JOURNAL OF GEOINTERFACE, Vol.1, No.1, July 2022 pp.16-27

Response of living benthic foraminifera to environmental variables in the Anchuthengu estuary, Kerala

Jeshma. P[1], Suresh Gandhi[1], R. Tharun[2] and A. Nallapa Reddy[3*]
[1]Department of Geology, University of Madras, Chennai-600025
[2]Christ college, Irinjalakuda, Thrissur-680125
[3]Majestic shore, Choolaimedu High Road, Chennai-600094
*Corresponding author: anreddy54@gmail.com

Abstract: The spatial distribution, total foraminifer number (TFN), and species richness (S) of living benthic foraminiferal assemblages were investigated in 20 surficial sediment samples collected in two seasons (premonsoon-May 12,2017 and Monsoon-Aug, 14,2017) from the Anchuthengu Estuary to understand its ecological significance. The patterns of foraminifer distribution, total foraminifer number, and species richness were correlated with environmental variables such as salinity, pH, and DO. The study reveals that the estuary sustains low to moderate TFN and low species richness of benthic foraminifera. There are 20 species of foraminifer taxa in the premonsoon and 19 taxa in the monsoon. In both seasons, Ammonia *beccarii*, *A. tepida* are persistent and dominant, while *A. convexa*, Elphidium norvangi, Hanzawaia conccentrica, Nonionoides elongatus and Pararotalia nipponica are sparse and low in abundance. Ecological variables like pH and salinity appear to have a relatively positive relationship with TFN and S, while DO has no such association. The premonsoon standing crop is #4311, which is higher than the monsoon standing crop of #1910, and this correlates to the average OM values. Low species richness and low to moderate but highly fluctuating TFN suggest that ecologically stressed conditions were prevalent in the Anchuthengu estuary during the study period.
Keywords: Benthic foraminifera, environmental variables, Anchuthengu estuary.

Introduction

Foraminifera are unicellular eukaryotes that live in all maritime habitats. They are good markers of worldwide change as well as prospective indicators of the environmental health of marine ecosystems. Foraminifera are effective bioindicators of the environmental changes caused by natural and human-caused processes (Alve, 1995; Khare et al., 2007; Pati and Patra, 2012; Sreenivasulu et al., 2017). Benthic foraminifera have thus been widely employed as environmental bioindicators to monitor environmental quality (Murray and Alve, 2002; Frontalini and Coccioni, 2011; Sarita et al., 2015), as they are influenced by a variety of ecological factors such as salinity and temperature changes, nutrient abundance, oxygen concentration, and anthropogenic pollution (Alve, 1995; Yanko et al., 1998; Armynot du Châtelet and Debenay, 2010). Benthic foraminifera have been widely used to study environmental changes in marginal marine, coastal, and marine shelf environments. The Anchuthengu Estuary was chosen for the present investigation because no baseline foraminifer studies had been done previously. The Anchuthengu estuary is located in the Thiruvananthapuram district of Kerala, between latitude 8º 16' 79" N and longitude 76º 71' 63" E (Fig. 1). The estuary is subjected to diurnal tidal influences. This estuary is one of the most important sites for the retting of coconut husk, which is the first step in the manufacture of the well-known golden coir fiber, and it has a significant impact on the estuarine system. At the mouth of the estuary, there is also a fishing harbor. The purpose of this research is to better understand the environmental factors that determine live benthic foraminifera distribution patterns and to assess the ecological quality of the Anchuthengu estuary. As a result, any paleoecological conditions of a coastal ecosystem can be predicted using the validated relationship between present benthic distribution, abundance, species richness, and environmental variables.

Methods of Study

Twenty sediment and bottom water samples were obtained during the post-monsoon (August 14, 2016) and pre-monsoon (May 12, 2017) seasons. With the use of a multi-probe, water parameters such as pH, dissolved oxygen (DO), and salinity were recorded on board. The procedure for sediment sample collection, staining, preservation, and processing for foraminifera was adopted from FoBiMo group (Schonfeld et al., 2012). The processed samples were observed under a stereo binocular microscope, and stained foraminifer tests were separated and mounted on faunal slides. Then, using Loeblich and Tappan (1988), the World Foraminiferal Database, the HMS Challenger Reports (1884), and direct comparison with foraminifer species deposited in the University of Madras Repository, the taxonomic identification was completed.

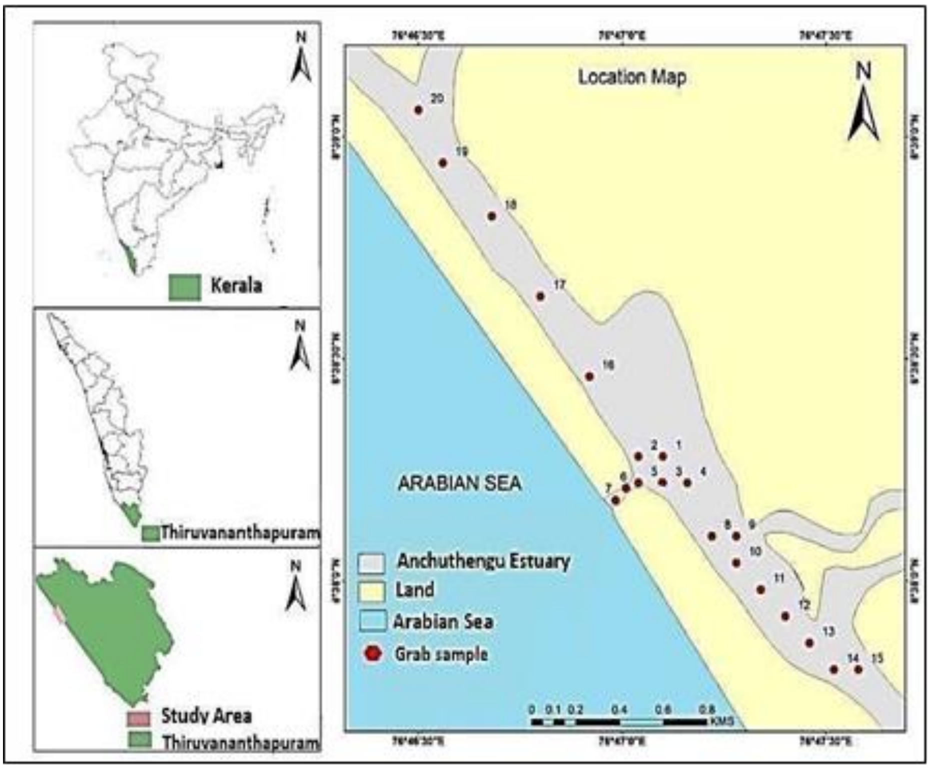

Fig. 1. Study area map showing sample locations in the Anchuthengu estuary.

