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Infaunal Characteristics of Benthic Foraminifera from the Muthupet Lagoon Ecosystem, South-East Coast of India

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ABSTRACT

A thorough review of literature showed that very little work has been carried out on foraminifera from the Muthupet Lagoon. The most notable research in this aspect has been the recent findings by Rajeshwara Rao *et al*. (2013), who provided an insight into the ecology of one particular species, *Asterorotalia trispinosa* (Thalmann, 1933). Infaunal habitat preferences of benthic foraminifera, however, have not been studied in any kind of ecosystem in India so far. It was, therefore, decided to study more on the benthic foraminifera from this important ecosystem with special emphasis on infaunal characteristics. Accordingly, three cores were manually retrieved from the lagoon at water depths ranging from 1 to 1.5 m by inserting acrylic pipes; each core was 45 cm long. The cores were sliced at 1-cm interval and all the sub-samples were rose Bengal-stained in order to establish infaunal depth preferences by species that were abundant or commonly occurring. Counts of living, dead and total populations of the species *Asterorotalia spinosa*, *Elphidium excavatum*, *Ammonia tepida* and *Ammonia beccarii* were made and their downcore variations analyzed. The results establish the presence of distinct micro-habitats in Muthupet Lagoon, controlling the populations of different species. The same species seems to prefer different infaunal depths within the lagoon, either facilitated by bioturbation or search for more hospitable oxygen conditions in the sediment.
Keywords: Benthic Foraminifera, Muthupet Lagoon, Microhabitats, Infaunal Characteristics, Ecosystem

I. INTRODUCTION

Foraminifera were first recorded by Herodotus in the 5th century B.C.; he observed the Nummulites in the rocks with which the Egyptian pyramids were constructed. It was, however, nearly 2,000 years later that were they recognized as being the fossil remains of organisms by Agricola in 1558 A.D. The smaller foraminifera were first described by Beccarius in 1731. Dujardin first demonstrated the protozoan nature of these organisms in 1835. The first larger-scale systematic work was that of d'Orbigny (1826), in which 5 families, 52 genera and 544 species were recognized. He defined genera and species within narrow limit and cited their geological occurrence as well. While the early continental workers concentrated on stratigraphic application of the foraminifera and faunal description (e.g., d'Orbigny, Reuss, Terquem, Berthelin), the English workers, in general, concentrated on morphological studies and description of recent faunas (e.g., Brady, Carter, Williamson, Heron-Allen, Earland).

Foraminifera are micro-unicellular organisms. They are almost entirely marine animals though a few live in brackish and even fresh water. These organisms build a shell and for paleontologists, the characteristics of the shell are the primary feature, which can be used to distinguish one species from another and hence, to use these distinction to form interpretation of time or environment. Foraminifers constitute the most diverse group of shelled microorganisms in modern oceans. Shells (usually called "tests") of extant foraminifers have been noticed in shore sands since the 17th century. An unusual early find was by the great microscopist, Antonie van Leeuwenhoek who, in 1700, wrote about foraminifer shells "no bigger than a coarse sand grain" in the stomachs of shrimps, and described the specimens as "very little small shells". Many foraminiferal species have adapted to extreme natural environments, such as habitats of high salinity, areas near hydrothermal vents (Jonasson *et al*., 1995), and even bacterial mats at hydrocarbon vents (Sen Gupta *et al*., 1997).

A. Review of Literature

Quite a few research studies have been made on foraminifera from lagoons and lakes in India. Seibold (1975) reported 69 benthonic foraminiferal species, including one new species, from the lagoon and coast of Cochin. The distribution, transport and ecological aspects of offshore and lagoonal benthonic foraminifera were studied by Seibold and Seibold (1981). Naidu (1983) recorded 101 foraminiferal taxa from Sanidanigadda and Bendi Lagoon in Andhra Pradesh. Jayaraju *et al.* (1998) carried out Q-mode factor analysis of 23 foraminiferal genera from 30 sampling stations which revealed 6 assemblages for each season within the Pulicat Lake environment. Jayaraju *et al*. (2000) studied living benthic foraminiferal assemblages of Pulicat Lake, east coast of India, and attempted to document the dominant living foraminiferal assemblages in 30 sampling stations in Pulicat Lake. They identified 35 living species and analyzed their abundance using Q-mode factor analysis. The diversity and distribution of foraminifera were investigated by Subhadra *et al*. (2008), who collected 20 sediment samples from the east and west shore and lagoon of Amini Island, Lakshadweep Archipelago, Arabian Sea. They identified 22 species belonging to 15 genera, 12 families and 4 suborders, among which *Marginopora vertebralis*, *Calcarina calcar*, *Amphistegina madagascarensis*, *A. radiata* and *A. lessonii* were found to be abundant.

