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A STUDY OF MICROHABITAT OF INTERTIDAL FORAMINIFERA FROM CHANDIPUR COAST, ODISHA

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ABSTRACT

This study serves as a first investigation report of benthic foraminifera from Chandipur, east coast of the Indian subcontinent. It concerns the microhabitats of the intertidal living foraminiferal population of Chandipur coast. Three short core samples of 20 cm each were collected from various sub-environments of the Chandipur coast (mud flat, estuary mouth and intertidal flat) and investigated for benthic foraminifera. Eleven genera of foraminifera have been identified, consisting both calcareous and agglutinated forms. The calcareous foraminifera are comprised of *Ammonia* spp., *Haynesina* spp., *Asterorotalia* sp. and *Quinqueloculina* sp.; with minor occasional occurences of *Cribroelphidium* sp. and the agglutinated species are *Trochammina* spp., *Miliammina* sp. and *Haplophragmoides* sp. The living foraminiferal count reduces drastically down the cores and shows one or more maxima deeper in the sediment. These different types of vertical distribution are reflections of the tolerance or preference levels of taxa with respect to one or more abiotic parameters. Food availability and dissolved oxygen might play a role in determining the lower downcore maxima. Bioturbation can also actively transport foraminifera to deeper sediment layers, and cause accidental occurrence of taxa that are usually found at the sediment surface. The living population consisted mainly of *Haynesina germanica, Haynesina depressula* and *Ammonia tepida*. Abundance of living populations of *Haynesina* spp. suggests a fluvial influence and higher clay percentages of this area. This also corroborates with good abundance of *Ammonia tepida*, indicating fluvial influence and lower percentages of sand. Good abundance of *Asterorotalia trispinosa* indicates high sedimentation rates.

Keywords: benthic foraminifera, intertidal region, microhabitat, Chandipur, east coast of India.

INTRODUCTION

Chandipur coast, as most of the coasts today, is experiencing huge pollution and causing a stressed environment for several organisms. In an ecosystem of complex biotic and abiotic factors, marine organisms do not have a simple relationship with environmental parameters. The environmental setting is governed by biotic factors like competition, space and food supply; whereas the abiotic factors comprises of temperature, salinity, dissolved oxygen, nutrients and coastal geomorphology. There are a variety of factors which influence bottom dwelling foraminifera; inclusive of dissolved oxygen, food availability (Corliss 1985; Gooday and Turley, 1990; Jorissen *et al*., 1992, 1995; Sen Gupta and Machain-Castillo, 1993; Mackensen *et al*., 1995; McCorkle *et al*., 1997; Schmiedl *et al*., 1997; Van der Zwaan *et al*., 1999; Den Dulk *et al*., 2000; Nomaki *et al*., 2008; Mackensen 2012; Mackensen and Schmiedl 2016), temperature, salinity (Nigam *et al*., 1992, 2008; Kurtarkar *et al*., 2011; Saraswat *et al*., 2011, 2015; Manasa *et al*., 2016), depth (Corliss and Chen 1988), sediment texture (Alve and Murray, 1999), and others (Boltovskoy *et al*., 1991; Murray 2001, 2006). These changes are well reflected in the distribution pattern of foraminifera. A better understanding of such complexities of the ecological processes will help in developing proxies for palaeoenvironmental studies.

Very few studies on using benthic foraminifera have been carried out from the eastern Indian margin (Gandhi *et al*., 2007, Gandhi and Solai, 2010, Caulle *et al*., 2015, Suokhrie *et al*., 2018, Singh *et al*., 2018) and subsurface distribution (Caulle *et al*., 2014, Enge *et al*., 2014, Gooday *et al*., 2009, Jannink *et al*., 1998, Larkin and Gooday 2008, Schumacher *et al*., 2007).

The surficial and vertical distribution of living benthic foraminifera, have not yet been studied from the Chandipur coast, Bay of Bengal that is sometimes called the treasure house of invertebrates. This is the first detailed taxonomical report on the foraminiferal groups studied from this part of the Indian east coast and to find out the ecological preferences of these unicellular eukaryotes by studying their distribution on surface and below the sediments.

ENVIRONMENTAL SETTING

Chandipur, also known as Chandipur-on-sea is a small coastal town lying on the eastern coast of India. It is situated in the Balasore district in Orissa, India on the coast of Bay of Bengal. The beach (Figure 1) is unique in the sense that the water level recedes up to 5 kilometres during ebb tide. So, it can be described as an endless tidal flat with marshy characteristics in between that emerges during low tide and submerges during high tide. (Mukhopadhyay *et al*., 2011). Geomorphology and physiography of this part of the east coast of India are influenced by dominant actions of waves, micro and macro-tidal cycles along with typical long shore currents. The Chandipur coast is a part of the coastal plain that extends from the River Buribalam in the north forming an extensive alluvial tract. Interplay of fluvial, fluvio-marine, marine and aeolian processes give rise to a variety of geomorphic features like beach, tidal flat, coastal dunes, swamps and the bar. The Buribalam River, which forms an estuary in this region, drains this area and its emerged terrace, is covered with marsh. Here, the groundwater is generally saline and the freshwater occurs in discontinuous patches. The shoreline indicates a NE-SW trend.