Results

For the sake of convenience, the estuary is divided into four sub-environments: lower estuary (stations. 1–7), backwaters (Stations 8–15), and upper estuary (stations. 16–20). Pre-monsoon samples are labeled G-PRE 1 while monsoon samples are labeled G-MON 1 and so on.

Ecological parameters: The regional distribution of critical water characteristics such as pH, salinity, and DO is shown in Table 1 and Table 2. The pH of bottom waters does not change significantly throughout the year. In the pre-monsoon, the pH ranged from 6.4 to 8, with an average of 7.2, the maximum value was recorded at stations G-PRE-5, G-PRE-6, and G-PRE- 7 (Lower estuary), and the lowest value at G-PRE-20. While in the monsoon, it ranged from 7.89 to 6.2 with an average of 7.05, with the highest value recorded at stations G-MON-5, G- MON-7, and G-MON-8 and the lowest at the station. G- PRE-20 and the somewhat alkaline nature of bottom waters are indicated by pH values ranging from 6.2 to 8. Salinity varied from 26.6‰ to 43 ‰ with an av. 34.8‰ in pre-monsoon with the highest value at G-PRE-7 and the lowest at G-PRE-20. In monsoon, it ranged from 19.2‰ to 44.2‰ with an average of 31.7‰, with the highest at G-MON-6 and lowest at G-PRE-20. The average salinity is relatively lower in the Monsoon. Slightly higher salinity values at stations 5, 6, and 7 in the monsoon may be attributed to increased turbidity caused by flood water mixing and resuspension of bottom sediments, as these stations are located at a confluence of sea, estuary, and backwaters. The salinity values reduced sizably in the monsoon season. The salinity values show a gradual decreasing trend from backwaters to upper estuary in both seasons. The salinity shows a broad linear relationship with TFN and S. Dissolved oxygen ranged between 3.03 - 3.37 mL/L with an average of 3.2mL/L in pre-monsoon, with the highest at station G-PRE-14, and lowest at G-PRE-6, while it ranged from 3.1 to 4.8 mL/L with an average of 3.95mL/L in monsoon., with the highest value at station G- MON-17 and lowest at station G-MON-3. The DO shows a gradual increasing trend toward the upper estuary in both seasons.

Total Foraminifer Number (TFN): Tables 3&4 illustrate the spatial distribution of TFN and S in both seasons. Total living foraminifer number (TFN) is relatively higher in pre-monsoon than in the monsoon (Tables 3&4). In pre-monsoon TFN ranges from 0-1394 with an average of 266, with the highest (1394 specimens/10g dry sediment) reported from station G-PRE-7 in the lower estuary, and no specimens at stations. G-PRE-18, 19, and 20 are found in the upper estuary. In monsoon; TFN ranges from 0-499 with an average of 96, with the highest (499 specimens/10g.dry sediment) at station. G- MON-11, and no specimens at stations. G-MON-19 and 20 are found in the upper estuary.

Table 1. Analysis of bottom water and sediment samples in the pre-monsoon.

Samples	pH	DO (mL/L)	Salinity (‰)	Organic matter %	Sand %	Silt %	Clay%
G-PRE- 1	7.1	3.33	34.6	2.34	70	30	0.4
G-PRE- 2	7.08	3.2	35.2	3.3	87	12.08	0.52
G-PRE- 3	7,05	3.23	36.3	3.03	58	38	3.8
G-PRE- 4	7.47	3.28	37.8	3.6	90	9.52	0.48
G-PRE- 5	8	3.16	41	3.9	63	36.98	0.42
G-PRE- 6	8	3.03	41.1	3.3	9	90.72	0.48
G-PRE- 7	8	3.31	43	2.88	55	44.18	0.42
G-PRE- 8	7.1	3.29	36.8	2.9	80	19.78	0.42
G-PRE- 9	6.98	3.26	36.6	3.4	96	4.02	0.38
G-PRE- 10	7.06	3.26	36.5	3.62	84	15.4	0.4
G-PRE- 11	6.93	3.29	35.2	2.9	85	14.22	0.38
G-PRE- 12	6.82	3.2	35.1	3.96	45	54.34	0.46
G-PRE- 13	7.8	3.3	37.1	3.86	71	28.38	0.42
G-PRE- 14	7.5	3.37	35.2	2.34	15	84.7	0.5
G-PRE- 15	7.02	3.16	35	3.26	27	72.26	0.54
G-PRE- 16	7.08	3.33	30.06	2.96	94	5.98	0.42
G-PRE- 17	6.92	3.2	30.2	2.87	99	0.78	0.42
G-PRE- 18	6.5	3.32	29.01	3.56	79	20.92	0.48
G-PRE- 19	6.54	3.17	28	2.92	85	14.92	0.48
G-PRE- 20	6.4	3.2	26.6	3.26	81	18.12	0.48
Average	7.2	3.2	34.8	3.15	54	45.75	2.09
Max.Value	8	3.37	43	3.96	99	90.72	3.8
Min.Value	6.4	3.03	26.6	2.34	9	0.78	0.38

Table 2. Analysis of bottom water and sediment samples in the monsoon.

Samples	pH	DO (mL/L)	Salinity (‰)	Organic matter %	Sand %	Silt %	Clay %
G-MON- 1	7.48	3.3	35.6	0.62	93.6	6.2	0.2
G-MON- 2	7.07	3.88	35.1	0.31	98.8	1	0.2
G-MON- 3	6.99	3.1	36.2	0.22	98.8	1	0.2
G-MON- 4	7.09	3.9	37	0.37	98.2	1.6	0.2
G-MON- 5	7.9	3.4	43.1	0.34	93	6.6	0.4
G-MON- 6	7.84	4.2	44.2	0.22	99.6	0.2	0.2
G-MON- 7	7.89	3.3	41.6	0.4	98.4	1.2	0.4
G-MON- 8	7.89	3.2	39.3	0.68	79.2	20.6	0.2
G-MON- 9	7.5	3.8	39.2	3.03	93.6	6	0.4
G-MON- 10	7.48	3.18	36.2	2.81	90	9.8	0.2
G-MON- 11	6.95	3.7	35.6	1.51	79.4	20.1	0.5
G-MON- 12	7.6	3.4	36.4	2.81	60.4	39.4	0.2
G-MON- 13	7.8	4.1	37.4	1.45	50.6	49	0.4
G-MON- 14	6.9	3.3	34.6	1.14	70	23.6	0.4
G-MON- 15	6.7	3.8	30.7	0.31	89	10.8	0.2
G-MON- 16	6.9	3.7	20.3	0.43	93.6	6.2	0.2
G-MON- 17	7.2	4.8	28.9	0.4	69	30.8	0.2
G-MON- 18	6.2	4.6	23.2	0.34	80.2	19.6	0.2
G-MON- 19	6.6	4	20.2	0.56	70	29.6	0.4
G-MON- 20	6.4	3.85	19.2	0.37	62	37.8	0.2
Average	7.05	3.95	31.7	1.63	75.1	19.8	0.35
Max.Value	7.9	4.8	44.2	3.03	99.6	39.4	0.5
Min.Value	6.2	3.1	19.2	0.22	50.6	0.2	0.2

Species richness (S): Species richness is in general low in both seasons, with pre-monsoon showing marginally higher than monsoon (Tables 3 and 4). In the pre-monsoon, S varies from 0 to 9 with an average of 3.25, and in monsoon, it ranges from 0-12 with an average of 4.25. The species richness is spatially patchy and closely corroborates in both seasons. However, S does not follow the TFN trend in both seasons. Most parts of the backwater region and upper estuaries support meager species richness in both seasons although environmental variables do not show much variation in both seasons.

