Core sediments witnessed higher numbers of deformed foraminifera than the surface sediments.




Dominance (D)
1.2
1
0.8
0.6
0.4
0.2
0
SP-1
SP-2
SP-4
SP-9
SP-10
SP-11
SP-13
SP-14
SP-15
SP- 16
SM-2-1
SM-2-2
SM-2-3
SM-2-4
SM-2-5
SM-2-6
SM-2-7
SM-2-8
SM-2-9
SM-2-10
SM-2-11
SM-2-12
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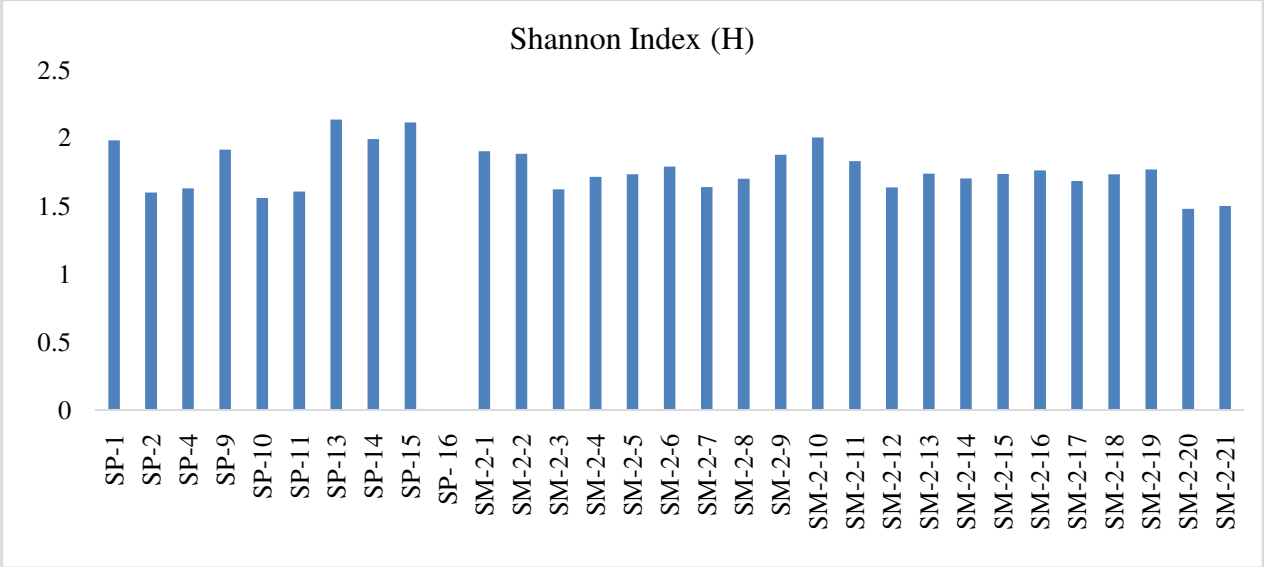
SM-2-18
SM-2-19
SM-2-20
SM-2-21


Shannon Index (H)
2.5
2
1.5
1
0.5
0
SP-1
SP-2
SP-4
SP-9
SP-10
SP-11
SP-13
SP-14
SP-15
SP- 16
SM-2-1
SM-2-2
SM-2-3
SM-2-4
SM-2-5
SM-2-6
SM-2-7
SM-2-8
SM-2-9
SM-2-10
SM-2-11
SM-2-12
SM-2-13
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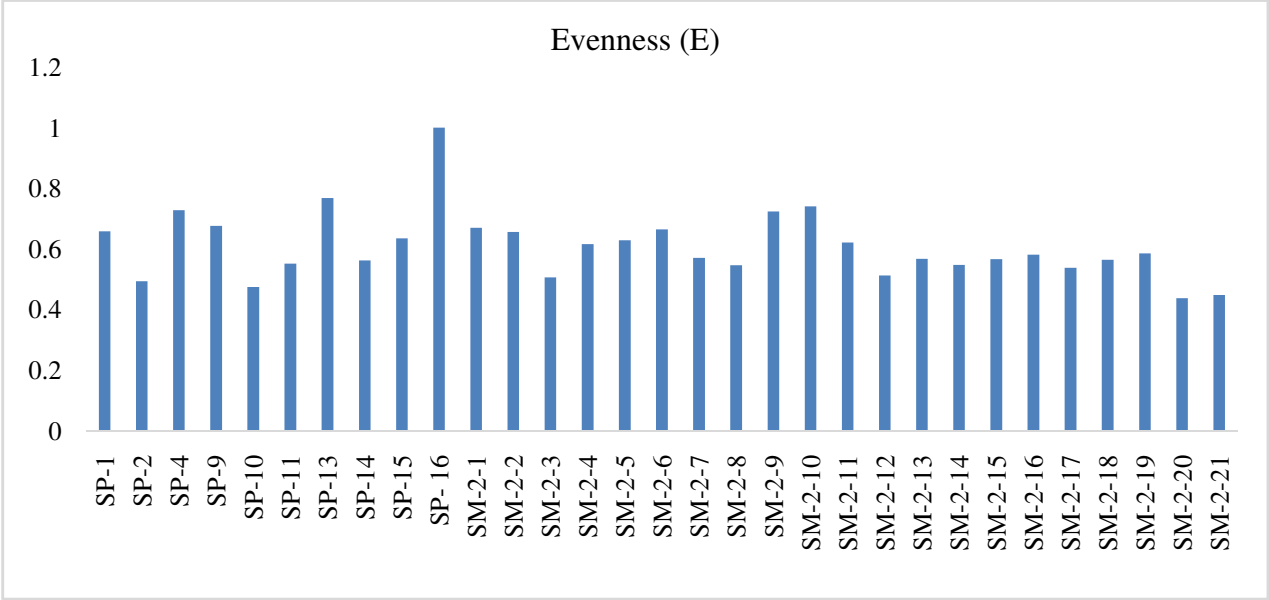
SM-2-18
SM-2-19
SM-2-20
SM-2-21


