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DWARF FORAMINIFERA OFF KERALA, INDIA: A RESPONSE TO MUDBANK FORMATION

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ABSTRACT

During the monsoon season, a mudbank forms off Alleppey, a coastal district in Kerala. The mudbank forms in the littoral waters within 15 m water depth. It is a small coastal zone with water being unaffected by monsoon waves' roughness. Apart, from the peculiar calmness, the water column in mudbank has very high quantity of suspended sediments. With these unique settings, mudbank defines a peculiar marginal marine environment having rich fish catch and is the source of livelihood for fishermen in Kerala during the lean fishing period of monsoon. Here, we have studied the effect of mudbank formation on benthic foraminiferal morphology. The surface sediment samples from the area were analyzed for foraminifera. The maximum diameter/length/width of foraminiferal species present in the mudbank were compared with the type species. The maximum diameter/length/width of all the living benthic foraminiferal species in the mudbank was smaller than the type species. Additionally, foraminiferal abundance in the mudbank was also poor, suggesting stressed environment. We, therefore conclude that dwarfism is a peculiar response of foraminifera to mudbank formation. The reduced foraminiferal test size can thus, be used as a tool to identify the previous mudbanks and also the spatial shift of mudbanks.

Keywords: Living benthic foraminifera, dwarfism, mudbank, Alleppey.

INTRODUCTION

In the south-eastern Arabian Sea off Alleppey, Kerala, India, the coastal water within 15-20 m water depth witness the formation of mudbank, during monsoon season. The mudbank is the highly turbid part of the coastal water due to re-suspension of bottom mud (Kurup, 1977; Silas, 1984; Mallik *et al.,* 1988; Tatavarti *et al.,* 1999) and is devoid of turbulent wave activity during rough monsoon season (Mathew *et al.,* 1995; Jiang and Mehta, 1996; Tatavarti and Narayana, 2006; Narayana *et al.,* 2008). The suppressed wave activity reduces coastal erosion in the mudbank area (Narayana *et al.* 2001). Even though the lateral extent of mudbank is variable, it is 3 to 4 km along and 8 to 10 km across the shoreline (Gopinathan and Qasim, 1974; Mallik *et al.,* 1988; Li and Parchure, 1998; Balachandran 2004; Narayana *et al.,* 2008). Damodaran (1973) described mudbanks as 'smooth water tracts' due to its peculiar calmness during monsoon. The calm coastal water makes these stretches a safe harbor for sea trawlers (Silas, 1984). The rough sea during monsoon prevents fishing at other coastal locations along the south-west coast of India, especially Kerala. In view of the seasonal re-suspension of bottom mud, increase in suspended particulate matter in the water column (Shynu *et al.,* 2017), low bottom water salinity (Murthy *et al.,* 1984, Muraleedharan *et al.*; 2017) and peculiar primary productivity pattern (Nair *et al.,* 1984), mudbank defines unique micro- environment.

The extremely rich fishery potential is an inseparable aspect of the mudbank area due to its tranquillity. It makes the phenomenon of mudbank socio-economically significant. The Central Marine Fisheries Research Institute (CMFRI) recorded 2011 kg (per landing center per day) of fish-catch from the Alleppey mudbank area and 356 kg (per landing center per day) from the non-mudbank area in 1965. Subsequently, the fish-catch in 1966 from the same regions was 10907 kg (per landing center per day) and 306 kg (per landing center per day), respectively (Rao 1967). Kerala contributes 22.32% of India's marine fish landings. The indigenous marine fishing sector employs approximately 6 lakh people directly and indirectly. The fishing activity is banned along the entire Kerala coast during the monsoon season. As a consequence, average monthly fish landing drops down to 7.5 – 25.0 thousand tonnes in the monsoon season, from 25.0 – 61.0 thousand tonnes in non-monsoon months. The overall loss in labor income is approximately Rs. 66 crores during the ban period (Ashwathy and Sathiadhas 2006). In such crisis period, the mudbank areas along the Kerala coast are boon to the fishermen community. On considering the fish landing from the mudbank area, the monsoon fish landing increases to 13 – 35 thousand tonnes (Gopinathan and Qasim 1974). In another study, the annual fish landing from the Alleppey mudbank region between 1966 and 1973, was recorded as 982.57 – 10425.21 metric tonnes; while the same from non-mudbank areas during monsoon season, was significantly low (369.98 – 6432.63 metric tonnes) (Ragunathan *et al.,* 1984). The cheap non-motorised (thermocol rafts) fishing crafts, which a poor fisherman can afford, were mostly operated in the mudbank during the fishing season of 2014 and 2015. Kerala marine fishing sector contributed 17.5% LC (at Landing Centre level) and 15.8% RC (at Retail Centre level) of the national marine fish landing valuation in 2014. The Punnapra fish landing point of Alleppey mudbank area contributed 1.6% and 0.88% of the total marine valuation in 2014 and 2015 respectively (Shyam *et al.,* 2016). Owing to the fisheries output that directly governs regional economics and subsequently impacts national marine valuation, efforts were made to study the various scientific aspects of mudbank. Several hypotheses were put forward to explain the cause(s) of re-suspension of bottom mud to understand the origin of mudbank (Kurup and Varadachari 1975; Murthy *et al.,* 1984; Balachandran 2004; Nayarana *et al.,* 2008; Loveson *et al.,* 2016).