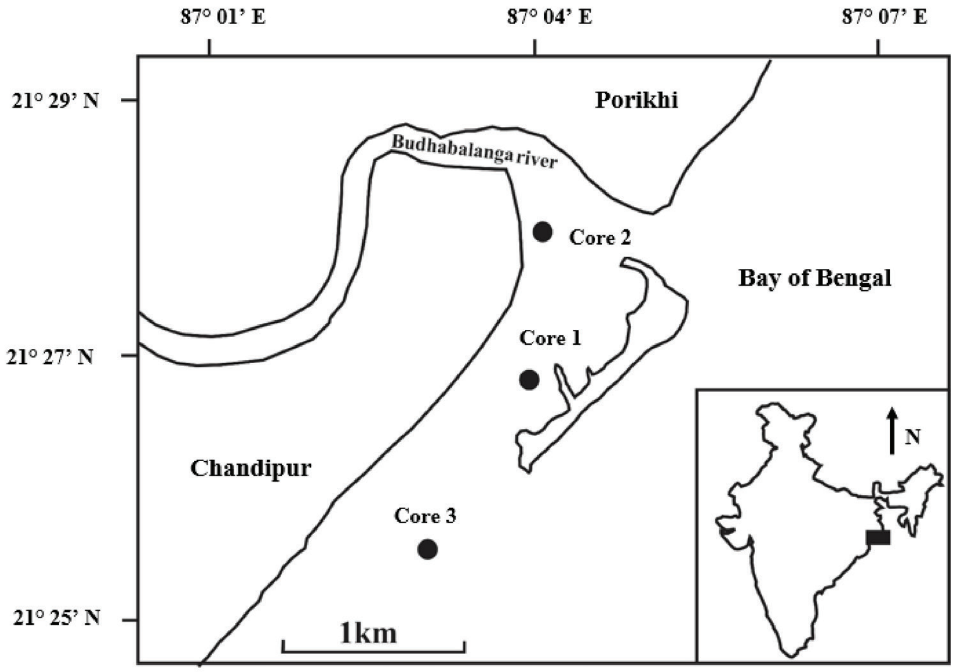


Fig. 1. Sampling stations in Chandipur coast, Odisha.

MATERIALS AND METHODS

Three short core samples of 20 cm each were collected with the help of PVC pipe, from different subenvironments of the Chandipur coast (Table 1); one from the mudflat region; the second one from the estuarine mouth region where river Buribalam meets the Bay of Bengal and the third one from the tidal flat area. The core tube had a diameter of 5 cm. The core samples were sliced at 1 centimetre, transferred into wide mouthed plastic containers, and stained with rose Bengal solution in the field itself. In the laboratory, the samples were washed by using a 63 µm (~230 mesh) sieve and then dried in an oven at 50ºC. With the help of this sieving, the silt and clay particles were eliminated, leaving behind the sand and larger fraction (i.e., the fraction which includes the size range of most foraminifera). The residual samples were dried and examined under stereozoom microscope (Nikon SMZ 1000). Further observation for precise identification and illustration was done by using a Scanning Electron Microscope (ZEISS EVO 18).

Table 1. Sampling location details from Chandipur intertidal zone.

Serial Number	GPS co-ordinates	Core environment	Core recovery length
Core 1	N 21°27'38" E 87°03'38"	Mud flat	18 cm
Core 2	N 21°28'13" E 87°03'40"	Swamp	19 cm
Core 3	N 21°27'01" E 87°03'03"	Tidal flat	20 cm

Systematics

Foraminifera identified from this study area are comprised mostly of calcareous forms with low abundance of agglutinated forms. The agglutinated forms are found mostly in the swamp region whereas the tidal flat region have an assemblage of calcareous foraminifera.

Sediments from the tidal flat are abundant in *Ammonia beccarii*, *Ammonia dentata*, *Ammonia tepida*, *Asterorotalia trispinosa*, *Cribroelphidium poeyanum*, *Haynesina germanica*, *Haynesina depressula* and *Quinqueloculina* sp. Minor agglutinated forms like *Trochammina inflata*, *Miliammina fusca* and *Haplophragmoides wilberti* are found near the swampy regions.

In the present study, the generic classification of Foraminiferida as proposed by Loeblich and Tappan (1988) has been followed. The taxa were identified using the works of Akimoto *et al*. (2002), Barker (1960), Wells (1985), Nomura and Seto (1992, 2002), Rijk and Troelstra (1997), Kathal (2002), Kathal *et al*. (2000), Khare *et al*. (2007), Devi and Rajshekhara (2009), Ghosh (2012), Ghosh *et al*. (2014), Gehrels and Newman (2004), Edwards *et al*. (2004), Culver and Horton (2005), Javaux and Scott (2003), Woodroffe *et al*. (2005), Horton and Edwards (2006), Kemp *et al*. (2009) and Hawkes *et al*., (2010). All the species are illustrated in Plate 1 and 2.

SYSTEMATICS

Order **Foraminiferida** Eichwald, 1830
Suborder **Rotaliina** Delage and Herouard, 1896
Superfamily **Rotaliacea** Ehrenberg, 1839
Family **Rotaliidae** Ehrenberg, 1839
Subfamily **Ammoniinae** Saidova, 1981
Genus ***Ammonia*** Brünnich, 1772

Ammonia beccarii Linnaeus, 1758
(Pl. 1, figs. 1, 2)

Remarks: It occurs abundantly in the tidal flat area and have minor occurences in the estuarine mouth area and swampy regions. Population mostly comprised of dead shells. Mostly found from the coarser fraction of sediments.

Ammonia dentata Parker and Jones, 1865
(Pl. 1, figs. 3, 4)

Remarks: It is found dominantly from the estuarine mouth region and the tidal flat area and have minor occurrence in the swamps. Population comprised mostly of dead shells. Found mainly in the coarser fraction of sediments.

Ammonia tepida Cushman, 1926
(Pl. 1, figs. 5, 6)

Remarks: This species is found in all the sub environments, which is in the swamps, tidal flat and estuarine mouth. Population comprised of both live (rose Bengal stained) and dead organisms. Prevalent mainly in the finer fraction of the sediments.

Genus ***Asterorotalia*** Hofker, 1950

Asterorotalia trispinosa (*Rotalia trispinosa* Thalmann, 1933)
(Pl. 1, figs. 7, 8)

Remarks: This unique species (reported only from the east coast of India: Kathal et al. 2000, Saraswat *et al*, 2017, Acta Geologica Sinica) is found from the tidal flat region mainly and have minor occurences in the swamps and estuarine mouth region. Population consists mostly of dead shells and are found mainly in the coarser fraction of the sediments.