B. About the Study Area and Core Details

Muthupet Lagoon is located at the southern end of the Cauvery River delta, Bay of Bengal, covering an area of ~13,500 ha, of which only 4% is occupied by well-grown mangroves. Most of the lagoon area is occupied by muddy silt ground that is devoid of mangroves. Beyond the lagoon, the mangroves are discontinuously found along the shore and extend up to Point Calimere. The Muthupet mangrove forest was under the control of Chatram Department from 1853 to 1912 (Chengappa, 1918). Three cores were retrieved from the lagoon at water depths ranging from 1 to 1.5 m. The cores were collected by pushing acrylic pipes into the sediment manually; the locations of the cores are given in Figure 1 and Table 1. Acrylic pipes facilitate observations in the field itself and provide an idea about the length recovered and sediment texture. The recovery in each of the three cores was 45 cm.

Table 1

Geographic co-ordinates of core locations

Core no.	Latitude	Longitude	Core length
1	10° 19′ 30.00″ N	79° 32′ 41.80″ E	45 cm
2	10° 20′ 16.50″ N	79° 32′ 29.60″ E	45 cm
3	10° 20′ 42.20″ N	79° 32′ 22.60″ E	45 cm

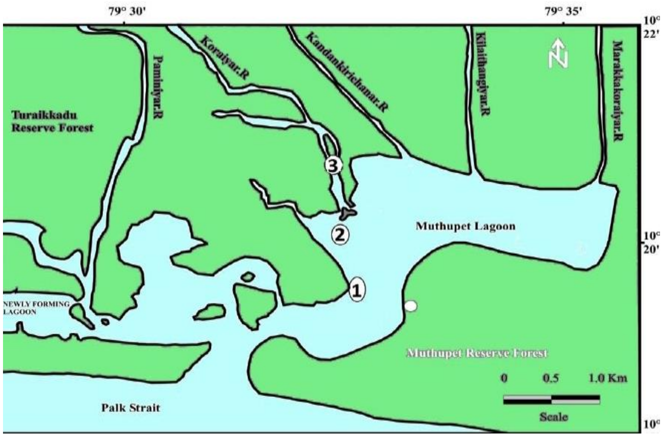

Figure 1: Map showing locations of the three cores

II. METHODS AND MATERIAL

All the three cores were sub-sampled at 1-cm interval to obtain accuracy in establishing infaunal depth preferences, if any, for the species. Each sub-sample was wet sieved through an ASTM 230 mesh sieve (opening = 63 microns) to eliminate the silt and clay (mud) content. The sand fraction retained on the sieve was subjected to the rose Bengal staining technique (Walton, 1952) to distinguish between living and dead tests. After oven-drying at 50° C, each sub-sample was fractionated using a nest of sieves: ASTM 30, 60, 80, 100 and 140. Foraminiferal tests were hand-picked from the comparatively coarser fractions using a soft-bristled brush under a binocular stereo zoom microscope (EUROMAX-NOVEX). The other relatively finer fractions were subjected to floatation using CCl_4 (Cushman, 1959). The foraminiferal tests picked were mounted on Plummer cells (24-chambered micropaleontological slides) and, after identifying the individual species, their living and total populations were counted.

A. Systematic Paleontology

The widely utilized classification proposed by Loeblich and Tappan (1987) has been followed in the present study. A species has been regarded as the sum total of specimens sharing all test characters, with such measurable, countable, or otherwise observable, variation in size and shape of some elements or of proportions between the latter in different ontogenic stages, which fits a pattern of normal distribution and whereby these specimens are separable from other similar groupings regarded as distinct species (Hottinger *et al*., 1993). Species have been identified using various atlases, monographs and research publications from all over the world. All objectively observable and defined test characters and features and their stable combination in (usually) more than one species have been regarded as of generic rank. A strict view of characters regarded as generic has been taken here, leading to the use of the valid genera proposed over the years and enumerated by Loeblich and Tappan (1987). In cases where generic revision has taken place, the new nomenclature has been adopted.