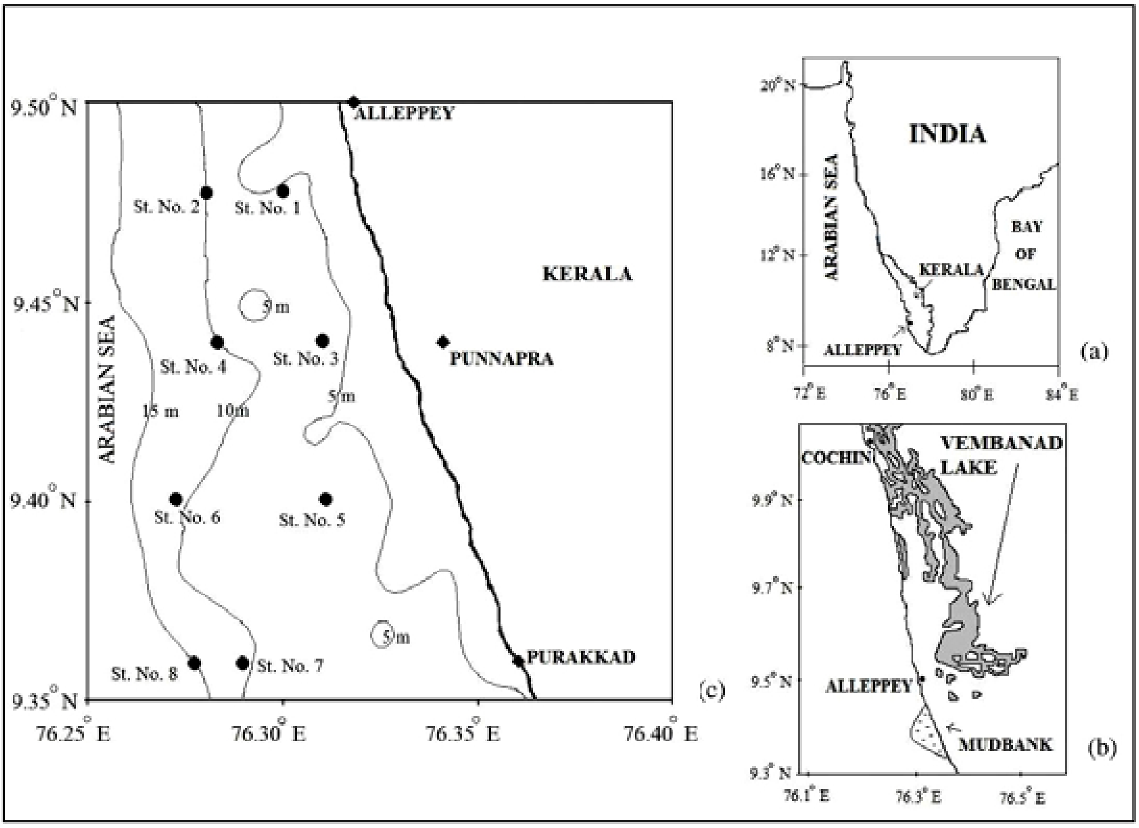

Fig. 1. Location map of mudbank, off Alleppey, Kerala, India. The inset map is of southern India (a) and its Kerala state (b). The station locations (c) are of pre-monsoon season.

The unique environment in the mudbank region is expected to affect marine biota as well. Benthic foraminifera are a significant biogenic component of the marine ecosystem.

They have wide range of occurrence from shallow coastal water to deep sea. Foraminifera are sensitive to changes in their surroundings and are often used to identify micro-environments (Boltovskoy and Wright, 1976; Setty and Nigam, 1980; Murray, 1991; Sen Gupta, 1999; Saraswat and Nigam, 2013; Saraswat, 2015). The traditional study of benthic foraminifera systematics and bathymetric distribution from off Kerala (Travancore coast) was carried out for the first time by Sethulakshmi (1958). Later, Antony (1968) studied the zonal distribution and abundance of living and dead benthic foraminifera from off Kannur to Vizhinjam (off Kerala). Seibold (1975) provided a detailed taxonomy of lagoonal and near coast benthic foraminifera from Cochin. A comparison of the living and dead foraminifera from the deeper offshore water off Cochin and from the peculiar habitat of Cochin bar mouth mudbank was attempted by Seibold and Seibold (1981). Nisha and Singh (2012) studied the response of benthic foraminifera to different physico-chemical parameters from the shelf and outer slope region (50 -200 m water depth) off the southwest coast and established a link between faunal abundance, sediment-size, and organic carbon content.

However, a comprehensive study, focused on Alleppey mudbank region with an objective to understand the benthic foraminiferal response to the seasonal occurrence of mudbank and relate it to the cause of mudbank formation, has not yet been attempted. Keeping the above objectives in mind, a seasonal sampling was done in the mudbank area off Alleppey and living benthic foraminifera were studied to get in situ information that can help to trace the cause of mudbank formation in the region. An attempt is made to relate the faunal response, with the probable hypothesis proposed for the origin of mudbank.

GEOLOGICAL SETTING

The outcrops in Kerala comprises of Precambrian crystalline rocks, Tertiary sedimentary formations and sub-recent to recent laterite, sandy and peat deposits. The major tectonic activity,