Family **Elphidiidae** Galloway, 1933
Subfamily **Elphidiinae** Galloway, 1933
Genus ***Cribroelphidium*** Cushman and Brönnimann, 1948

Cribroelphidium poeyanum
(*Polystomella poeyana* d'Orbigny, 1839)
(Pl. 1, fig. 9; Pl. 2, fig. 1)

Remarks: This species is observed in all the three sub environments; the tidal flat, the estuarine mouth and the swamps. Population consists mostly of dead shells. Found in both coarser and finer fraction of sediments.

Superfamily **Nonionacea** Schultze, 1854
Family **Nonionidae** Schultze, 1854
Subfamily **Nonioninae** Schultze, 1854
Genus ***Haynesina*** Banner and Culver, 1978

Haynesina depressula Walker and Jacob, 1798
(Pl. 2, fig. 2)

Remarks: It is found abundantly in all the sub environments, i.e., swamp, estuarine mouth and tidal flat region. Population consists of both dead and live (stained by rose Bengal) solution. Found mainly in the finer fraction of the sediments.

Haynesina germanica Ehrenberg, 1840
(Pl. 2, fig. 3)

Remarks: This species is found abundantly in all the sub environments, i.e., tidal flat, swamp and the estuarine mouth region. Good abundance of both live (rose Bengal stained) and dead individuals are observed; mainly in the finer fraction of the sediments.

Suborder **Miliolina** Delage and Hérouard, 1896
Superfamily **Miliolacea** Ehrenberg, 1839
Family **Miliolidae** Ehrenberg, 1839
Subfamily **Quinqueloculininae** Cushman, 1917
Genus ***Quinqueloculina*** d' Orbigny, 1826

Quinqueloculina seminulum Cushman, 1944
(Pl. 2, fig. 4)

Remarks: This species is found in all the three sub environments, i.e., tidal flat, estuary mouth and swamps. Population consists of both dead and live individuals in both coarser and finer fraction of the sediments. Proportion of this form increases down the core.

Superfamily **Trochamminacea** Schwager, 1877
Family **Trochamminidae** Schwager, 1877
Subfamily **Trochammininae** Schwager, 1877
Genus ***Trochammina*** Parker and Jones, 1859

Trochammina inflata (Montagu, 1808)
(Pl. 2, figs. 5, 6, 7)

Remarks: It is found mostly near the swampy regions and it completely absent in the tidal flat region. Population consists of both live and dead individuals. Prevalent mainly in the finer fraction of the sediment.

Suborder **Textularina** Delage and Hérouard, 1896
Superfamily **Rzehakinacea** Cushman, 1933
Family **Rzehakinidae** Cushman, 1933
Genus ***Miliammina*** Heron-Allen and Earland, 1930

Miliammina fusca (*Quinqueloculina fusca* Brady, 1870)
(Pl. 2, fig. 8)

Remarks: This species is observed mostly near the swamps and is absent in the tidal flat region. Population consists of both live and dead individuals. Observed mainly in the finer fraction of the sediment.

Superfamily **Lituolacea** de Blainville, 1827
Family **Haplophragmoididae** Maync, 1952
Subfamily **Haplophragmoidinae** Maync, 1952
Genus ***Haplophragmoides*** Cushman, 1910

Haplophragmoides wilberti Andersen, 1953
(Pl. 2, fig. 9)

Remarks: This species was observed mostly near the swamps and was absent from the tidal flat region. The population consisted mostly of dead individuals, found from the finer fraction of the sediments.

RESULTS AND DISCUSSION

The foraminiferal population consists mostly of Rotaliids, with little abundance of Milioliids and Textulariids. Five genera of calcareous foraminifera have been identified, out of which five are rotaliids and one is a milioliid. The identified calcareous foraminifera are *Ammonia beccarii*, *Ammonia dentata*, *Ammonia tepida*, *Asterorotalia trispinosa*, *Haynesina germanica*, *Haynesina depressula*, *Cribroelphidium poeyanum* and *Quinqueloculina seminulum*. Three textulariids have been identified, namely, *Trochammina inflata*, *Miliammina fusca* and *Haplophragmoides wilberti*.

Several statistical analysis were done with the data collected and the results are being discussed below. At first, the population of the different sub orders of foraminifera (both living and dead population) were plotted along downcore [Figure 2(a) and 2(b)]. With the help of this analysis, the microhabitats of the different groups of foraminifera could be identified. In the first core,

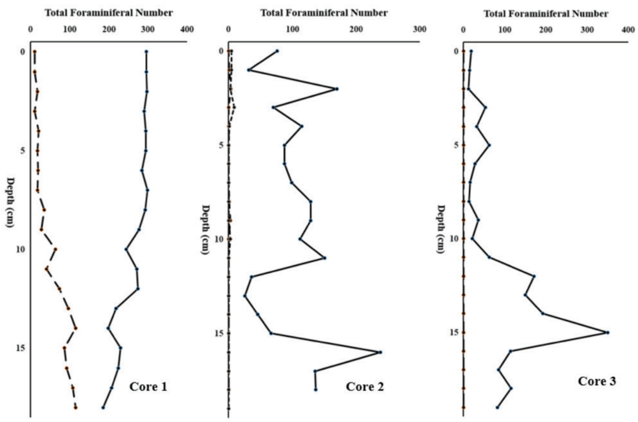


Fig. 2(a). Down core variation of different sub orders of foraminifera (dashed line indicates miliolids whereas bold line indicates rotalids).