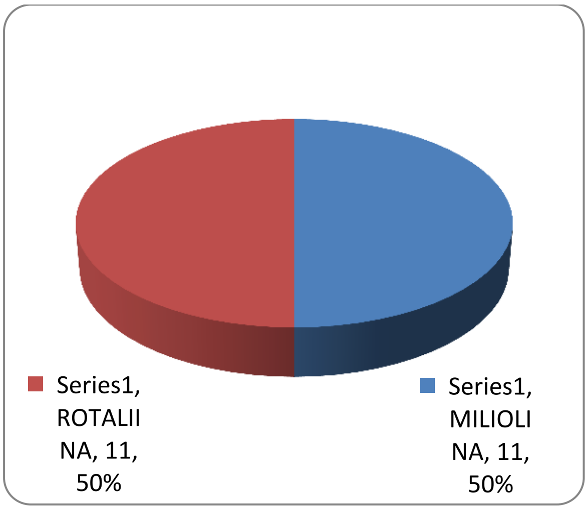

Figure 2: Pie chart showing equal distribution of the suborders

In the following pages, 22 benthic foraminiferal species belonging to 6 genera, 4 families, 2 superfamilies and 2 suborders have been reported (Figure 2). Among these, 11 are calcareous, imperforate, porcelaneous forms (suborder MILIOLINA) and 11 species are calcareous, perforate forms (suborder ROTALIINA). All the species and varieties have been duly indexed and deposited in the Department of Applied Geology, University of Madras, Chennai 600 025, India.

Order FORAMINIFERIDA Eichwald, 1830
Suborder MILIOLINA Delage and Hérouard, 1896
Superfamily MILIOLACEA Ehrenberg, 1839
Family SPIROLOCULINIDAE Wiesner, 1920
Genus SPIROLOCULINA d'Orbigny, 1826
Spiroloculina antillarum d'Orbigny, 1839
Original citation: *Spiroloculina antillarum* D'ORBIGNY, 1839, p. 166, pl. 7, figs. 3, 4.
Spiroloculina communis Cushman and Todd, 1944
Spiroloculina communis CUSHMAN and TODD, 1944, pp. 63 64, pl. 9, figs. 4, 5, 7 and 8.
Spiroloculina costifera Cushman, 1917
Spiroloculina costifera CUSHMAN, 1917, p. 34, pl. 6, figs. 1–3.
Spiroloculina depressa d'Orbigny, 1826
Spiroloculina depressa D'ORBIGNY, 1826, p. 298, model no. 92.
Spiroloculina henbesti Petri, 1955
Spiroloculina henbesti PETRI, 1955, v. 6, no. 2, p. 82, figs. 4–6.
Spiroloculina nitida d'Orbigny, 1926
Spiroloculina nitida D'ORBIGNY, 1826, v. 7, p. 298.
Spiroloculina orbis Cushman, 1921
Spiroloculina orbis CUSHMAN, 1921, v. 4, p. 403, pl. 83, fig. 3.
Family HAUERINIDAE Schwager, 1876
Subfamily HAUERININAE Schwager, 1876
Genus QUINQUELOCULINA d'Orbigny, 1826
Quinqueloculina elongata Natland, 1938
Quinqueloculina elongata NATLAND, 1938, v. 4, no. 5, p. 141, pl. 4, fig. 5.
Quinqueloculina lamarckiana d'Orbigny, 1839
Quinqueloculina lamarckiana D'ORBIGNY, 1839, p. 189, pl. 11, figs. 14, 15.
Quinqueloculina oblonga (Montagu, 1803)
Vermiculum oblongum MONTAGU, 1803, p. 522, pl. 14, fig. 9.
Quinqueloculina seminula (Linne, 1758)
Serpula seminula LINNE, 1758, p. 786, pl. 2, figs. 1a–c.
Suborder ROTALIINA Delage and Hérouard, 1896
Superfamily ROTALIACEA Ehrenberg, 1839
Family ROTALIIDAE Ehrenberg, 1839
Subfamily AMMONININAE Saidova, 1981
Genus AMMONIA Brunnich, 1772
Ammonia beccarii (Linnaeus, 1758)
Nautilus beccarii LINNAEUS, 1758, v. 1, p. 710.
Ammonia dentata (Parker and Jones, 1865)