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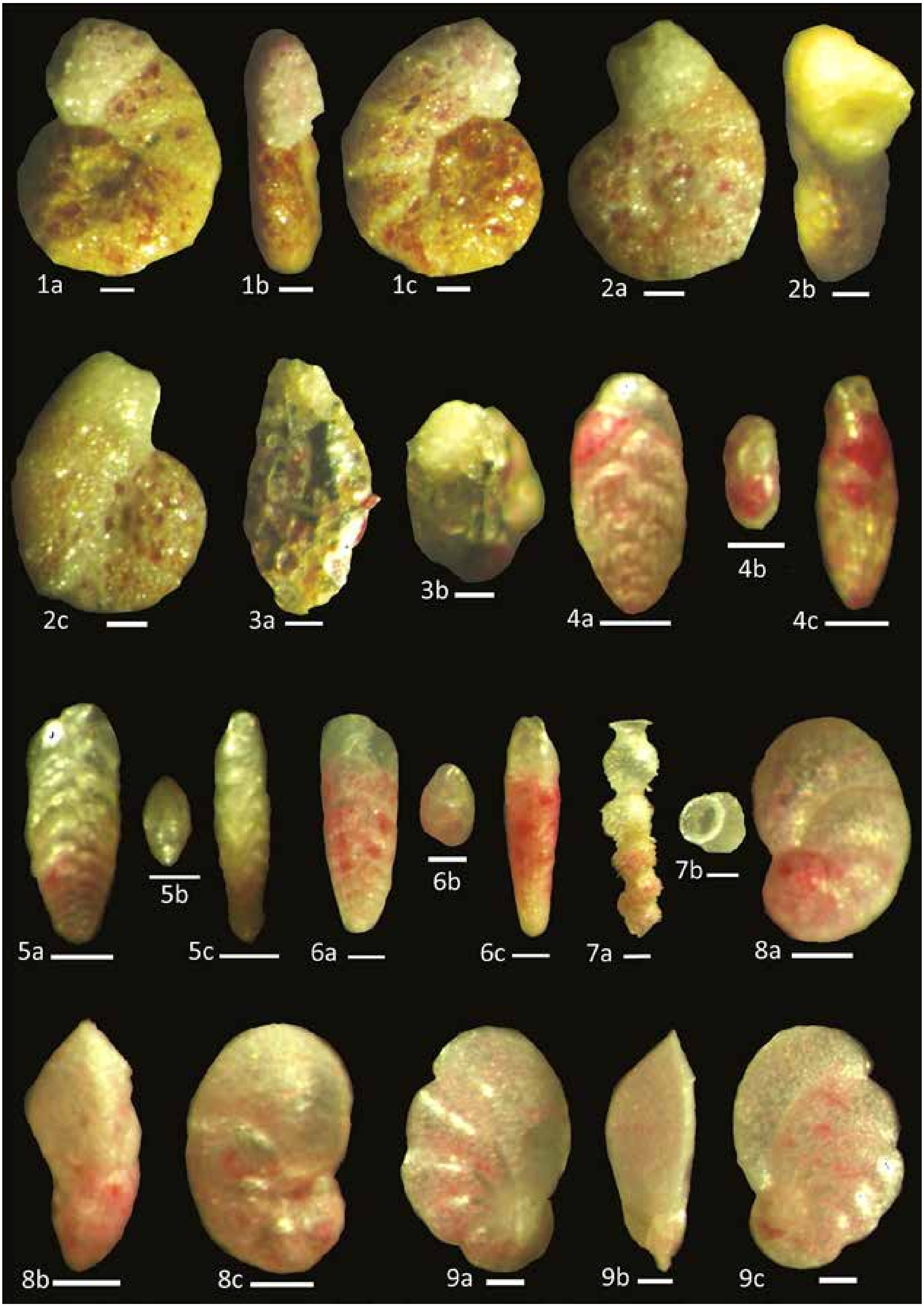
EXPLANATION OF PLATE I

A few abundant species reported from the mudbank area. The bar length is 100 µm. 1. ***Ammobaculites dilatatus*** (Cushman and Bronnimann 1948) (a) ventral view (b) apertural view (c) dorsal view; 2. ***Ammobaculites exiguus*** (Cushman and Bronnimann 1948) (a) dorsal view (b) apertural view (c) ventral view; 3. ***Nouria polymorphinoides*** (Heron-Allen and Earland 1914) (a) side view (b) apertural view; 4. ***Brizalina limbata*** (Brady) (a) side view (b) apertural view (c) lateral view; 5. ***Brizalina ordinaria*** (Phleger and Parker 1954) (a) side view (b) apertural view (c) lateral view; 6. ***Brizalina striatula*** (Cushman 1922) (a) side view (b) apertural view (c) lateral view; 7. ***Siphogenerina virgula*** (Brady) (a) side view (b) aperture view; 8. ***Cancris auricula*** (Fichtel and Moll) (a) dorsal view (b) apertural view (c) ventral view; 9. ***Cancris carinatus*** (Millet 1904) (a) ventral view (b) apertural view (c) dorsal view.

Plate I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featuring high-grade metamorphism and formation of the depositional basin, is of the Precambrian and Tertiary. The coastline along Kerala is 560 km long with the Arabian Sea on its west and the Western Ghats on the eastern side. The Vembanad Lake is another geomorphic feature in Kerala. It is the largest wetland system of south India and extends from Cochin in the north to Alleppey in the south (Varadarajan and Nair, 1978; National Wetland Atlas Kerala 2010; Ramakrishnan and Vaidyanandhan, 2010; Soman, 2013). The rivers/streams in the area are seasonal and originate from the Western Ghats. The rivers draining northern and southern regions of Kerala debouch into the Arabian Sea. The rivers draining the central Kerala, discharge into the Vembanad Lake. The geological history of the shoreline suggests that mudbank area off Alleppey was a part of a bay from which the lake and present-day shoreline has evolved (Padmalal *et al.,* 2014a, 2014b).

MATERIALS AND METHODS

The area covered in this study is 53.28 km^2, lying between 9.48-9.36°N latitude and 76.32-76.28°E longitude, within 15 m water depth. The surface sediment and water samples were collected along four latitudinal transects, spaced at 0.04°. Station 1 and 2 (transact I), called as northern peripheral stations (NPS) lie north of mudbank area. Station 3 and 4 (transact II) lie in the mudbank area and are referred as core mudbank stations (CS). Stations 5 to 8 (transact III and IV) lie south of mudbank and are referred as south peripheral stations (SPS) (Fig. 1 and Table 1). In all, 24 grab samples were collected, 8 each in pre-monsoon, monsoon and post-monsoon season by using *Santa Cruz* trawler. During each sampling, the top 2 cm sediment was immediately preserved in buffered Rose-Bengal and ethanol solution. After a minimum staining period of two weeks, sediments were processed following the standard procedure for foraminiferal study (Manasa *et al.,* 2016). The sediments were soaked in filtered seawater for 12 hours. The overlying sea water was then decanted to remove ethanol. The sediments were then freeze-dried in a lyophilizer. The freeze-dried sediments were weighed and then soaked for 24 hours. Subsequently, the sediments were wet sieved by using 63 µm sieve, with a gentle shower. The coarse fraction (>63 µm) retained on the sieve was oven dried and weighed.