Evenness (E)
1.2
1
0.8
0.6
0.4
0.2
0
SP-1
SP-2
SP-4
SP-9
SP-10
SP-11
SP-13
SP-14
SP-15
SP- 16
SM-2-1
SM-2-2
SM-2-3
SM-2-4
SM-2-5
SM-2-6
SM-2-7
SM-2-8
SM-2-9
SM-2-10
SM-2-11
SM-2-12
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SM-2-19
SM-2-20
SM-2-21

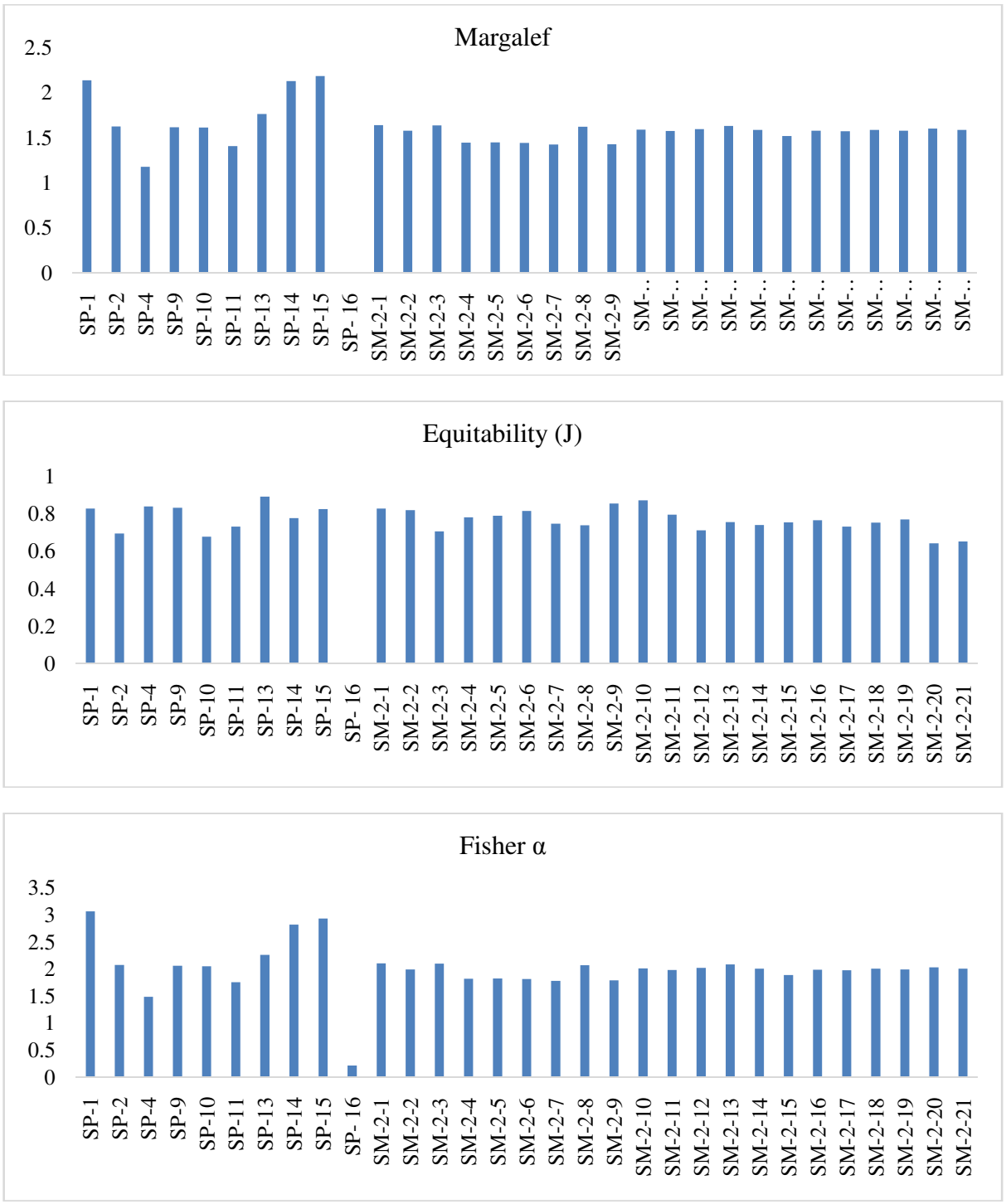

Figure-2
Statistical parameters based on the relative abundances of benthic foraminifera

Conclusion

In the present study, 95 species of benthic foraminifera have been identified from 30 sediment samples. The foraminiferal assemblage show an increase in species diversity in the inner continental shelf. *Amphistegina*, *Quinqueloculina*, *Cibicides* and *Triloculina* are the dominant genera. Epifaunal forms are abundant in coarse grained, high energy environment. The outer shelf – upper slope assemblage exhibits low species diversity, higher abundance of *Uvigerina peregrina*, *Bulimina marginata* and *Bolivina spathulata*. Nonion is the most abundant genera in the core sediments. Relatively fewer tests showing

abnormalities suggest that they are deformed naturally. Majority of the surface sampling sites are sandy in nature. The grain size distribution of core sediments range from muddy sand to sandy mud. Thus, grain size, depth, few oceanographic parameters like currents and salinity are the primary controlling factors of foraminiferal distribution in this region. Low sedimentation rate is inferred by the occurrence of relict foraminifera.

Acknowledgment

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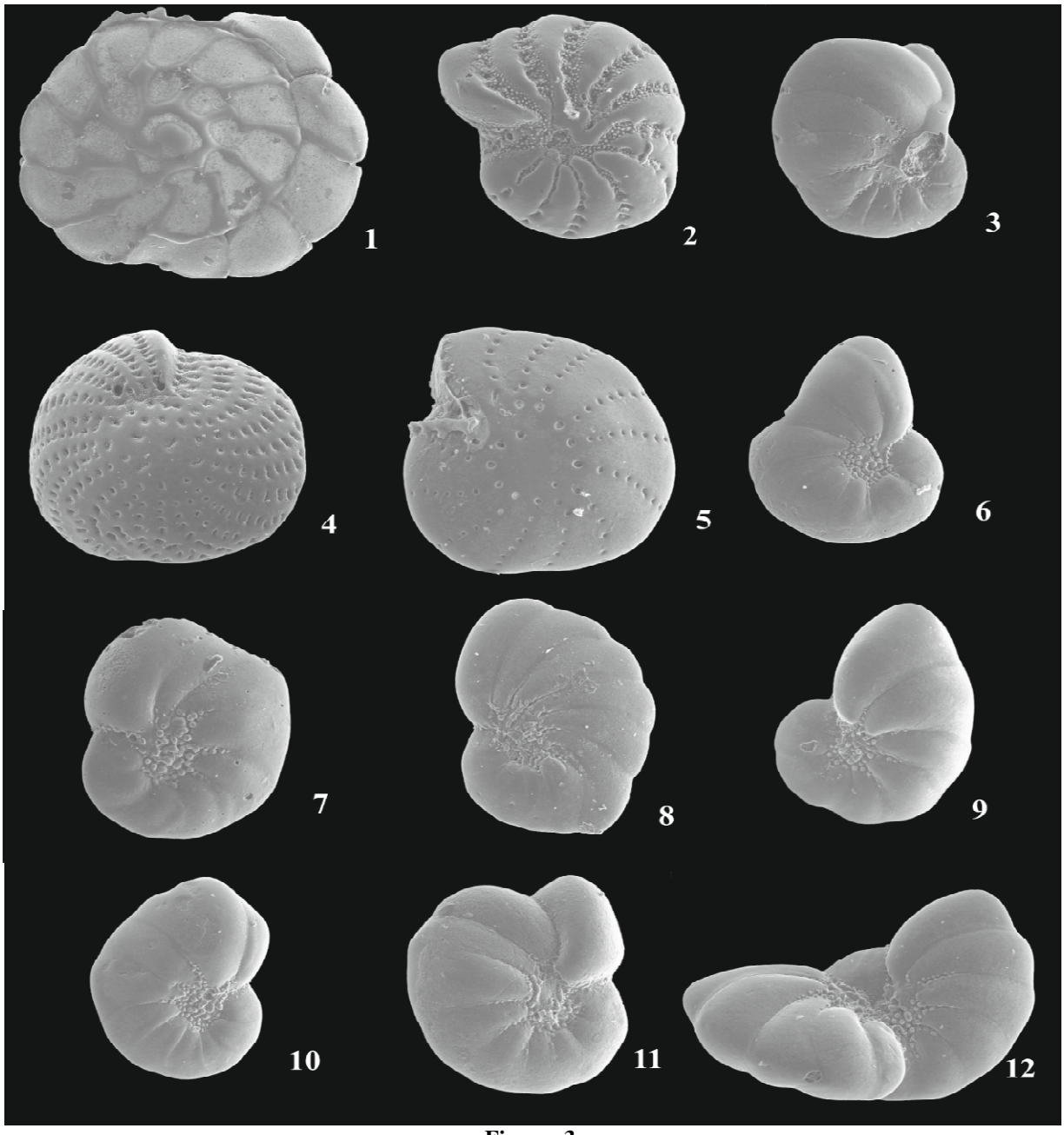