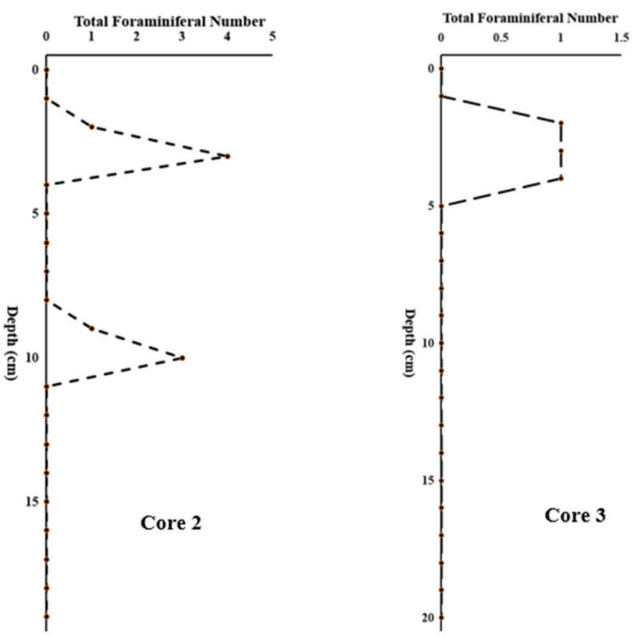


Fig. 2(b): Down core variation of miliolids in Core 2 and Core 3.

the proportion of the rotaliids decreased down the core at the expense of the miliolids; whereas the population of miliolids are negligible for core 2 and core 3. The counts are all below five and maybe accounted due to reworking effects.

The deeper part of the core indicates a shallow marine environment with low fluvial influence. The abundance of epiphytic taxa, i.e., milioliid groups suggests low turbidity (Massari *et al*., 2004). The conditions indicate the assemblages to be possibly far from river outlets (Rossi *et al*., 2008)

The increase in populations of rotaliids such as *Ammonia* sp., *Cribroelphidium* sp. and *Haynesina* sp. indicates turbulent conditions that may be attributed to environment nearer to estuarine mouth. The higher clay percentages is suitable for the abundance of rotaliids as compared to miliolids. Hence, a change in suborders of foraminifera suggest a shift in environment from normal marine to brackish marginal marine settings.

The first-order discrimination of marine environments is achieved by the ternary plot of Murray (2006) based on wall types in foraminifera. The three major types of wall structure in foraminifera are agglutinated, calcareous porcelaneous and calcareous hyaline. The method involves plotting the percentage abundance of the three wall types in the collected sample on the ternary plot. The marginal marine, shelf sea and deep-sea samples can be distinctly distinguished, despite some overlaps. Murray's ternary diagram was plotted for the three cores (Figure 3); which shows the variation in the different type of tests; agglutinated, calcareous porcelaneous and calcareous hyaline. Core 1 show two distinct clusters: the lower part of the core have assemblages with calcareous porcelaneous wall type (which also corroborates with Figure 1). The other cluster consists of assemblages from the upper part of the core, which has calcareous hyaline wall type. Core 2 has assemblages constituted mostly near the calcareous hyaline forms with little bit of agglutinated ones but in Core 3, all of the assemblages mostly have calcareous hyaline walls.

Overall, the assemblages are indicative of marginal marine to marsh environment. Core 1 shows mostly porcelaneous to hyaline walls, thus indicating a riverine inflow in marine waters. The presence of porcelaneous forms indicate that the seawater is quite enriched with calcium carbonate; which is why the shells have taken it up effortlessly to form the thick porcelaneous shell walls in lower part of Core 1. Core 2 has some amount of agglutinated walls that can be explained by the fact that it is not directly connected to the open ocean. Since this area does not have a continuous supply of marine water, some population of the foraminifera does not depend upon the calcium carbonate but instead build up the wall with available detrital grains in marsh environment. Core 3 entirely consists of