A minimum of 300 living benthic foraminifera specimens were picked from weighed aliquots, obtained by coning and quartering. In samples, where 300 living specimens were not available, the entire coarse fraction was used to pick all the stained specimens. The doubtful specimens were transferred to a pertidish filled with water and examined under the microscope on a white base, to ascertain the living status of foraminifera. The specimens exhibiting a wholesome mass of pink color, either shrunk to the proloculus (in juvenile forms) or evenly distributed in the entire shell (in adult forms) were considered as living.

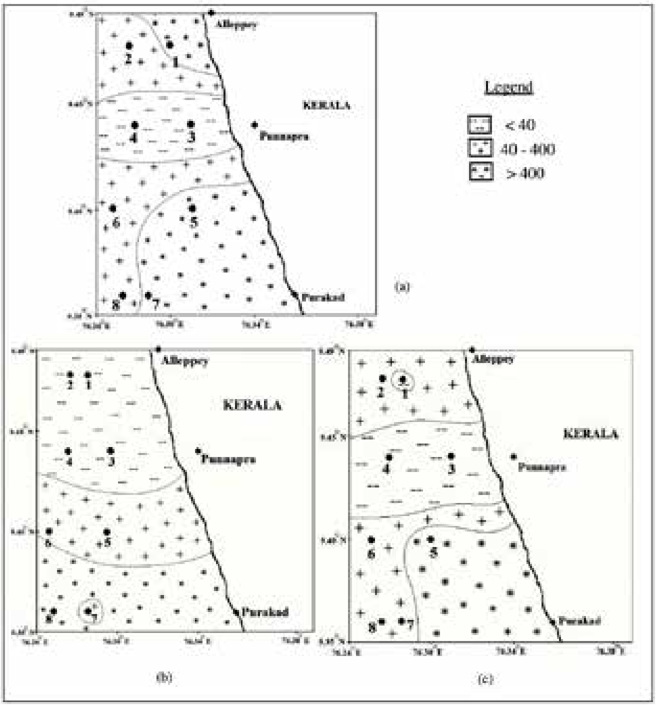

Fig. 2. The absolute abundance of living benthic foraminifera during (a) Pre-monsoon, (b) Monsoon and (c) Post-monsoon season.

The absolute abundance of total living foraminifera (TLN) was calculated for each sample. The value was normalized for 10 g of sediment (Table 1). To ascertain the dwarf character of fauna, size (diameter/length/width) of the largest specimen of each species from every station for all three seasons (24 samples) was measured under a calibrated stereo-zoom microscope (Table 3).

A Seabird SBE 19 plus conductivity-temperature-depth (CTD) profiler was used to record water column temperature and salinity with a depth bin of 0.2 m. The instrument was well calibrated and had a measuring range for conductivity 0-9 S/m (accuracy of +-0.0005 S/m), for temperature -5.0 to 35.0 °C (±0.005 °C) and 0.1% of full scale for a pressure rating of 100 m depth. The CTD profiler malfunction limited the pre-monsoon measurements (Table 2). A Niskin water sampler was used to collect water samples. The water samples were fixed on board with Winkler A and B solutions for dissolved oxygen (DO) analysis. The DO analysis was carried out in the chemical laboratory of the National Institute of Oceanography, Regional Centre, Cochin.

RESULTS

The absolute abundance of living benthic foraminifera (TLN) at CS, NPS and SPS during pre-monsoon, monsoon and

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EXPLANATION OF PLATE II

1. ***Nonion belridgense*** (Barbat and Johnson 1934) (a) side view (b) apertural view; 2. ***Nonion scapha*** (Fichtel and Moll) Cushman 1939 (a) side view (b) apertural view; 3. ***Protelphidium* cf. *schmitti*** (Cushman and Wickenden 1929) (a) side view (b) apertural view (c) side view; 4. ***Pararotalia* cf. *globosa*** (Millet 1903) (a) dorsal view (b) apertural view (c) ventral view; 5. ***Ammonia sobrina*** (Schupack 1934) (a) dorsal view (b) apertural view (c) ventral view; 6. ***Ammonia tepida*** (Cushman 1926) (a) dorsal view (b) apertural view (c) ventral view; 7. ***Asterorotalia dentata*** (Parker and Jones 1865) (a) dorsal view (b) apertural view (c) ventral view; 8. ***Cribrononion somaense*** (Takayangi 1955) (a) apertural view (b) side view; 9. ***Elphidium excavatum*** (Cushman 1930) (a) side view (b) apertural view; 10. ***Florilus*(?) *tobagoensis*** (McCulloch 1981) (a) side view (b) apertural view. The bar length is 100 µm except in figure 7 where it is 50 µm.