Substrate nature and organic matter: Tables 1&2 illustrate the substrate and organic matter(OM). In pre-monsoon, sand is the dominant lithology at all stations, except Station6, 12, and 14. The lower estuary (Station1-7) has an average of 50% sand, 19.82% silt, and 3.19% OM; backwaters (Station 8 and 9) has 66.75% sand, 11.9% silt, and 3.15% OM; backwaters (Station10-15) contain 22% sand, 22.5% silt, and 3.32% OM, and the upper estuary (Station16-20) comprise 24.2% sand, 24.2% silt, and 3.1% OM; while in monsoon, the lower estuary (Station1-7) has an average 97.1% sand, 2.54% silt, and 0.35% OM; backwaters (Station 8 and 9) has 86.4% sand, 13.3% silt, and 1.85% OM; middle estuary (Station10-15) contain 73.2% sand, 25.45% silt, and 1.67% OM, and the upper estuary (Station16-20) comprise 74.96% sand, 24.2% silt, and 0.42% OM. Relatively % sand increased by 24% and silt and OM content reduced (92%, and 250% respectively) in the monsoon, compared to the pre-monsoon. The drastic reduction in silt (av.16.05%) and OM (av.0.91%) in the monsoon, may be attributed to the fresher water influx and relatively decreased intensity of the retting process. Relatively % sand increased by 24% and silt and OM content reduced (92%, and 250% respectively) in the monsoon, compared to the pre-monsoon. The drastic reduction in silt (av.16.05%) and OM (av.0.91%) in the monsoon, may be attributed to the fresher water influx and relatively decreased intensity of the retting process. The OM in pre-monsoon varies from 2.34% to 3.96% with an average of 3.2%, which is higher than the average OM (2.7%) for retting zone areas along the Kerala coast (Murthy and Veerayya, 1972; Manoj et al., 2014).

Figure 2 demonstrates the pattern of the spatial relationship between pH, salinity, DO and TFN, and S in both seasons, respectively. A pH range of 6.8 to 8 closely correlates with relatively high TFN and S, while a pH range of 6.2 to 7.1 correlates with relatively low TFN and S. Relatively high TFN and S were recorded in pre-monsoon during which average pH is 7.2. Low pH levels have been linked to low abundance (TFN) and diversity (S) of live foraminifera (Boltovskoy and Wright, 1976). In both seasons, the salinity readings demonstrate a decreasing tendency from the lower to the upper estuary. In both seasons, the salinity has a broad linear relationship with TFN and S. Many coastal water bodies along the east coast of India have shown a favorable association between salinity, TFN, and S (Ramnathan, 1970; Reddy and Reddy, 1982, 1994; Jayaraju and Reddy, 1992; Nagendra et al., 2015; Nagendra and Reddy, 2019). The DO values of bottom waters do not fluctuate much in both seasons and at all stations. However, there is no linear relationship found between the dissolved oxygen and the TFN and S in the study area. During premonsoon marginally higher DO values were recorded at some stations compared to monsoon. The DO values are lower than the normal values of 5mL/L in both seasons, and low values may be attributed to the coconut husk retting process (Nagendra et al., 2011), and land-derived detritus. In the Anchuthengu estuary, ecological variables such as pH and salinity have a relatively positive relationship with TFN and S, although DO has no such association.

Discussions

On the basis of the present study, a relationship between the benthic foraminifer number (density) and species richness (diversity) and the ecological parameters is analyzed to assess the environmental quality of the Anchuthengu estuary.

Distribution of Foraminifer species

Ammonia group is widespread in marginal marine environments (Murray, 2006), and its pH survival range is 3.0–9.3 (Bradshaw 1957) and the salinity reproduction range is 25‰ to 40‰ (Saraswat et al., 2011). This is why Ammonia is the most widely distributed species in the Anchuthengu estuary. It is the most dominant and persistent at most stations in both seasons and is represented by mainly two species, A.tepida and A.beccarii. The well-preserved taxa are SEM photographed and illustrated in plate 1. Figure 3 shows the spatial distribution of dominant species of *Ammonia*. In pre-monsoon, 20 species belonging to 14 genera are recorded. The assemblage density varies from 0-1394 specimens/10g. dry sediment. *A. beccarii* is relatively dominant and consistent over *A. tepida*. *A. beccaii* has a moderate density in the lower estuary (Station1-6) consisting of 3-149 specimens with an average of 55; stn. 7 has the highest with 1264 specimens; the Station 8 and 9 contain 234 and 339 specimens; while Station 10-12 have individuals ranging from 20-78 with an average of 62; Station13 and 14 have 914 and 126 specimens respectively; Station 15-17 have 15, 12, and 2 individuals respectively; no specimens at Station18-20 in the upper estuary. *A. tepida* ranges from 1-249 specimens at Station 1-7 (lower estuary) with an average of 79; stn.4 is poor with 1 specimen; Station8-13 in backwaters contain poor count with 1-5 with an average of 2; stn. 14 contain 66 specimens, and Station15-20 in the upper estuary contains no specimens. *A. beccarii* is more persistent and relatively dominant in premonsoon.