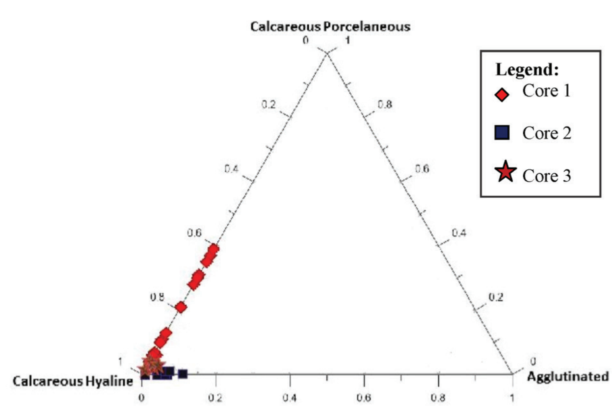
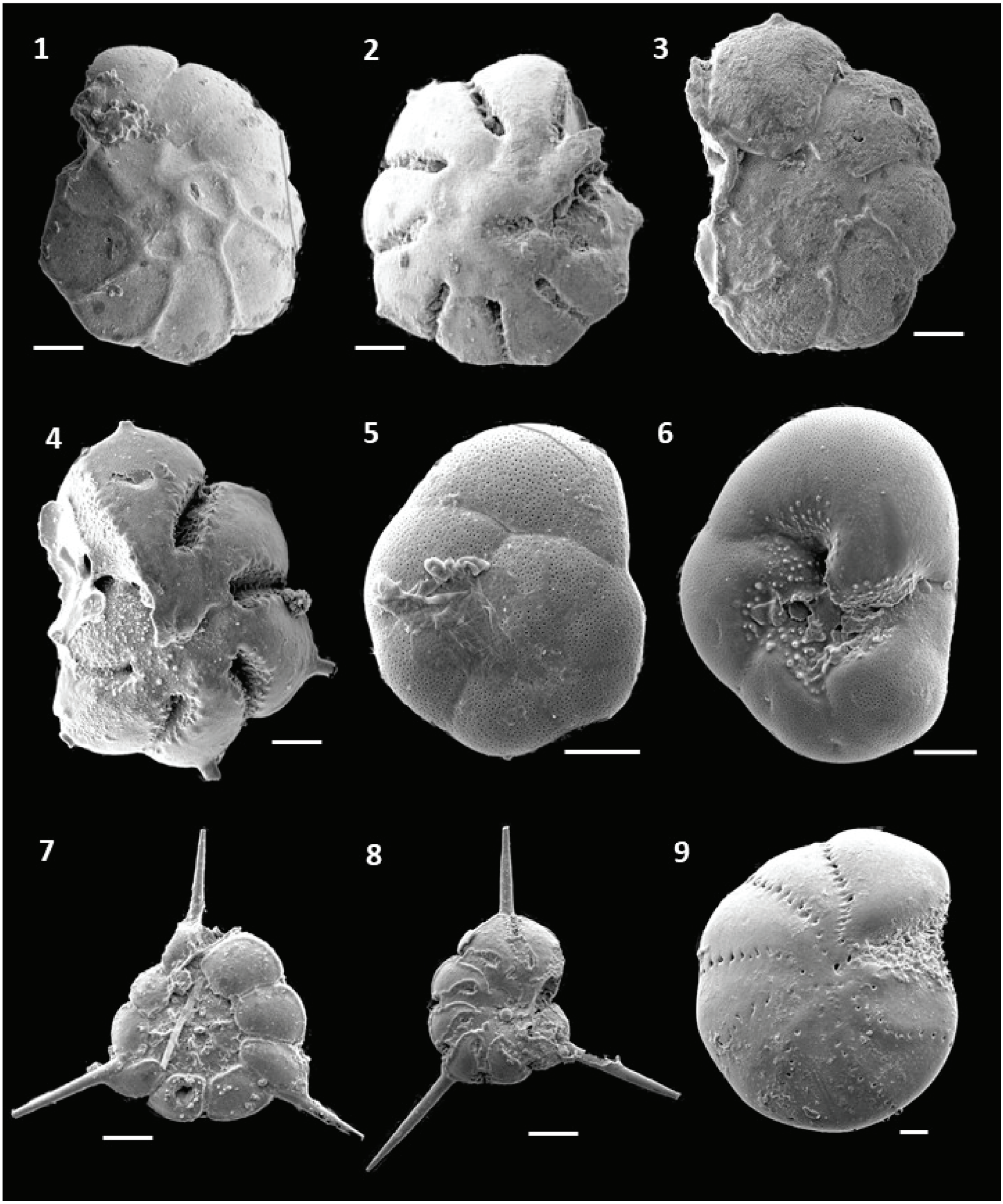


Fig. 3. Murray's ternary diagram of the different cores.

EXPLANATION OF PLATE I

Scanning Electron Microscopy images of the benthic foraminifera documented from Chandipur coast. Scale bar represent 100 µm Fig. 1. ***Ammonia beccarii*** Linnaeus, 1758 (Spiral view), Fig. 2. ***Ammonia beccarii*** Linnaeus, 1758 (Umbilical view), Fig. 3. ***Ammonia dentata*** Parker and Jones, 1865 (Spiral view) Fig. 4. ***Ammonia dentata*** Parker and Jones, 1865 (Umbilical view), Fig. 5. ***Ammonia tepida*** Cushman, 1926 (Spiral view), Fig. 6. ***Ammonia tepida*** Cushman, 1926 (Umbilical view), Fig. 7. ***Asterorotalia trispinosa*** (*Rotalia trispinosa* Thalmann, 1933) (Spiral view), Fig. 8. ***Asterorotalia trispinosa*** (*Rotalia trispinosa* Thalmann, 1933) (Umbilical view), Fig. 9. ***Cribroelphidium poeyanum*** (*Polystomella poeyana* d'Orbigny, 1839) (Umbilical view).

Plate I



hyaline type wall structure. The absence of porcelaneous wall structure from this part of the study area can be attributed some local anomalies which causes the marine water of this area to be not too much saturated with calcium carbonate. In addition, agglutinated forms are not prevalent as this is an area connected to the open ocean and the fauna living here get a continuous supply of marine water and does not have to depend on detrital grains for test formation.

To find out the diversity type of the foraminiferal population, Fisher's alpha index was plotted which plots the total number of species versus the total number of individual for each centimetre of the core. In the figure (Figure 4), the star shapes indicate values for core 1, round shapes indicate values for core 2 and square shapes indicate values for core 3. While plotting this, it has been seen that the overall diversity for this study area is quite low; values lying mostly between 1 to 2. This is because of the dynamic environment of Chandipur – the high sediment load brought by the river Buribalam and action of waves and currents causes migration of the bar – interbar system in this intertidal setting. Hence, the species variation is low in this area. Similar low variation of species has been observed in the mangrove ecosystem of the Indian Sunderbans (Ghosh *et al*., 2014)

The Shannon diversity index (H) is another index that is commonly used to characterize species diversity in a community. Shannon's index accounts for both abundance and evenness of the species present. The cross-plot of Fisher's α-diversity and information function H further distinguishes marginal marine, shelf sea and deep-sea environments, although some overlap exists. We plotted Shannon diversity index against Fisher's alpha index for our dataset and got the following results.

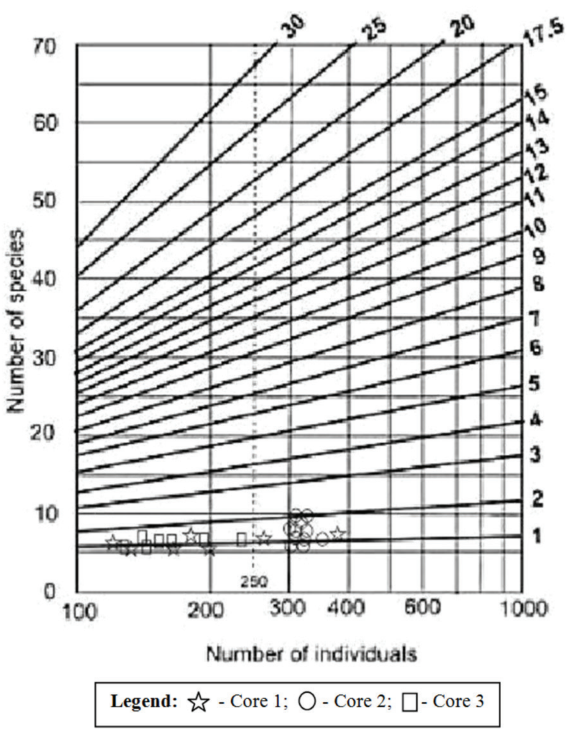


Fig. 4. Fisher's alpha diversity graph.