Plate II

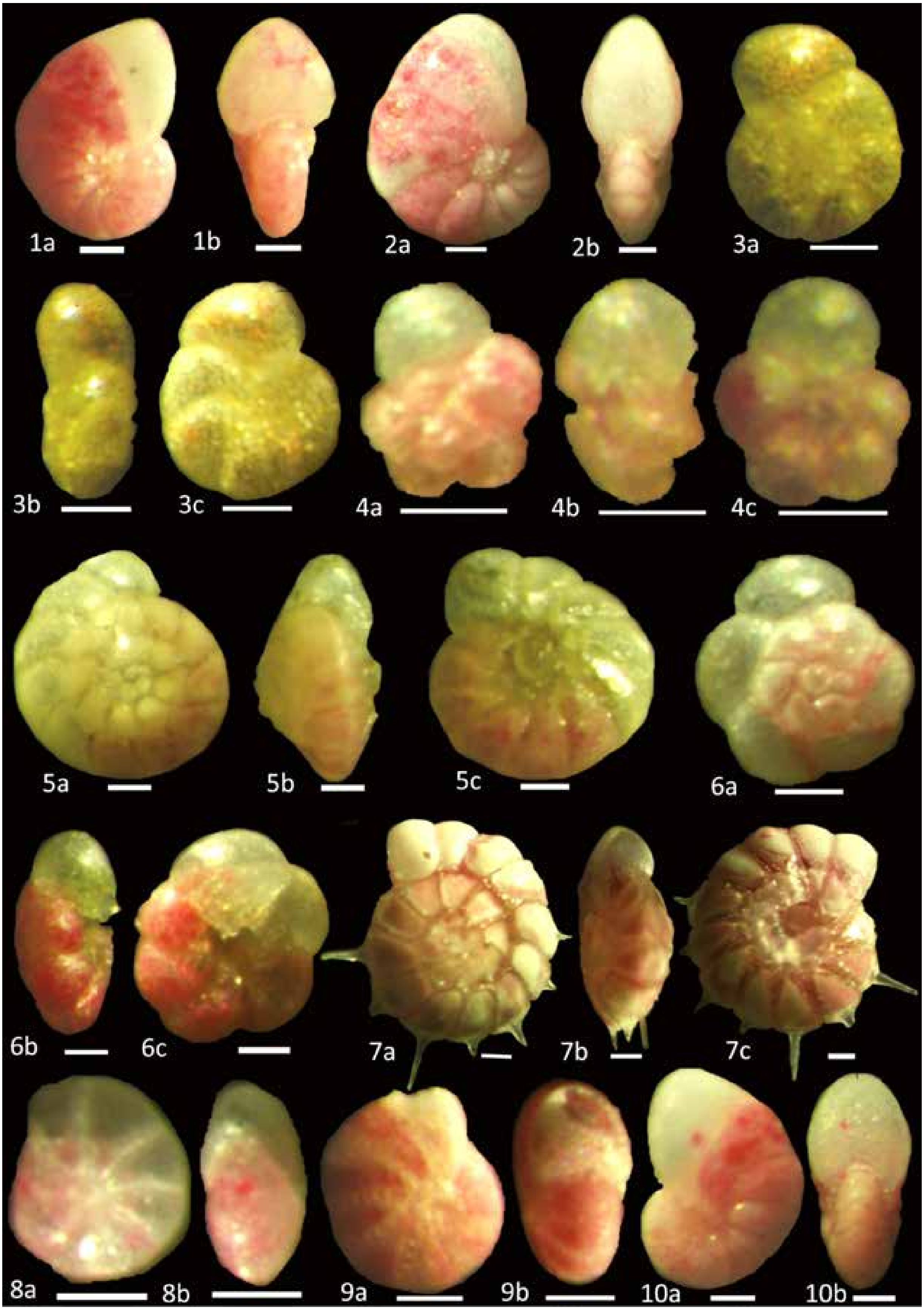
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Table 1. Details of sampling locations and absolute abundance of living foraminifera (TLN) from mudbank area off Alleppey, Kerala per 10 g sediment during (a) pre-monsoon, (b) monsoon and (c) post-monsoon season.

S. No.	Station No.	Longitude (˚E)	Latitude (˚N)	Depth (m)	TLN
1	St. No. 1	76.3	9.48	6	454.0
2	St. No. 2	76.28	9.48	10	231.0
3	St. No. 3	76.31	9.44	6	22.0
4	St. No. 4	76.28	9.44	10	29.0
5	St. No. 5	76.31	9.4	7	554.0
6	St. No. 6	76.29	9.4	11	322.0
7	St. No. 7	76.3	9.36	11	709.0
8	St. No. 8	76.29	9.36	15	57.0

(a)

S. No.	Station No.	Longitude (˚E)	Latitude (˚N)	Depth (m)	TLN
1	St. No. 1	76.29	9.48	9	100.0
2	St. No. 2	76.28	9.48	12	59.0
3	St. No. 3	76.3	9.44	8	19.0
4	St. No. 4	76.28	9.44	13	28.0
5	St. No. 5	76.3	9.4	8	195.0
6	St. No. 6	76.27	9.4	14	364.0
7	St. No. 7	76.29	9.36	13	77.0
8	St. No. 8	76.27	9.36	16	1214.0

(b)

(c)

S. No.	Station No.	Longitude (˚E)	Latitude (˚N)	Depth (m)	TLN
1	St. No. 1	76.29	9.48	8	8.0
2	St. No. 2	76.28	9.48	11	61.0
3	St. No. 3	76.31	9.44	6	18.0
4	St. No. 4	76.28	9.44	11	27.0
5	St. No. 5	76.3	9.4	8	616.0
6	St. No. 6	76.27	9.4	12	91.0
7	St. No. 7	76.29	9.36	13	248.0
8	St. No. 8	76.28	9.36	15	247.0

Table 2. Details of bottom water salinity, dissolved oxygen and temperature from the mudbank area off Alleppey, Kerala during (a) pre-monsoon, (b) monsoon and (c) post-monsoon season.