In monsoon, 19 species belonging to 10 genera are recorded. The assemblage density varies from 0-499 specimens/10g. dry sediment. The most dominant and rather consistent taxa are *Ammonia tepida* and *A. beccarii* followed by *A. convexa*, Nonionoides elongatus and Elphidium norvangi, which are sparse and restricted to the lower estuary (stations 1-7). *A. tepida* and *A. beccarii* are absent at Station18-20 in the upper estuary. *A. tepida* is relatively more abundant than *A. beccarii*, and both taxa show inverse trends in their respective density. *A. tepida* is dominant in parts of backwaters (Station9-11), wherein it has a high density ranging from 436-457 specimens, and reduces rapidly at Station 12-14 with a density of 12-22 and further decreasing to only 3 individuals at stn.18, and absent at Station19 and 20. This taxon has considerably low numbers (11-66 individuals) at Station1-8 in the lower estuary. Its spatial distribution shows a patchy negative relationship with pH and salinity. *A. beccarii*, on the other hand, is relatively less abundant and shows a clear non-linear relationship with *A. tepida*. *A. beccarii* is relatively dominant ranging from 5-101specimens in the lower estuary (Station1-7); and less abundant at Station8-11 in backwaters, wherein it ranges from 5-30 individuals; and drastically reduces to only 2 individuals at Station12-13, and 1-3 specimens at Station16 and 17, and absent at Station14, 15, 19 and 20. *A. beccarii* shows a close positive correlation with pH and salinity. Other species Nonionoides elongatus present in low numbers, while Asterorotalia inflata, Elphidium norvangi are inconsistent and very sparse and occur only in the lower estuary.

In premonsoon, the high density (av.381 specimens) of *A. beccarii* at Station7-14 relates to the substrate with average sand of 66.455%, silt 33.13% and organic matter (OM) 3.23%, while high density (av.93 specimens) of *A. tepida* at Station1-7 correlates with an average sand% of 61.7, silt 37.35% and OM 3.19%. In monsoon, *A. beccarii* has a moderate density (53 specimens) at Station1-4, wherein an average of 97.35% of sand, silt 2.45%, and OM 0.38%, and A. *tepida* show relatively high density (av.288 specimens) at Station9-12 where av. 85.5% sand, silt 14.1% and OM of 2%, and this taxon has low density (av.6 specimens) at Station1-7 where sand% averages at 97.2%, silt 3.82%, and OM at 0.35%. The study reveals that the relatively high density of *A. beccarii* and *A. tepida* show just an inverse relationship with % sand, silt and OM. A. beccarii favored relatively more sand, less silt and OM conditions, while *A. tepida* preferred relatively less sand, more silt and OM conditions.

The TFN is spatially highly variable in the present estuary in both seasons and is probably impacted by species reproductive rates and sedimentation rates, which can determine varied degrees of sediment dilution (Cearreta et al., 2002; Bergamin et al., 2009). The pre-monsoon standing crop is #4311, which is significantly greater than the monsoon standing crop of #1910, and this corresponds to the average OM values of 3.2% in premonsoon and 0.91% in monsoon. The appearance of Elphidium species in low numbers in monsoon indicates a little better adaption of the genus to lower pH and higher DO in the Anchuthengu estuary (Uthicke et al., 2013; Little et al., 2021).

The findings of this study show that the Anchuthengu estuary has long been a hotspot for coconut husk retting. The density and diversity of benthic foraminifers in relation to environmental variables such as pH, salinity, and DO of bottom waters disclose a crucial database for determining the ecological health of the ecosystem. This research serves as a baseline for determining the current environmental quality of the Anchuthengu estuarine habitat. The estuary's biological condition is deteriorating, as evidenced by the low faunal density and species richness of benthic foraminifera. The poor abundance of living foraminifera in the study area may be attributed to suspended matter-driven turbidity (Narayana et al., 2008; Shynu et al., 2017) and bottom sediments re-suspension (Tatavarti et al., 1999), due to increased retting activity and freshwater mix-up in the upper estuary.

Table 3. Spatial Distribution of Benthic foraminifera in Premonsoon (A=absolute abundance; R%=relative abundance; #= total standing crop).

Species name / Stations	G-PRE-1	G-PRE-2	G-PRE-3	G- PRE-4	G- PRE-5	G-PRE-6	G-PRE-7	G-PRE-8	G- PRE-9	G-PRE- 10	G-PRE-11	G-PRE- 12	G-PRE- 13	G-PRE- 14	G-PRE- 15	G-PRE- 16	G-PRE- 17	G-PRE- 18	G-PRE- 19	G-PRE- 20	A	R%
Aesterorotalia inflata	2	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0.2
Ammonia beccarii	51	3	149	6	42	81	1264	234	339	73	20	78	914	126	15	12	2	0	0	0	3409	79
Ammonia convexa	0	0	1	4	13	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	19	0.4
Ammonia dentata	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0.1
Ammonia tepida	94	31	249	1	60	92	126	5	4	1	0	2	1	66	0	0	0	0	0	0	732	17
Amphistegina radiata	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Cibicides refulgens	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Cribrononion simplex	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0.1
Elphidium norvangi	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Hanzawaia concentrica	0	0	2	1	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14	0.3
Nonionella labradorica	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Nonionoides elongatus	8	1	13	0	33	15	3	6	14	0	0	3	0	2	0	0	0	0	0	0	98	2.3
Nonionoides grateloupi	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Nonion incisum	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0.1
Nonion scaphum	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0.1
Ozwaia sp.	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Pararotalia calcar	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24	0.6
Pararotalia nipponica	0	0	0	0	3	1	0	0	0	0	0	0	0	2	0	0	0	0	0	0	6	0.1
Quinqueloculina venusta	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0
Rotalidium annectans	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	1	0
Total Foraminifera Number (TFN)	**185**	**36**	**416**	**14**	**171**	**194**	**1394**	**245**	**357**	**74**	**20**	**83**	**916**	**197**	**15**	**12**	**2**	**0**	**0**	**0**	**#4331**	**100**
Species Richness (S)	**7**	**4**	**7**	**6**	**10**	**6**	**5**	**3**	**4**	**2**	**1**	**3**	**3**	**5**	**1**	**1**	1	**0**	**0**	**0**		

Table 4. Spatial Distribution of Benthic foraminifera in Monsoon (A= absolute abundance; R%= relative abundance; #= total standing crop.