Fig. 5. Bivariate plot for Core 1.

Fig. 6. Bivariate plot for Core 2.

The assemblages of the first core and second core (Figures 5 and 6) suggests a brackish marginal marine setting (Murray, 2006). The third core (Figure 7) shows two distinct clusters, the upper cluster represented by the upper part of the core (from 1 to 10 cm) and the lower part of the core (11 to 20 cm) is a clear indication of a change in environment from brackish marginal marine to normal marine conditions (Murray, 2006).

Cluster analysis is used to identify groups of items, e.g. samples with counts or presence-absence of a number of taxa. Such groups may be interpreted in terms of biogeography, stratigraphy or environment. R mode cluster analysis was done with the help of PAST software for three different cores and the results have been shown below.

The cluster analysis for the first core (Figure 8) shows two distinct clusters and three single stocks. The cluster containing *Ammonia beccarii* and *Asterorotalia trispinosa* corresponds to the coarser sediments whereas the cluster containing *Ammonia tepida*, *Haynesina depressula* and *Haynesina germanica* corresponds to the finer fraction of the sediments.

EXPLANATION OF PLATE II

Scanning Electron Microscopy images of the benthic foraminifera documented from Chandipur coast. Scale bar represent 100 µm (Unless otherwise mentioned), Fig. 1. ***Cribroelphidium poeyanum*** (*Polystomella poeyana* d'Orbigny, 1839), (Zoomed view), Fig. 2. ***Haynesina germanica*** Ehrenberg, 1840 (Umbilical view), Fig. 3. ***Haynesina depressula*** Walker and Jacob, 1738 (Umbilical view), Fig. 4. ***Quinqueloculina seminulum*** Cushman, 1944 (Side view), Fig. 5. ***Trochammina inflata*** Montagu, 1808 (Spiral view), Fig. 6. ***Trochammina inflata*** Montagu, 1808) (Umbilical view), Fig. 7. ***Trochammina inflata*** Montagu, 1808 (Zoomed view) Fig. 8. ***Miliammina fusca*** (*Quinqueloculina fusca* Brady, 1870), (Side view), Fig. 9. ***Haplophragmoides wilberti*** Andersen, 1953 (Umbilical view).

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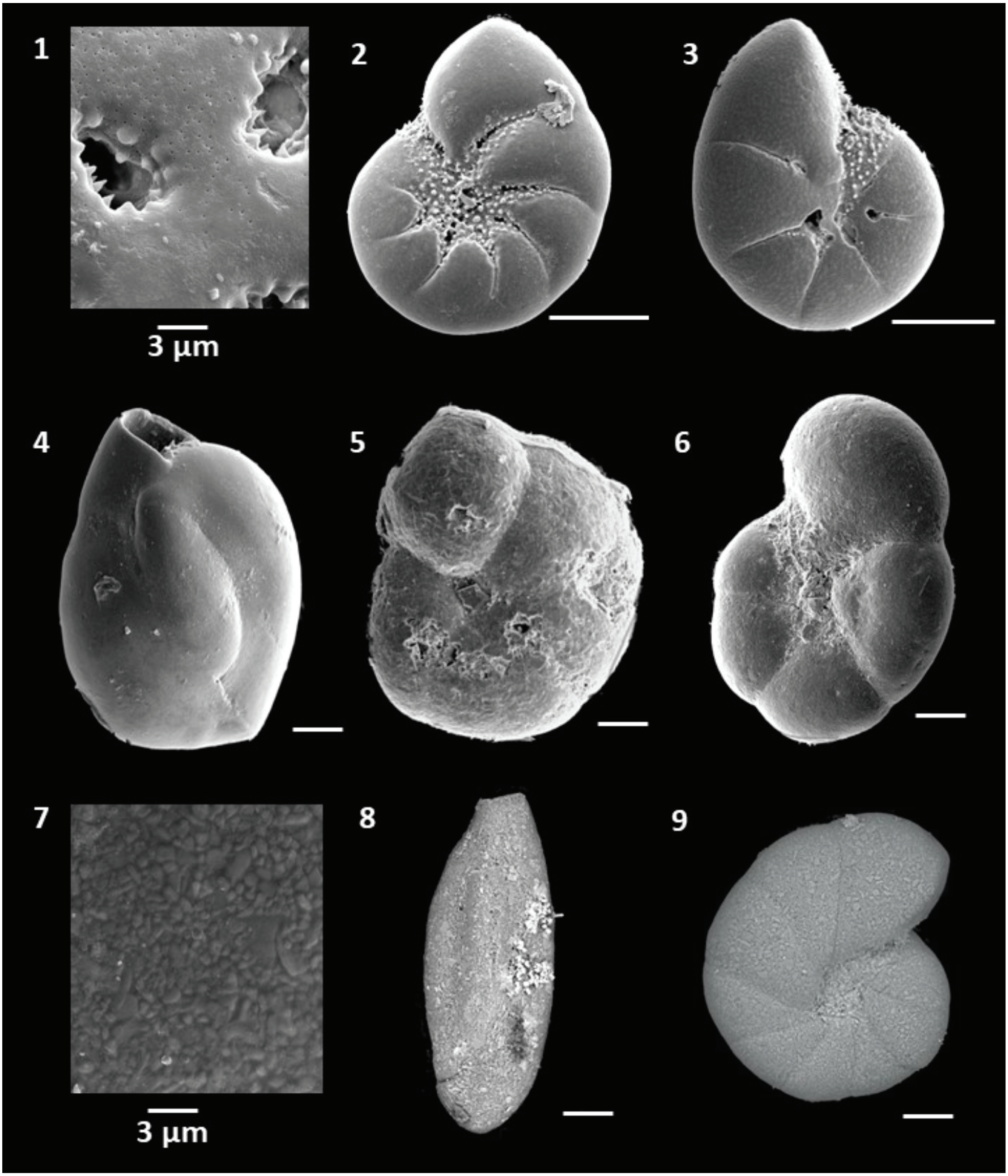
Plate II