Figure -3

SEM photomicrographs of deformed individuals: (1) ***Ammonia beccarii*** **(Linnaeus, 1758) X100 (2)** ***Elphidium excavatum*** **(Terquem, 1875) X270 (3)** ***Nonion fabum*** **(Fichtel & Moll, 1798) X190 (4)** ***Elphidium craticulatum*** **(Fichtel & Moll, 1798) X130 (5)** ***Elphidium discoidale*** **(d'Orbigny, 1839) X270 (6) & (7)** ***Nonion fabum*** **(Fichtel & Moll, 1798) X180, X200 (8)** ***Nonion commune*** **(d'Orbigny, 1846) X150 (9) & (10)** ***Nonionella labradorica*** **(Dawson, 1860) X250, X210 (11)** ***Nonion fabum*** **(Fichtel & Moll, 1798) X230 (12)Twinned** ***Nonion fabum*** **(Fichtel & Moll, 1798) X210**

Table-3
List of Species

Nonion elongatum	*Rotalinoides compressiusculus*
Nonion fabum	*Rotalia annectens*
Nonion scapha	*Amphistegina gibbosa*
Nonionellina labradorica	*Amphistegina radiata*
Nonionoides turgida	*Amphistegina lessonii*
Nonionella grateloupi	*Amphistegina papillosa*
Nonionella stella	*Amphistegina bicirculata*
Spiroloculina excavata	*Pararotalia sp.*
Spiroloculina costifera	*Pararotalia calcariformata*
Spiroloculina antillarum	*Eponoides repandus*
Spiroloculina depressa	*Ammobaculites exiguus*
Spiroloculina communis	*Cancris auriculus*
Ammonia beccarii	*Cancris oblongus*
Ammonia dentata	*Rosalina globularis*
Ammonia tepida	*Adelosina mediterranensis*
Ammonia parkinsoniana	*Adelosina longirostra*
Ammonia papillosa	*Bolivina striatula*
Triloculina tricarinata	*Bolivina persiensis*
Triloculina trigonula	*Bolivina spathulata*
Triloculina echinata	*Bulimina marginata*
Triloculina insignis	*Pseudobrizalina lobata*
Cycloforina sidebottomi	*Textularia agglutinans*
Quinqueloculina variolata	*Textularia pseudogramen*
Triloculina terquemiana	*Textularia candeiana*
Elphidium crispum	*Spiroplectammina sagittula*
Elphidium macellum	*Lagenammina atlantica*
Elphidium complanatum	*Peneroplis pertusus*
Elphidium somaense	*Reophax scorpiurus*
Elphidium discoidale	*Hansenisca soldanii*
Elphidium craticulatum	*Clavulina angularis*
Elphidium advenum	*Stainforthia fusiformis*
Lobatula lobatula	*Amphicoryna scalaris*
Cibicides wuellerstorfi	*Lenticulina orbicularis*
Cibicides kullenbergi	*Lenticulina gibba*
Cibicides refulgens	*Lagena perlucida*
Cibicides praecinctus	*Reussella spinulosa*
Cibicides pachyderma	*Alveolinella quoii*
Quinqueloculina lamarckiana	*Borelis melo*
Quinqueloculina lata	*Operculina granulosa*
Quinqueloculina undulose costata	*Operculina ammonoides*
Quinqueloculina seminula	*Uvigerina mediterranea*
Quinqueloculina parkeri	*Uvigerina peregrina*
Quinqueloculina philippinensis	*Rectiuvigerina phlegri*
Siphonaperta agglutinans	*Planorbulinella larvata*
Miliolinella circularis	*Calcarina hispida*
*Miliolid sp.*A	*Neorotalia calcar*
Quinqueloculina sp. A	*Pyrgo denticulata*

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