Species name / Stations	**G-MON-1**	**G-MON-2**	**G-MON-3**	**G-MON-4**	**G-MON-5**	**G-MON-6**	**G-MON-7**	**G-MON-8**	**G-MON-9**	**G-MON-10**	**G-MON-11**	**G-MON-12**	**G-MON-13**	**G-MON-14**	**G-MON-15**	**G-MON-16**	**G-MON-17**	**G-MON-18**	**G-MON-19**	**G-MON-20**	**A**	**R%**
Aesterorotalia inflata	10	0	1	4	0	0	17	0	0	0	0	0	0	0	0	0	0	0	0	0	32	1.675
Ammonia beccarii	27	34	101	52	5	9	35	5	7	13	30	2	2	0	0	3	1	0	0	0	326	17.06
Ammonia convexa	10	0	45	32	1	3	34	1	0	0	0	0	0	0	0	0	0	0	0	0	126	6.6
Ammonia dentata	1	0	7	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0.52
Ammonia tepida	11	0	1	10	4	2	15	54	436	206	457	21	15	12	1	7	4	3	0	0	1259	65.88
Amphistegina radiata	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0.05
Elphidium discoidale	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0.05
Elphidium excavatum	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0.05
Elphidium norvangi	5	3	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0.57
Eponides cribrorepandus	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0.1
Eponides repandus	0	0	2	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0.21
Hanzawaia concentrica	2	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0.31
Helenina anderseni	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0.1
Nonionoides elongatus	17	1	0	1	0	1	16		16	6	12	0	0	0	0	0	0	0	0	0	70	3.66
Ozwaia sp.	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0.1
Pararotalia calcar	0	0	0	0	1	0	7	0	1	0	0	0	0	0	0	0	0	0	0	0	9	0.47
Pararotalia nipponica	9	2	0	6	2	0	18	0	0	0	0	0	0	0	0	0	0	0	0	0	37	1.94
Rotalidium annectans	3	1	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0.57
Total Foraminifera Number(TFN)	**97**	**42**	**167**	**109**	**14**	**15**	**151**	**60**	**460**	**225**	**499**	**23**	**17**	**12**	**1**	**10**	**5**	**3**	**0**	**0**	**#1910**	**100**
Species Richness (S)	**11**	**6**	**9**	**8**	**6**	**4**	**12**	**3**	**4**	**2**	**3**	**2**	**2**	**1**	**1**	**2**	**2**	**1**	**0**	**0**		

The upper estuary (Station16-20) is the main site for coir retting activity and thus the area is virtually barren of living benthic foraminifera. This can be explained by the fact that the process of coir retting releases hydrogen sulphide gas which has a propensity to reduce water pH, as average pH of 7.05-7.2 in the study area reflects its effects.

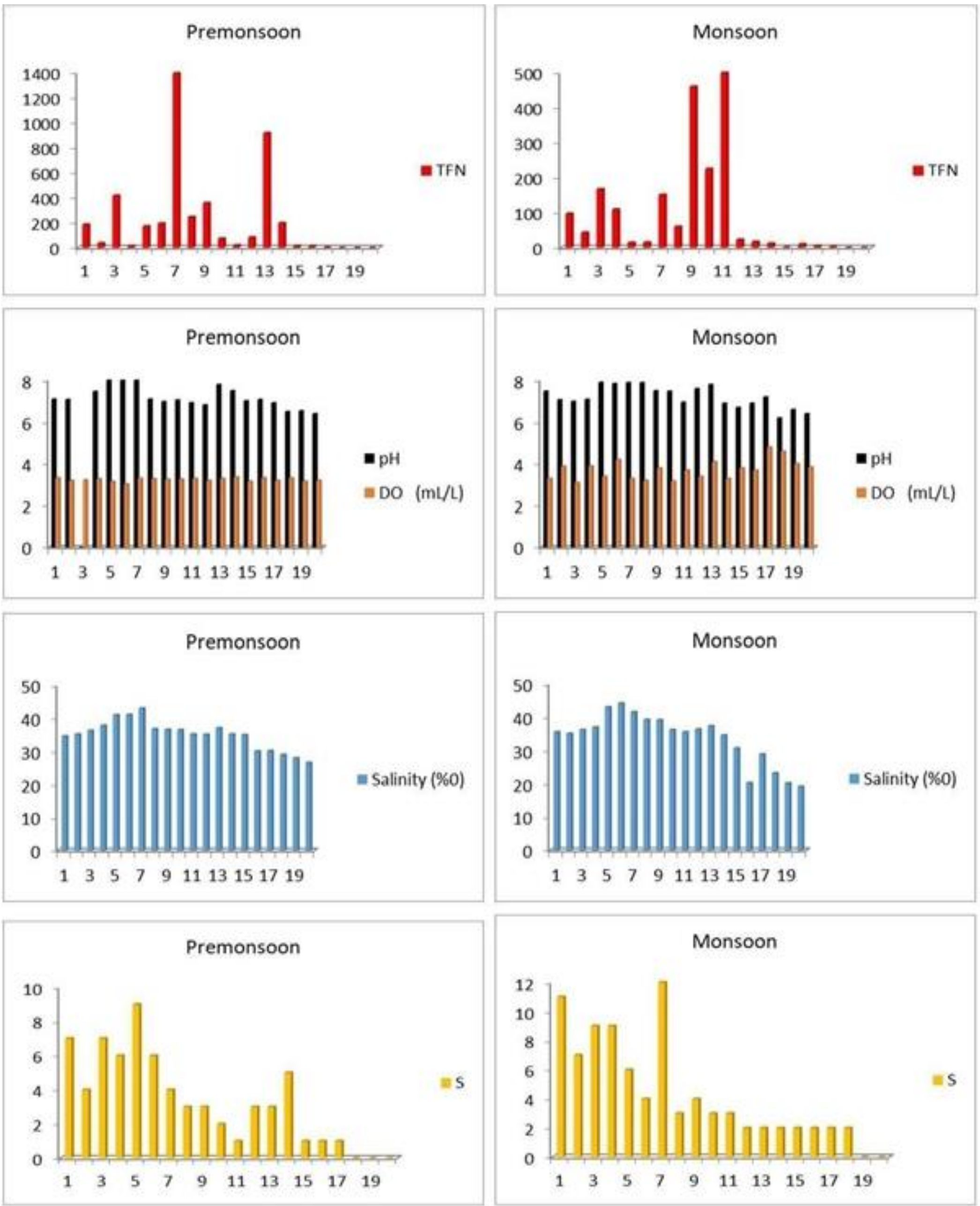

Fig. 2. Relationship between Living Foraminifera and Ecological parameters. Spatial distribution of TFN, S along with pH, salinity, and DO in both seasons.

The H2S also depletes dissolved oxygen at water- substrate interface producing low/anoxic conditions (Nagendra et al., 2011; Gayathri et al., 2013). The reduction in oxygen levels (<3.05-3.85ml/L) as observed in the Anchuthengu estuary was probably due to the addition of deoxygenated water from the retting grounds (Leena grace and Viveka, 2020). Retting also causes enormous amounts of organic substances and chemicals to be released, such as pectin, pentosan, tannins, polyphenols, sulphide, phosphate, nitrate, hydrogen sulphide, and ammonia, resulting in higher biological oxygen demand levels (Bijoy Nandan, 2007; Gautham Basu et al., 2015). In the present estuary, high levels of hydrogen sulphide, ammonia, and BOD, along with anoxic conditions, resulted in a low community diversity of benthic fauna (Bijoynandan, 2007; Remani et al., 2007). This represents the risky scenario in the Anchuthengu estuary, as sulphides are very poisonous and capable of destroying all organisms in ecosystems except anaerobic bacteria (Leena grace and Viveka, 2020). The benthic foraminifera in the Anchuthengu estuary appears to be smaller in size, indicating that the test evolved dwarf characteristics due to the reduced metabolism of the organism in a stressful environment (Boltovskoy and Wright, 1976; Sundararaja Reddy et al., 2009, 2016).