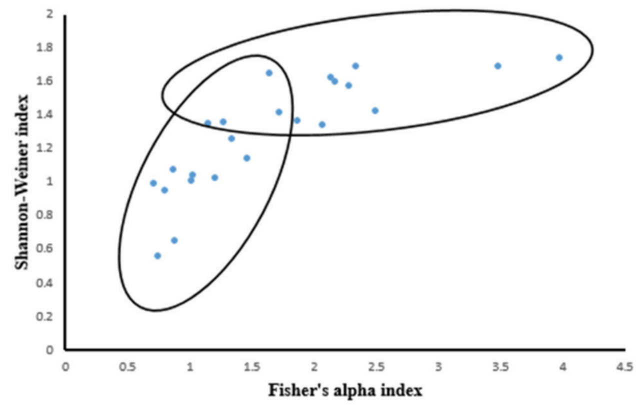


Fig. 7. Bivariate plot for Core 3.

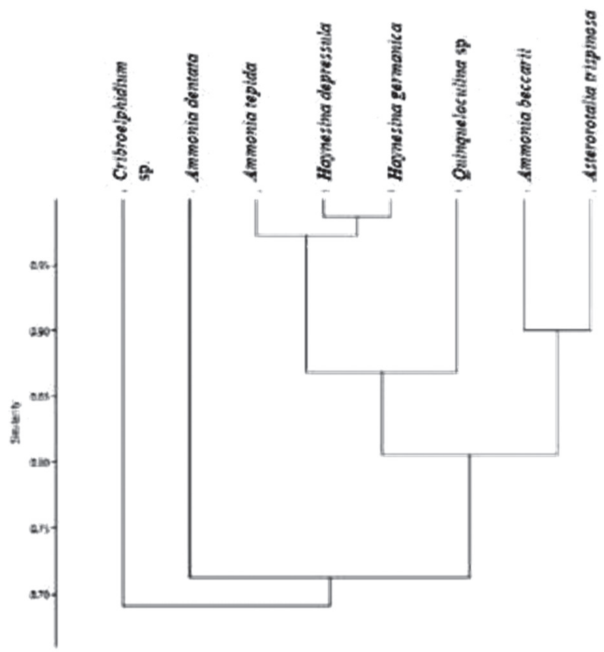


Fig. 8. R mode cluster analysis for Core 1.

For the second core (Figure 9), three different clusters have been observed, one cluster containing of *Ammonia tepida* and *Ammonia dentata*, representing the silty fraction of the sediment, the second cluster contains *Asterorotalia trispinosa* and *Ammonia beccarii* representing the coarser fraction of the sediment and the third cluster consists of the forms *Quinqueloculina seminulum* and *Trochammina inflata* which represents the clayey fraction of the sediment.

In the R mode cluster analysis of the third core (Figure 10), again, two distinct clusters are observable, out of which the cluster containing *Ammonia tepida* and *Haynesina germanica* can be the representative of a finer substrate and the other cluster consisting of *Asterorotalia trispinosa* and *Ammonia beccarii* represents the coarser fraction of the sediments. Further sediment analysis will help in determining these results.

When the living community of foraminifera was studied, there was an interesting observation. Except the first one, no other core showed the maximum living population in the topmost layer of the sediment (Figure 11). All three cores had either one

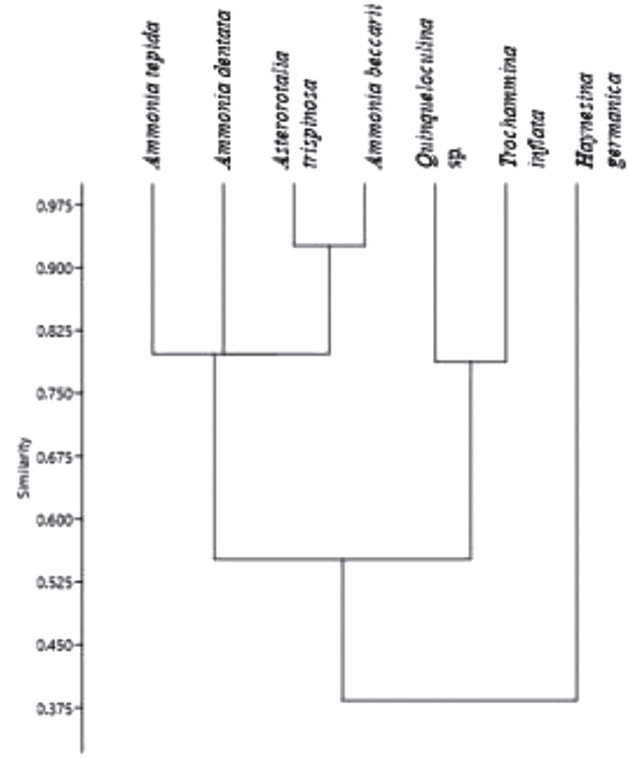


Fig. 9. R mode cluster analysis for Core 2.

or more than one down core maxima of living population.