Original citation: *Rotalia beccarii* (LINNE) var. *dentata* PARKER and JONES, 1865, pp. 387, 388, 422, pl. 19, figs. 18a–c.
Ammonia tepida (Cushman, 1926)
Rotalia beccarii (Linne) var. *tepida* CUSHMAN, 1926, p. 79, pl. 1; 1931, p. 61, pl. 13, figs. 3a–c.
Genus ASTEROROTALIA Hofker, 1950
Asterorotalia multispinosa (Nakamura)
Asterorotalia multispinosa (Nakamura) – In: RAO and RAO, 1974, tab. 7, pl. 2, figs. 12a, b.
Asterorotalia trispinosa (Thalmann, 1933)
Rotalia trispinosa THALMANN, 1933, v. 26, no. 2, pp. 249, 250, pl. 12.
Family ELPHIDIIDAE Galloway, 1933
Subfamily ELPHIDIINAE Galloway, 1933
Genus CRIBRONONION Thalmann, 1947
Cribrononion simplex (Cushman, 1933)
Elphidium simplex CUSHMAN, 1933, pt. 2, p. 52, pl. 12, figs. 8, 9.
Genus ELPHIDIUM de Montfort, 1808
Elphidium crispum (Linnaeus, 1758)
Nautilus crispus LINNE, 1758, p .709.
Elphidium craticulatum Fichtel and Moll, 1798
Nautilus craticulatus FICHTEL and MOLL, 1798, p. 51, pl. 5, figs. h–k.
Elphidium hispidulum Cushman, 1936
Elphidium hispidulum CUSHMAN, 1936, v. 12, pt. 4, p. 83, pl. 14, figs, 13a, b.
Elphidium norvangi Buzas, Smith and Beam, 1977
Elphidium norvangi BUZAS, SMITH and BEAM, 1977, p. 96, pl. 7, figs. 1–4. *Elphidium* sp.

III. RESULTS AND DISCUSSION

Living and total population counts revealed that only two species were dominant in Core-1: *Asterorotalia trispinosa* and *Elphidium excavatum*. *A. trispinosa* has been adequately described by Flint (1899), Thalmann (1933) and Hofker (1951). Ghose (1966) gave a detailed account of its morphological variations and nomenclature based on 88 specimens obtained from Digha Beach, Southern Bengal. Ragothaman (1974) recorded this species as *Asterorotalia pulchella* (Thalmann) from off Porto Novo. Ganapati and Satyavati (1958) observed this species to be common in the littoral zone all along the east coast of India from Calcutta (now Kolkata) in the north to Madras (now Chennai) in the south.

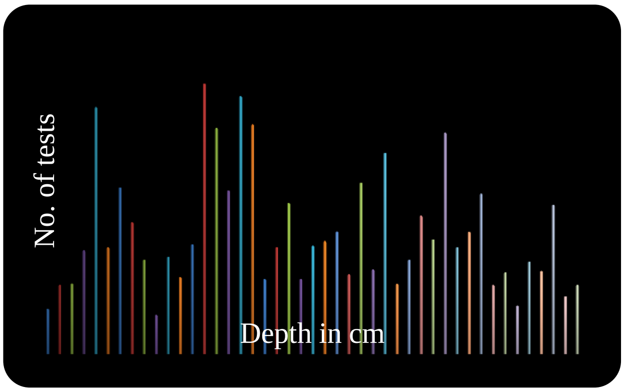

Figure 3: Downcore variations in total populations of *Asterorotalia trispinosa* in Core –1

Downcore variations in total populations of *A. trispinosa* (Figure 3) show that it is more or less uniformly distributed throughout Core-1, suggesting its dominant presence at this location, which is closer to the mouth of the lagoon than the locations of the other two cores. Near the mouth of the lagoon, there is more turbulence due to wave action and the sediment is continuously kept in suspension. Ghose (1966) opined that the spines of this species may increase its buoyancy and allow it to live just above the sediment-water interface. It is now considered that this species might be a suspension feeder and hence its rather uniformly high total populations in Core-1. Downcore living populations of *Asterorotalia trispinosa* are very interesting as they exceed the dead populations in all the sub-samples of Core-1. Infaunal depth preferences for this species have not been studied in any ecosystem anywhere in the Indian or south-east Asian region. This study has, therefore, for the first time, provided an insight into the infaunal characteristics of this species, which had so far been considered to be epifaunal above the sediment-water interface.