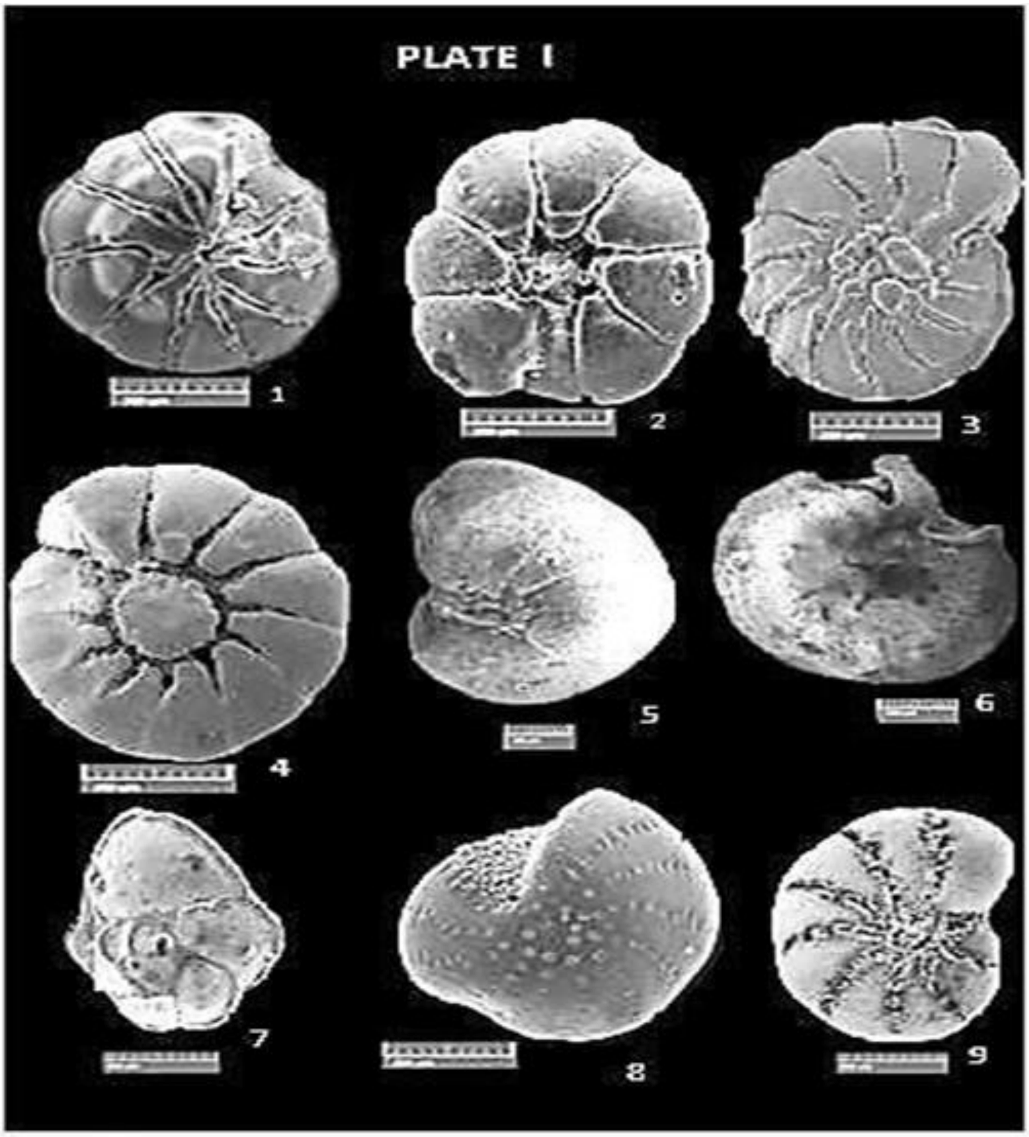

Plate 1. 1) *Ammonia beccarii* (Linnaeus, 1758), side view; sample no. G-PRE-7; 2) *Ammonia tepida* (Cushman, 1926), ventral view: sample no. G-MON-9; 3) *Ammonia dentata* (Parker and Jones, 1865), ventral view; sample no.G-PRE-1; 4) Ammonia convexa (Collins, 1958), side view; sample no.G-MON-3; 5) *Nonionoides elongatus* (d'Orbigny, 1852), side view; sample no.G-PRE-5; 6) *Amphistegina radiata* (Fichtel and Moll, 1798), side view; sample no.G- MON-4; 7) *Eponides repandus* (Fichtel and Moll, 1798), dorsal view; sample no.G-MON-3; 8) *Elphidium norvangi Buzas*, Smith and Beam, 1977, side view; sample no.G-MON-1; 9) *Elphidium excavatum* (Terquem, 1875), side view; sample no.G-MON-7.

If anthropogenic stress in the form of coir retting continues, it may result in changes in benthic foraminifers' community structure, high abundance of opportunistic species, test deformations, changes in test chemistry, and barren areas (Murray, 2006; Ferraro et al., 2006; Nigam et al., 2006) in the Anchuthengu estuary. However, our findings imply that human activities have an impact on the distribution, density and diversity of benthic foraminifera, and we believe that research like this can help us learn more about environmental contamination caused by anthropogenic pressure.