S. No.	Station No.	Longitude (˚E)	Latitude (˚N)	Depth (m)	Salinity (‰)	Temp. (˚C)
1	St. No. 1	76.31	9.48	6	na	na
2	St. No. 2	76.28	9.48	10	na	na
3	St. No. 3	76.31	9.44	6	na	na
4	St. No. 4	76.28	9.44	10	na	na
5	St. No. 5	76.31	9.4	7	na	na
6	St. No. 6	76.29	9.4	11	na	na
7	St. No. 7	76.30	9.36	11	na	na
8	St. No. 8	76.29	9.36	15	na	na

(a)

S. No.	Station No.	Longitude (˚E)	Latitude (˚N)	Depth (m)	Salinity (‰)	Temp. (˚C)
1	St. No. 1	76.29	9.48	9	34.6	23.9
2	St. No. 2	76.28	9.48	12	34.2	23.6
3	St. No. 3	76.30	9.44	8	24.4	24.8
4	St. No. 4	76.28	9.44	13	26.9	24.4
5	St. No. 5	76.30	9.4	8	34.7	23.5
6	St. No. 6	76.27	9.4	14	34.6	23.3
7	St. No. 7	76.29	9.36	13	34.8	23.2
8	St. No. 8	76.27	9.36	16	34.8	23.0

(b)

S. No.	Station No.	Longitude (˚E)	Latitude (˚N)	Depth (m)	Salinity (‰)	Temp. (˚C)
1	St. No. 1	76.29	9.48	8	33.8	29.1
2	St. No. 2	76.28	9.48	11	33.8	28.8
3	St. No. 3	76.31	9.44	6	31.9	29.1
4	St. No. 4	76.28	9.44	11	26.7	28.8
5	St. No. 5	76.30	9.4	8	33.9	29.1
6	St. No. 6	76.27	9.4	12	33.9	28.7
7	St. No. 7	76.29	9.36	13	34.0	28.7
8	St. No. 8	76.28	9.36	15	33.9	28.7

(c)

the post-monsoon season was used to understand spatial variation in benthic foraminifera during different seasons.

Spatial variation in absolute abundance: In the core mudbank region, TLN ranges from 22 to 29 during pre-monsoon, from 19 to 28 during monsoon and from 18 to 27 during the post-monsoon season (Fig. 2). Benthic foraminiferal abundance is higher in northern peripheral mudbank stations as compared to that in CS, during all three seasons. The TLN in NPS varies from 231 to 454 in pre-monsoon, from 59 to 100 in monsoon and from 8 to 61 in the post- monsoon season (Fig. 2). The highest living benthic foraminiferal abundance was reported in southern peripheral mudbank stations. The TLN ranges from 57 to 709 in pre-monsoon, from 77 to 1214 in monsoon and from 91 to 616 in the post-monsoon season (Fig. 2).

Dwarf character of fauna: A total of 19 species of living benthic foraminifera were reported from the mudbank area off Alleppey. These are shown in Plate 1: (1) *Ammobaculites dilatatus* (Cushman and Bronnimann 1948); (2) *Ammobaculites exiguus* (Cushman and Bronnimann 1948); (3) *Nouria polymorphinoides* (Heron-Allen and Earland 1914); (4) *Brizalina limbata* (Brady); (5) *Brizalina ordinaria* (Phleger and Parker 1954); (6) *Brizalina striatula* (Cushman 1922); (7) *Siphogenerina virgula* (Brady); (8) *Cancris auricula* (Fichtel and Moll); (9) *Cancris carinatus* (Millet 1904); and Plate 2: (1) *Nonion belridgense* (Barbat and Johnson 1934); (2) *Nonion scapha* (Fichtel and Moll) Cushman 1939; (3) *Protelphidium* cf. *schmitti* (Cushman and Wickenden 1929); (4) *Pararotalia* cf. *globosa* (Millet 1903); (5) *Ammonia sobrina* (Schupack 1934); (6) *Ammonia tepida* (Cushman 1926); (7) *Asterorotalia dentata* (Parker and Jones 1865); (8) *Cribrononion somaense* (Takayanagi 1955); (9) *Elphidium excavatum* (Cushman 1930) and (10) *Florilus* (?) *tobagoensis* (McCulloch 1981). The size of all these species was measured and compared with type species. In case of *Asterorotalia dentata* (Parker and Jones 1865) and *Brizalina limbata* (Brady), as the dimension of type species was not available in the catalogue, a comparison was done with topotype. All the above-mentioned species in the mudbank area are invariably smaller than their type specimens (Table 3).

DISCUSSION

The absolute abundance of living benthic foraminifera is different in the core mudbank and peripheral mudbank regions. The CS has the lowest range of faunal abundance, irrespective of the season. The highest range of benthic foraminiferal abundance is in SPS and intermediate in NPS (CS<NPS<SPS). The mudbank formation is associated with re-suspension of bottom sediments (Tatavarti *et al.,* 1999) resulting in high concentration of suspended particulate matter in the bottom water (Narayana *et al.,* 2008; Shynu *et al.,* 2017). The poor abundance in CS suggests that the increased suspended matter driven turbidity in the mudbank region adversely affects benthic foraminifera. A comparatively lower benthic foraminiferal abundance in the CS, even during the post-monsoon season, further indicates that the stable substrate condition, favorable for faunal growth, does not reinstate even in non-monsoon months. Thus, it can be said that the CS must be getting affected

Table 3. Comparison of foraminifera size from the study area with holotype/topotype.