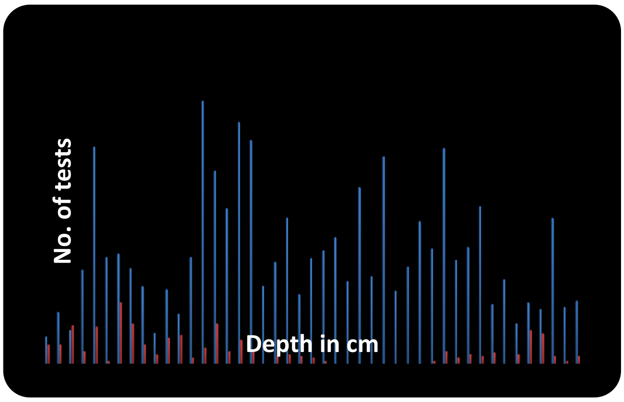

Figure 4: Downcore variations in living (blue) and dead (red) populations of *Asterorotalia trispinosa* in Core –1

Downcore variations in total populations of *Asterorotalia trispinosa* (Figure 5) exhibit peaks at 5-, 7-, 14-, 17-, 21-, 27-, 29-, 34-, 37- and 43-cm depths suggesting vertical migration of this species downward into the sediment facilitated by bioturbation by animals and plant roots (Goldstein and Harben, 1993), or as a response of this species to changes in oxygen concentrations at different depths in the sediment (Alve and Bernhard, 1995; Kitazato and Ohga, 1995). The results for Core-1 show that *A. trispinosa* is a shallow to deep infaunal species (Saffert and Thomas, 1998).

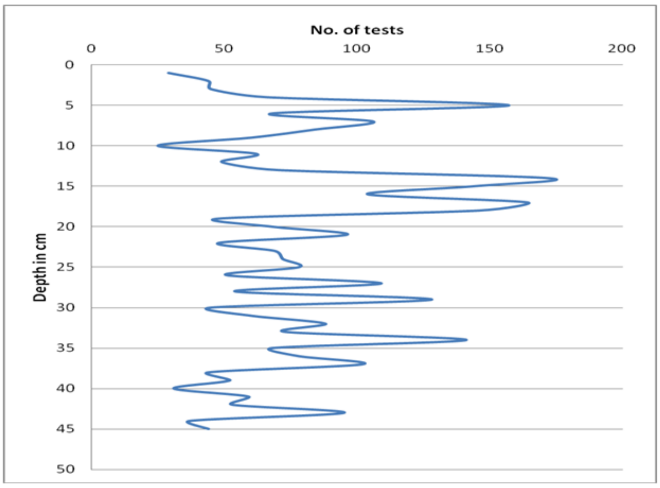

Figure 5: Downcore variations in total populations of *Asterorotalia trispinosa* in Core-1

Elphidium excavatum is a common component of the inter-tidal to shallow sub-tidal (6 m) temperate, brackish water assemblages of the Skagerrak, Oslo Fjord and the Kattegat. The macro-tidal Elbe Estuary in Germany has mainly an *E. excavatum* assemblage with subsidiary *Ammonia* group, whereas in the estuary mouth the *Ammonia* assemblage dominates with *E. excavatum* becoming subsidiary (Murray, 1991). Downcore variations in total populations of this species in Core-1 (Figure 6) reveal that its infaunal depth preference to be limited to a range of 4 to 8 cm inside the sediment. A few tests in the depth range of 25 to 35 cm suggest post-mortem vertical migration facilitated by bioturbation by animals and plant roots (Goldstein and Harben, 1993). The results suggest that this species is shallow to intermediate infaunal (Saffert and Thomas, 1998).

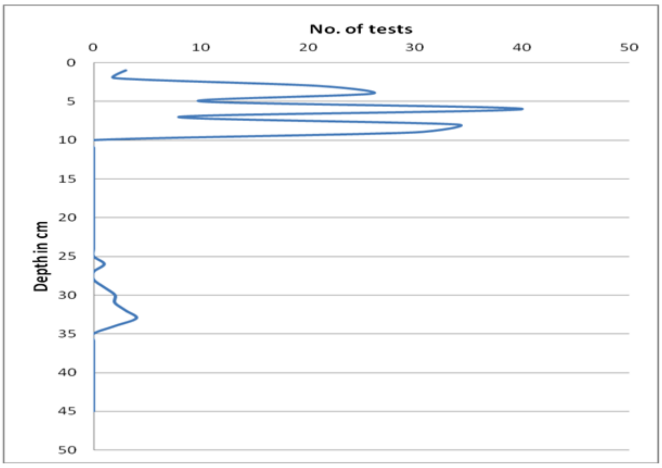

Figure 6: Downcore variations in total populations of *Elphidium excavatum* in Core-1

In Core-2, the dominant species are *Asterorotalia trispinosa*, *Ammonia tepida* and *Elphidium excavatum*. Total and living populations of *A. trispinosa* are considerably less than in Core-1 (Figs. 7 and 8, respectively). In fact, the maximum living as well total populations were observed at a depth of 3 to 4 cm only. A few living specimens were observed at 32–33 cm depth, attributable to vertical migration. The results clearly show that the location of Core-2 is not favorable for this species.