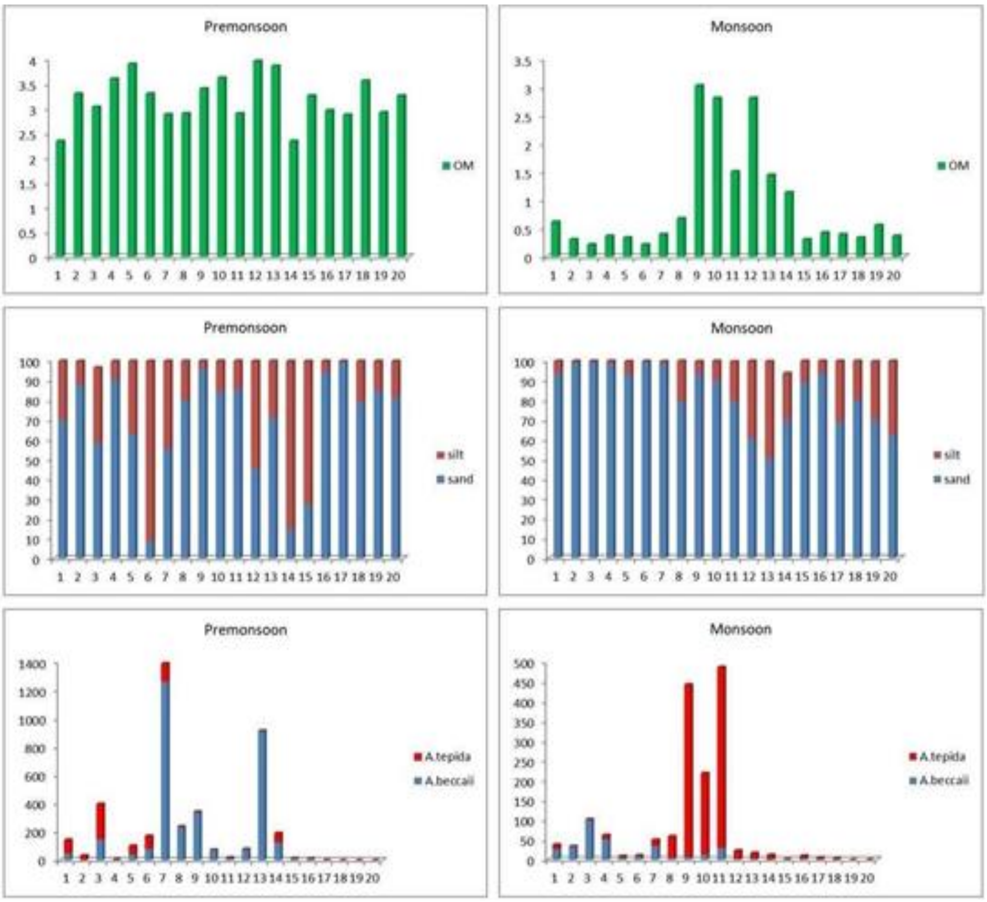

Fig. 3. Spatial distribution of Ammonia species along with percentages of sand, silt and organic matter (OM) in both seasons.

Conclusions

The study conducted in the Anchuthengu estuary contributes to the advancement of understanding of benthic foraminifera. The findings show that benthic foraminifera are vulnerable to stress, regardless of whether it is recurring or fortuitous. The following are the highlights of the study.

a. In the Anchuthengu estuary, the benthic foraminiferal standing crop is meager. In both seasons, there is no linear relationship between species richness (S) and TFN.
b. The TFN is highly variable in space and shows various trends in different seasons. Species richness is modest, and both seasons show comparable trends.
c. The analysis of physicochemical parameters and the composition of living foraminifers' assemblage revealed significant differences between both seasons. The TFN has a strong linear relationship with pH and salinity, whereas the DO does not.
d. The premonsoon standing crop is #4311, which is significantly greater than the monsoon standing crop of #1910, and this corresponds to the average OM values.
e. Organic pollution created by the coir retting process in the estuary is attributed to lower pH, salinity, and DO.
f. A drastic reduction in silt and organic matter in sediments in the monsoon may be attributed to the more fresh water influx and decreased intensity of the retting process.
g. The retting process, which produces H2S, ammonia, and other toxics and results in hypoxic conditions at the water-substrate interface, has a significant impact on the low density and diversity of benthic foraminifera.
h. Stress-tolerant taxa such as Ammonia beccarii and A. tepida are dominant and persistent in the estuary and can be used as bio proxies to assess environmental stress.
i. The benthic foraminifer tests in the Anchuthengu estuary are decreased in size, indicating that the test evolved a dwarf character due to slowed metabolism of the organism, which was influenced by chemicals and gases released during the coir retting process.

References

Alve, E. (1995) Benthic foraminiferal responses to estuarine pollution: a review. Journal of Foraminiferal Research, v. 25, pp.190-203.

Armynot du Châtelet, É. and Debenay, J.-P. (2010) The anthropogenic impact on the western French coasts as revealed by foraminifera: A review. Revue de Micropaléontologie, v.5, pp.129-137.

Bergamin, L., Romano,E., Finoia, M.G., Venti, F., Bianchi, J., Colasanti, A. and Ausili, A. (2009) Benthic foraminifera from the coastal zone of Baia (Naples, Italy): Assemblage distribution and modification as tools for environmental characterization. Marine Pollution Bulletin, v. 59, pp.234– 244.

Bijoy Nandan, S. (2007) Retting of coconut husk - a unique case of water pollution on the South West coast of India. Int. J. Environ. Stud. pp.335-355.

Boltovskoy, E. and Wright, R. (1976) Recent Foraminifera. Junk, The Hague, 515 p.

Bradshaw (1957) Laboratory studies on the growth of the foraminifer “Streblus beccaii Linne var. tepida Cushman”, J. Paleontol. v.31, pp.1138-1147.

Brady, H.M. (1884) Report of foraminifera dredged by HMS Challenger during the years 1873- 1876. Report Scientific Results. Exploration Voyage HMS challenger, Zoological Report, no.9, pp.1-814.

Ferraro L, Sprovieri, M., Alberico, I., Lirer, F., Prevedello, L. and Marsella. E. (2006) Benthic foraminifera and heavy metals distribution: a case study from the Naples Harbour (Tyrrhenian Sea, Southern Italy). Environ Pollut., v.142, pp.274–287.

Frontalini, F. and Coccioni, R. (2011) Benthic foraminifera as bioindicators of pollution: A review of Italian research over the last three decades. Revue de Micropaléontologie, v.54, pp.115-127.

Gautam B., Leena M., Seiko J. and Ashis Kumar S. (2015). Accelerated retting cum softening of coconut fibre. Industrial Crops and Products, v.77, pp. 66-73.

Gayathri, R., Nagendra, R., Reddy, A.N., Sathiyamoorthy, and Suresh, N. (2013) Benthic Foraminifera in a Sedimentary Core from Kollam Coastal Plain, South Kerala, India. Int. Jour. Earth Sci. Eng. v.7, pp.289-296.

Jayaraju, N., Reddy, B.C.S., Reddy, K.R. and Reddy, A.N. (2011) Impact of Iron ore tailing on foraminifera of Uppateru River Estuary, East coast of India. Jour. Environ. Prot., v.2, pp.213-220.

Jayaraju, N. and Reddi, K.R. (1996) Impact of pollution on coastal zone monitoring with benthic foraminifera of Tuticorin, South East Coast of India, Indian Jour. Marine Sci., v.25, pp.376-378.

Khare, N., Chaturvedi, S.K. and Mazumdar, A. (2007) An overview of foraminiferal studies in near shore areas off eastern coast of India and Andaman and Nicobar Islands. Indian Jour. Marine Sci., v.36, pp.288-300.

Leena Grace, B. and Viveka, S. (2020) Effect of Coconut Husk Retting on Three Backwater Regions along the Southwest Coast of India. Terrestrial and Aquatic Environmental Toxicology, pp.62-64.