S.No.	Dimension of species from study area	Dimension of holotype or topotype
1.	*Ammobaculites dilatatus* Cushman and Bronnimann 1948 height = 0.23 – 0.37 mm maximum diameter = 0.23 – 0.33 mm thickness = 0.05 – 0.09 mm	*Ammobaculites dilatatus* Cushman and Bronnimann 1948 (Ellis and Messina Cat. No. 032938) height = 0.50 – 0.65 mm maximum diameter = 0.40 – 0.45 mm
2.	*Ammobaculites exiguus* Cushman and Bronnimann 1948 height = 0.28 – 0.33 mm diameter of coiled part = 0.20 – 0.24 mm diameter of uncoiled part = 0.11 – 0.12 mm	*Ammobaculites exiguus* Cushman and Bronnimann 1948 (Ellis and Messina 032941) height = 0.30 – 0.45 mm diameter of coiled part = 0.13 – 0.20 mm diameter of uncoiled part = 0.10 – 0.12 mm
3.	*Nouria polymorphinoides* Heron-Allen and Earland 1914 length = 0.47 – 0.55 mm breath = 0.20 – 0.23 mm thickness = 0.09 mm	*Nouria polymorphinoides* Heron-Allen and Earland 1914 (Ellis and Messina Cat. No. 14276) Kerimba specimen: length = 1 – 1.9 mm, breath = 0.6 – 1 mm New Zealand specimen: length = 0.7 – 0.85 mm, breath = 0.25 – 0.30 mm
4.	*Asterorotalia dentata* Parker and Jones 1865 height = 0.26 – 0.97 mm maximum diameter = 0.23 – 0.95 mm thickness = 0.14 – 0.50 mm	*Rotalia beccarii* (Linne) var. *dentata* Parker and Jones 1865 (Sethulekshmi, 1958, pl. 3, fig. 112 a, a_1, a_2, b_1, b_2, p. 73) diameter = 0.69 – 0.80 mm
5.	*Brizalina** *limbata* Brady length = 0.18 mm maximum width = 0.09 mm thickness = 0.06 mm	*Loxostoma limbatum* Brady (Cushman, 1937, pl. 21, fig. 26 – 29, p. 186) length = 1 mm maximum width = 0.35 – 0.40 mm thickness = 0.20 – 0.25 mm
6.	*Brizalina*† *ordinaria* Phleger and Parker 1954 length = 0.20 mm maximum width = 0.07 mm thickness = 0.06 mm	*Bolivina simplex* Phleger and Parker 1951 (Ellis and Messina Cat. No. 73632) length = 0.32 mm maximum width = 0.14 mm thickness = 0.07 mm
7.	*Brizalina** *striatula* Cushman1922 length = 0.23 – 0.33 mm maximum width = 0.09 – 0.12 mm thickness = 0.07 – 0.09 mm	*Bolivina striatula* Cushman 1922 (Ellis and Messina Cat. No. 1957) length = 0.35 mm
8.	*Siphogenerina virgula* (Brady) length = 0.39 mm maximum breath = 0.09 mm	*Sagrina virgula* (Brady) 1879 (Ellis and Messina Cat. No. 20069) length = 0.50 mm
9.	*Cancris auricula* Fichtel and Moll height = 0.20 mm maximum diameter = 0.14 mm thickness = 0.09 mm	*Nautilus auricula* Fichtel and Moll 1798 (Ellis and Messina Cat. No. 74021) height = 0.90 mm maximum diameter = 0.55 mm thickness = 0.31 mm
10.	*Cancris carinatus* Millet 1904 height = 0.30 – 0.33 mm maximum diameter = 0.20 – 0.23 mm thickness = 0.11 – 0.14 mm	*Pulvinulina oblonga* (Williamson) var. *carinata* Millet 1904 (Ellis and Messina Cat. No. 79666) height = 0.48 mm diameter = 0.31 mm thickness = 0.20 mm
11.	*Nonion belridgense* Barbat and Johnson 1934 height = 0.20 – 0.25 mm maximum diameter = 0.16 mm thickness = 0.06 – 0.07 mm	*Nonion belridgense* Barbat and Johnson 1934 (Cushman, 1939, pl. 5, fig. 1, p. 18) height = 0.47 mm maximum diameter = 0.32 mm thickness = 0.24 mm
12.	*Nonion scapha* (Fichtel and Moll) Cushman 1939 height = 0.24 – 0.33 mm maximum diameter = 0.20 – 0.24 mm thickness = 0.07 – 0.09 mm	*Nonion scapha* (Fichtel and Moll) Cushman 1939 (Cushman, 1939, pl. 5, figs. 18 – 21, p. 20) height = 0.42 – 0.76 mm maximum diameter = 0.30 – 0.49 mm thickness = 0.11 – 0.24 mm
13.	*Protelphidium* cf. *schmitti* Cushman and Wickenden 1929 height = 0.18 mm maximum diameter = 0.14 mm thickness = 0.07 mm	*Elphidium schmitti* Cushman and Wickenden 1929 (Ellis and Messina Cat. No. 6223) diameter = 0.36 mm thickness = 0.15 mm
14.	*Pararotalia* cf. *globosa* Millet 1903 height = 0.10 mm maximum diameter = 0.08 mm thickness = 0.05 mm	*Rotalia murrayi* Heron-Allen and Earland 1915 (Ellis and Messina Cat. No. 19529) height = 0.20 – 0.23 mm diameter = 0.25 – 0.32 mm
15.	*Ammonia sobrina* Schupack 1934 height = 0.1 – 0.24 mm maximum diameter = 0.08 – 0.22 mm thickness = 0.05 – 0.15 mm	*Rotalia beccarii* (Linne) var. *sobrina* Schupack 1934 (Ellis and Messina Cat. No. 19330) diameter = 0.3 – 0.6 mm thickness = 0.15 – 0.4 mm