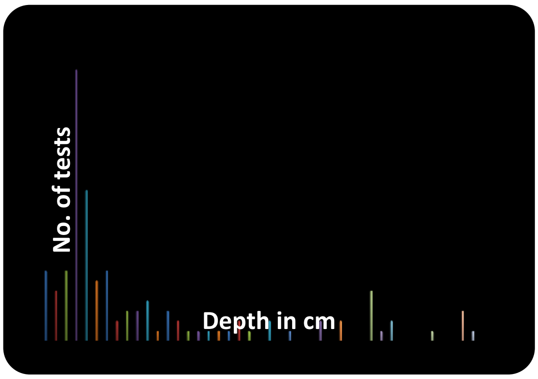

Figure 7: Downcore variations in total populations of *Asterorotalia trispinosa* in Core –2

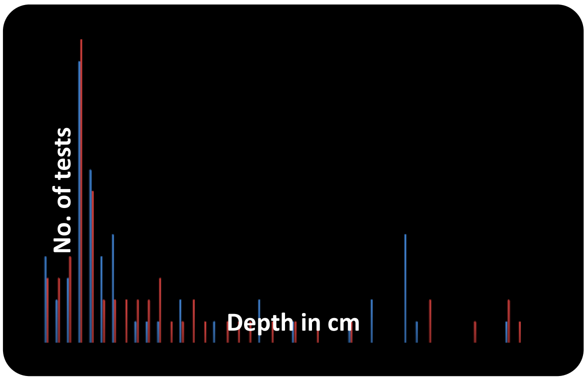

Figure 8: Downcore variations in living (blue) and dead (red) populations of *Asterorotalia trispinosa* in Core –2

Ammonia tepida is a euryhaline species (Alday *et al*., 2013), and has been recorded from several environments such as the protected low-energy bay in St. Lucia, West Indies (Sen Gupta and Schafer, 1973), near shore lagoons of Trinidad (Todd and Brönniman, 1957), brackish water settings in Cuba (Bandy, 1964), and mangroves on Qeshm Island in the Persian Gulf (Mollayousefy *et al*., 2006). Downcore variations in total populations of this species (Figure 9) clearly suggest an infaunal depth preference of 8 to 10 cm inside the sediment. The peaks in total populations at deeper levels inside the sediment (at 28- and 33-cm) are attributable to vertical migration prior to death facilitated by bioturbation by animals and plant roots (Goldstein and Harben, 1993), or in response to changes in oxygen concentrations (Alve and Bernhard, 1995; Kitazato and Ohga, 1995). From the results obtained from Core-2, it can be presumed that *Ammonia tepida* is a shallow infaunal species (Saffert and Thomas, 1998).

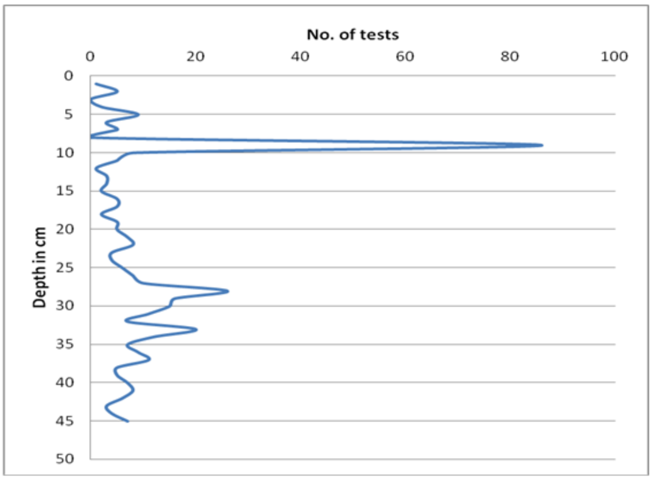

Figure 9: Downcore variations in total populations of *Ammonia tepida* in Core–2

Downcore variations in total populations of *Elphidium excavatum* in Core-2 are completely different from Core-1. Although the numbers are relatively less than in Core-1, the peaks at 6-, 17- and 30-cm (Figure 10) are indicative of either post-mortem vertical migration of this species facilitated by bioturbation, or by downward migration by living specimens in response to changes in oxygen levels in the sediment.