Little, S.N., Peter Hengstum, J.V., Beddows, P.A., Donnelly, J. P., Winkler, T.S. and Albury, N.A. (2021) Unique Habitat for Benthic Foraminifera in Subtidal Blue Holes on Carbonate Platforms. frontiers in Ecology and Evolution, v.9, pp.1-18.

Loeblich, A.R. and Tappan, H. (1988) Foraminiferal genera and their classification. New York: Van Nostrand Reinhold Company, pp.1-970.

Manoj, K., Suraj, M.A., Shidhi, P.R., Hidesh, H., Sheeja, K., Pradeep, P. and Jisha, P. (2014) Study on Environmental Degradation by Retting Activities in Backwaters of Kodungallur, Thrissur District, Kerala State, South India. Jour. Environ. Sci. Computer Sci. and Eng. and Technology, v.3, pp. 156-162.

Murray JW. (1973) Distribution and Ecology of Living Benthic Foraminiferids. London: Heinemann Educational Books Ltd; 274 p.

Murray, J.W. and Alve, E. (2002) Benthic foraminifera as indicators of environmental change: marginal marine, and upper-slope environments. In: S.K. Haslett (ed.), Quaternary Environmental Micropalaeontology. Edward Arnold (Publishers) Limited, London, pp.59-90.

Murray, J.W. (2006) Ecology and Applications of Benthic Foraminifera: Cambridge University Press, Cambridge, UK, 426p.

Murthy, P.S.N. and Veerayya, M. (1972) Studies on the sediment of Vembanad Lake, Kerala State: Part – I - Distribution of organic matter. Indian Journal of Marine Sciences, v.1, pp.45–51.

Nagendra, R., Prakash, T.N., Jayamurugan, K., Gayathri, R. and A.N. Reddy. (2011) A Preliminary report on Benthic Foraminiferal Assemblage in the Ashtamudi Estuary, Kerala. Journal of the Palaeontological Society of India, v.56, pp.137-142.

Nagendra, R., Sathiyamoorthy, P., Nallapa Reddy, A. and Ramachandran, A. (2015) Spatial distribution of recent Benthic Foraminifera in the Palar River Estuary, Tamil Nadu Coast, India. Jour. Geol. Soc. India, v.86, pp.305- 316.

Nagendra, R. and Nallapa Reddy, A. (2019) Benthic Foraminifera Response to Ecosystem Pollution in the Uppanar Estuary, Tamil Nadu Coast, India. Jour. Geol. Soc. India, v.93, pp.555-566.

Narayana, A.C., Jago, C.F. Manojkumar, P. and Tatavarti, R. (2008) Nearshore sediment characteristics and formation of mudbanks along the Kerala coast, southwest India. Estuarine, Coastal and Shelf Science, v.78, pp.341-352.

Nigam R., Saraswat R., and Panchang R. (2006) Application of foraminifers in ecotoxicology: Retrospect, perspect and prospect. Environment International, v.32, pp.273-283.

Pati, P. and Patra, P.K. (2012) Benthic foraminiferal responses to coastal pollution: a review. International Journal of Geology, Earth and Environmental Sciences, v.2, pp.42-56.

Ramanathan, R.M. (1970) Quantitative differences in the living benthic foraminifera of Vellarestuary. Jour. Geol. Soc. India, v.11, pp.127-141.

Reddy, A.N. and Reddy, K.R. (1982) Recent benthonic foraminifera from the Araniar River Estuary, Tamil Nadu. Indian Jour. Marine Sci., v.11, pp.249- 250.

Reddy, A.N. and Reddy, K.R. (1994) Seasonal distribution of foraminifera in the Araniar River estuary of Pulicat, Southeast India. Indian Jour. Marine Sci., v.23, pp.39-42.

Remani, K. N. Nirmala, E. and Nair, S. R. (2007) Pollution due to coir retting and its effect on estuarine flora and fauna. Int. J. Env. Studies. pp.285-295.

Saraswat, R., Kouthanker, M., Kurtarkar, S., Nigam, R. and Linshy, V. N. (2011) Effect of salinity induced pH changes on benthic foraminifera: a laboratory culture experiment. Biogeosciences Discuss., v.8, pp.8423–8450.

Sarita, C., Delminda, M., Simon, C., David, S. and Tomasz, B. (2015) Ecological zonation of benthic foraminifera in the lower Guadiana Estuary (southeastern Portugal). Marine Micropaleontology, v.114, pp.1-18.

Schönfeld, J., Alve, E., Geslin, E., Jorissen, F., Korsun, S., Spezzaferri, S., Members of the FOBIMO group. (2012) The FOBIMO (FOraminiferal BIo-MOnitoring) initiative-Towards a standardized protocol for softbottom benthic foraminiferal monitoring studies. Marine Micropaleontology, v.94-95, pp.1-13.

Shynu, R., Purnachandra Rao, V., Samiksha, S. V., Vethamony, P., Naqvi, S. W. A., Pratima M. K., Babu, M. T. and Dineshkumar, P.K. (2017) Suspended matter and fluid mud off Alleppey, southwest coast of India. Estuar. Coast. Shelf Sci., v.185(5), pp.31-43.

Sreenivasulu, G., Jayaraju, N., SundaraRaja Reddy, B.C., Lakshmi Prasad,T., Nagalakshmi, K. and Lakshmanna, B. (2017) Foraminiferal research in coastal ecosystems of India during the past decade: A review. Geoscience Res. Jour., v.13, pp.38–48.

Sundara Raja Reddy, B.C., Jayaraju, N., Reddy, K.R. and Reddy, A.N. (2009) Pollution Signatures of Benthic Foraminifera: A Study from the Pennar River Estuary, India. Research Journal of Earth Sciences, v.1, pp. 7-14.

Sundara Raja Reddy, B.C., Jayaraju, N., G. Sreenivasulu, G., Suresh, G. and A.N. Reddy. (2016) Heavy metal pollution monitoring with foraminifera in the estuaries of Nellore coast, East coast of India. Marine Pollution Bulletin, v.113, pp.542-551.

Tatavarti, R., Narayana, A.C. and Manojkumar, P. (1999) Mudbank regime off the Kerala coast during monsoon and non-monsoon seasons. Proceedings of the Indian Academy of Sciences (Earth and Planetary Sciences), v.108, pp.57-68.

Uthicke, S., Momigliano, P. and Fabricius, K. E. (2013) High risk of extinction of benthic foraminifera in this century due to ocean acidification. Sci. Rep., v.3, p.1769.

Yanko, V., Ahmad, M. and Kaminski, M.A. (1998) Morphological deformities of benthic foraminiferal tests in response to pollution by heavy metals: implications for pollution monitoring. Journal of Foraminiferal Research, v.28, pp.177-200.

Manuscript received: 04-04-2022
Manuscript accepted: 24-06-2022