16.	*Ammonia tepida* Cushman 1926 height = 0.09 – 0.23 mm maximum diameter = 0.08 – 0.20 mm thickness = 0.06 – 0.10 mm	*Rotalia beccarii* (Linne) var. *tepida* Cushman 1926 (Ellis and Messina Cat. No. 19332) diameter = 0.35 mm
17.	*Cribrononion*[‡] *somaense* Takayangi 1955 height = 0.10 – 0.11 mm maximum diameter = 0.09 – 0.10 mm thickness = 0.06 mm	"*Elphidium*" *somaense* Takayangi 1955 (Matoba, 1970, pl. 7, fig. 11 – 12, p. 53) height = 0.19 – 0.22 mm maximum diameter = 0.16 – 0.19 mm thickness = 0.07 – 0.08 mm
18.	*Elphidium excavatum* Cushman 1930 height = 0.16 mm maximum diameter = 0.13 mm thickness = 0.07 mm	*Polystomella excavata* Terquem 1875 (Ellis and Messina Cat. No. 17361) height = 0.35 mm diameter = 0.32 mm
19.	*Florilus (?) tobagoensis* Mc Culloch 1981 height = 0.14 – 0.25 mm maximum diameter = 0.11 – 0.20 mm thickness = 0.05 – 0.08 mm	*Florilus (?) tobagoensis* Mc Culloch 1981 height = 0.27 – 0.37 mm maximum diameter = 0.27 mm thickness = 0.06 – 0.17 mm

over consecutive seasons. On the other hand, large seasonal change in TLN is observed in both the northern and southern peripheral stations. The decrease in TLN from pre-monsoon to monsoon season in NPS confirms the northwards proliferating effect of mudbank, which in turn affects the living population of benthic foraminifera. With the withdrawal of monsoon and onset of the post-monsoon season, TLN in the northern peripheral region does not show an appreciable increase, indicating longer duration required for complete restoration of the substrate. In the southern region, TLN decreases at shallower stations of transact III and IV from pre-monsoon to monsoon, suggesting the minor influence of mudbank extending in shallower depths, south of core mudbank area. Interestingly, TLN in the SPS decreases at deeper stations of transact II and IV from monsoon to post-monsoon. In contrast to that, the TLN increases at shallower stations, with the withdrawal of mudbank effect from this region. Thus, it can be inferred that shallower stations remain under mudbank influence whereas deeper stations of southern region are under the effect of monsoon. The lower faunal abundance in the northern region, as compared to the southern region and continued lower abundance at shallow stations in post-monsoon season, that is the withdrawl phase of mudbank, indicates that north of core mudbank region is more affected than south.

The bottom water salinity in CS during monsoon, ranges from 24.4 to 26.9 psu. The salinity in NPS varies from 34.2 to 34.6 psu and in SPS from 34.6 to 34.8 psu. During non- monsoon season, the salinity in CS ranges from 26.7 to 31.9 psu, in NPS it is 33.8 psu and in SPS, the range of salinity is from 33.9 to 34.0 psu. The core mudbank region has the lowest salinity (Held *et al.* 2014) as compared to the peripheral regions. The salinity measurements are in agreement with that from the Alleppey mudbank in the year 1971-1972 (Murthy *et al.*, 1984). Apart from the disturbed bottom mud, the low bottom water salinity, further adds to the stressed benthic environment and collectively form the cause of poor faunal abundance in the core mudbank area (Nigam *et al.*, 2006; 2008; Kurtarkar *et al.*, 2011). The DO measurements of the bottom water show the seasonal change between monsoon and non- monsoon months. But no significant spatial change is observed between CS, NPS and SPS in any season. It ranges from 0.2 to 0.6 mg/l in monsoon season and 4.6 to 5.9 mg/l in non- monsoon season.

A peculiar feature observed in the mudbank fauna of Alleppey is their relatively smaller test size (Seibold and Seibold 1981) which is considered as a dwarf character of foraminifera (Boltovskoy and Wright, 1976). The invariably smaller test size (Table 3), is the result of stressful environment, under which the organism has reduced metabolism and thus develop smaller tests and reduce reproduction (Boltovskoy and Wright 1976 Nigam *et al.*, 2006; 2008; Kurtarkar *et al.*, 2011). In case of mudbank area, the ideal living conditions of foraminifera are interrupted, as is well depicted by dwarfism of the fauna. The presence of dwarf fauna in the entire mudbank area can be explained in light of marginal effect in the peripheral regions (i.e., towards north and south), the extent of which vary in every season. Thus, it can be inferred that Alleppey mudbank area represents a typical marginal marine ecosystem where bottom water salinity is low and bottom mud remains unstable which modulates species-specific response in foraminifera exhibited as dwarfism and poor abundance. The bottom water DO does not show any spatial variation in any season and seems not to be a key factor in characterizing stressful environment of the core mud bank region. However, the area becomes more interesting owing to low bottom water salinity in the absence of any river/ stream in Alleppey. Earlier, Loveson *et al.* (2016) suggested a subterraneous flow from a nearby lake to the nearshore region, through sub-surface paleo-channels to be the cause of mudbank formation off Alleppey. This may also qualify as the reason for low bottom water salinity and disturbed bottom mud.

CONCLUSIONS

We report that the living benthic foraminifera adapts to the stressful environment of mudbank by reducing their metabolism and proliferating as dwarf forms. The stressed benthic environment is also evident from an extremely poor foraminiferal abundance. The faunal response suggests that the anomaly in benthic environment of Alleppey mudbank originates in core mudbank area (CS) and proliferates northwards (NPS) and to a shallower depth in the south (SPS). The disturbance of muddy bottom layer and low bottom water salinity constitute the prime environmental stress factors in the mudbank area. Based upon the localised faunal response, low bottom water salinity and absence of river/streams in Alleppey, it can be said, that out of various hypotheses proposed to explain the cause of re-suspension of bottom mud leading to the formation of mudbank, the subterraneous flow hypothesis seems to be the most plausible cause of mudbank formation off Alleppey.

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