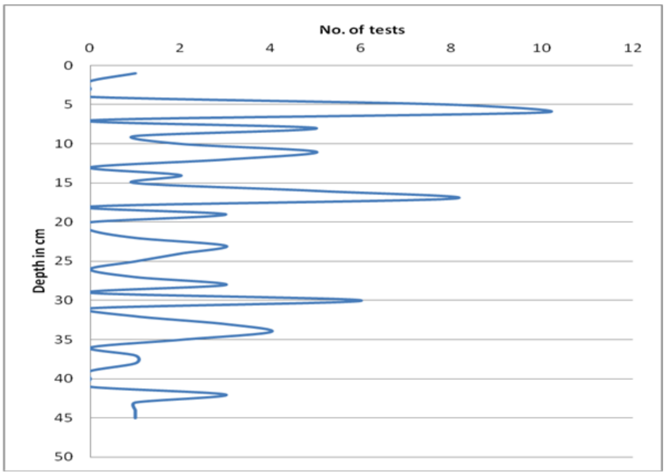

Figure 10: Downcore variations in total populations of *Elphidium excavatum* in Core–2

Ammonia beccarii is the most dominant species in Core-3, followed by *Asterorotalia trispinosa* and *Ammonia tepida*. There are innumerable records of *Ammonia beccarii* from all over the world. This species has been recorded from a wide variety of environments. According to Hatta and Ujiie (1992), this species shows wide variation in reflecting differences of environmental conditions, because it prefers to live in brackish to shallow sea-waters where large local and/or diurnal changes in environmental factors can be expected. It is a cosmopolitan species that commonly occupies shallow infaunal habitats but sometimes is even found in attached macrobenthos on hard substrates (Takata *et al*., 2010). In Core-3, downcore variations in total populations of *Ammonia beccarii* suggest an infaunal characteristic different from that opined by Takata *et al*. (op cit.). The peaks at 9-, 15-, 17-, 20-, 24-, 36- and 41-cm (Fig. 11) indicate that this species is intermediate to deep infaunal at this site (Saffert and Thomas, 1998).

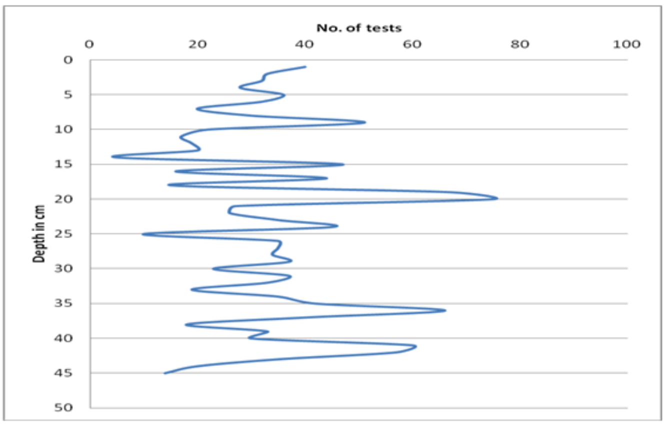

Figure 11: Downcore variations in total populations of *Ammonia beccarii* in Core–3

In Core-3, the total populations of *Asterorotalia trispinosa* are slightly higher than in Core-2, but again considerably less than in Core-1 (Fig. 12). This location is, however, dominated by the predominance of dead tests; living specimens were observed to be very rare (Fig. 11). The life cycle of this species has not been established as yet, so it is possible that conditions at this site were not favorable for reproduction, resulting in the accumulation of dead tests. As living specimens were rare in this core, it is not possible to suggest any infaunal depth preference(s) at this location in the lagoon.

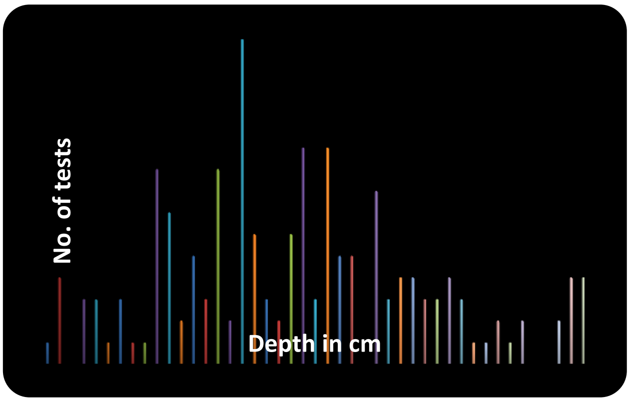

Figure 12: Downcore variations in total populations of *Asterorotalia trispinosa* in Core –3

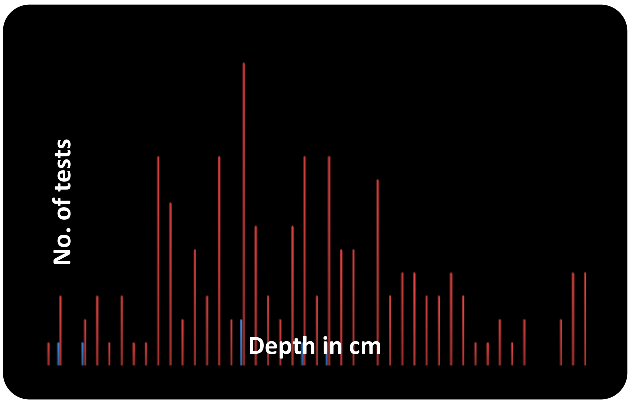

Figure 13: Downcore variations in living (blue) and dead (red) populations of *Asterorotalia trispinosa* in Core –3

The total populations of *Ammonia tepida* (Figure 14) in Core-3 are less than those in Core-2, and downcore variations also suggest different infaunal depth preferences compared to Core-2. The peaks in total populations at 20-, 37-, 42- and 44-cm inside the sediment are attributable to either post-mortem vertical migration of this species facilitated by bioturbation, or by downward migration by living specimens in response to changes in oxygen levels in the sediment. The results indicate that this species is intermediate to deep infaunal at this site.

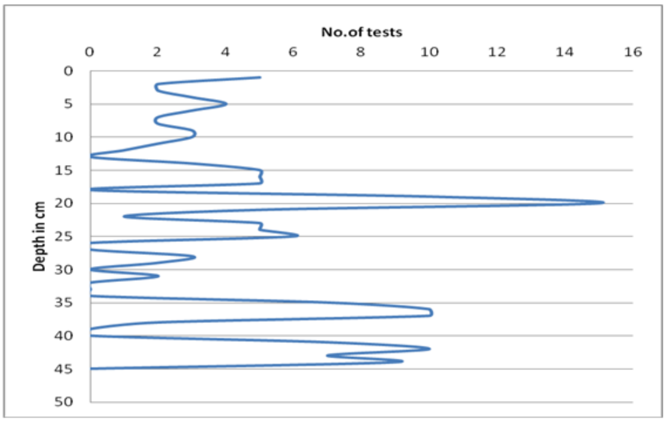

Figure 14: Downcore variations in total populations of *Ammonia tepida* in Core–3

The results obtained for the dominant species in each of the three cores reveal that there are different micro-environments in the Muthupet Lagoon, controlling the populations of different species or groups of species. Moreover, the same species seems to prefer different infaunal depths within the lagoon, indicating that controlling factors can be extremely localized. This study has, for the first time in India, established the shallow to deep infaunal habitat for the species *Asterorotalia trispinosa* (Thalmann, 1933).

IV. CONCLUSION

The results for Core-1 show that *Asterorotalia trispinosa* is a shallow to deep infaunal species. Downcore variations in total populations of *Elphidium excavatum* in Core-1 reveal that its infaunal depth preference to be limited to a range of 4 to 8 cm inside the sediment. The results suggest that this species is shallow to intermediate infaunal. The location of Core-2 is not favorable for *Asterorotalia trispinosa*. Downcore variations in total populations of *Ammonia tepida* clearly suggest an infaunal depth preference of 8 to 10 cm inside the sediment. Based on the results obtained from Core-2, it can be presumed that this species is shallow infaunal. Downcore variations in total populations of

Elphidium excavatum in Core-2 are completely different from Core-1. The results indicate that it is intermediate to deep infaunal in Core-2. *Ammonia beccarii* is the most dominant species in Core-3. Downcore variations in its total populations suggest that this species is intermediate to deep infaunal in Core-3. Majority of the specimens of *Asterorotalia trispinosa* in Core-3 are dead; It is, therefore, not possible to suggest any infaunal depth preference at this location in the lagoon. The results for Core-3 indicate that *Ammonia tepida* is intermediate to deep infaunal at this site. This study has provided, for the first time in India, provided an insight into the infaunal characteristics of *Asterorotalia trispinosa*, which had so far been considered to be epifaunal, living above the sediment-water interface. Most importantly, the results obtained for the dominant species in each of the three cores reveal that there are distinct micro-habitats in the Muthupet Lagoon, which control the populations of different species or groups of species. Moreover, the same species seems to prefer different infaunal depths within the lagoon, indicating that controlling factors can be extremely localized.

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