Core 1 shows a combination of a surface maximum with another down deep maximum at 8 cm resembling Type-D profile (Sengupta, 2002). Core 2 and Core 3 has relatively low surficial

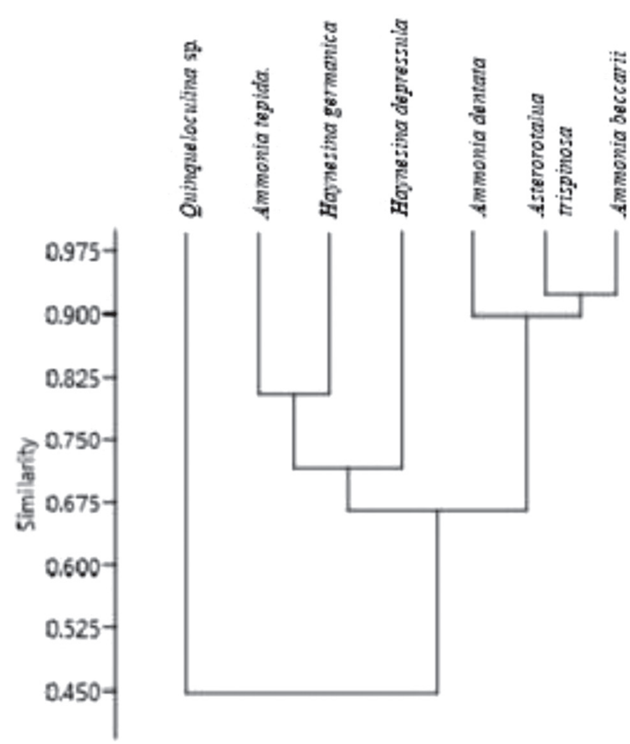


Fig. 10. R mode cluster analysis for Core 3.

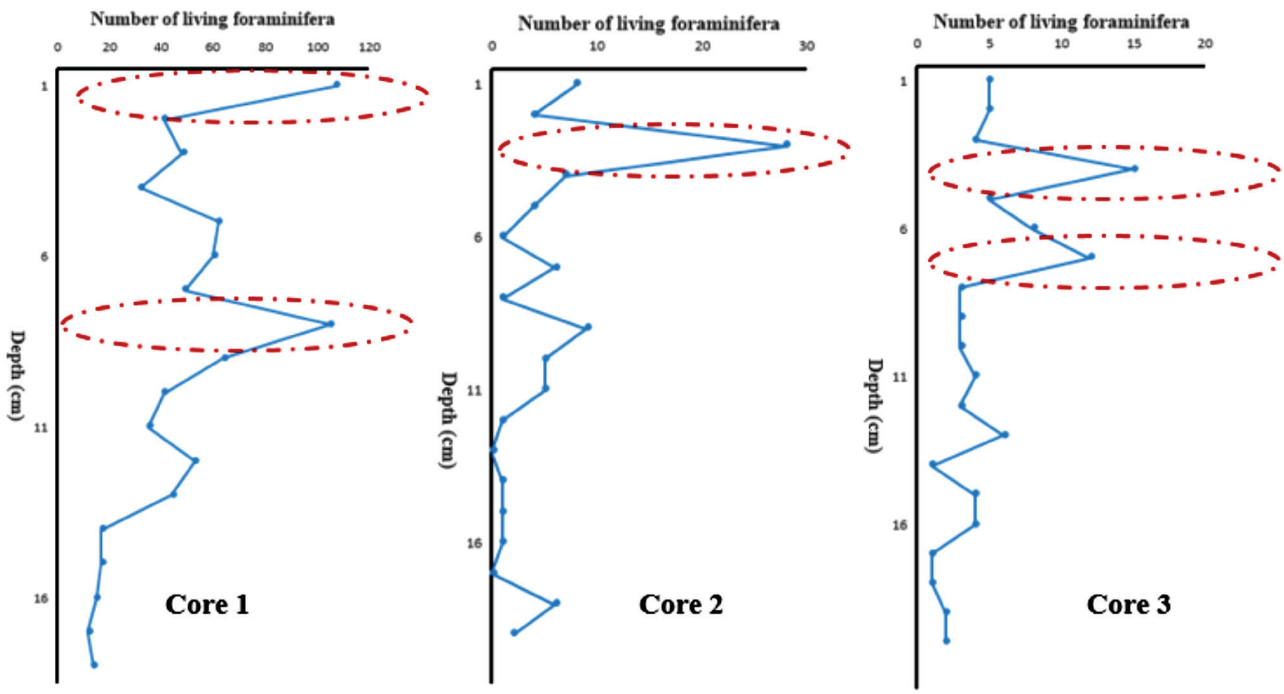


Fig. 11. Variation of living population in the three cores.

values but have downcore maxima; similar to Type-C profile (Sengupta, 2002). In Core 2, there is only one-downcore maxima at around 4 cm and in Core 3; there are two down deep maxima, one at 4 cm and another at around 8 cm. Lot of workers such as Corliss, 1985, Corlios and Chen, 1988, Nigam *et al*. 2007, Manasa *et al*. 2016, Suohkrie et al. 2017, Naik et al. 2017, Singh *et al*. 2018 attempted to understand the ecological preferences of benthic foraminifera in the marine realm. Seasonal change in dissolved oxygen and food availability plays a key role for downcore maxima of living benthic forms. Bioturbation can actively transport living foraminifera into deeper sediments. Living population consists of *Haynesina* spp. and *Ammonia tepida*, suggesting fluvial influence and higher clay percentages. The presence of living populations of *Haynesina* spp. and *Ammonia tepida* (symmetrical rounded form) suggests fluvial influence, turbulent environment and higher clay percentages (Nigam *et al*., 1992, Nigam *et al*., 2009 and Manasa *et al*., 2016). This is well corroborated by presence of river Buribalam in the Chandipur coastal settings.

CONCLUSIONS

Eleven species of foraminifera have been identified of both calcareous and agglutinated wall types. Calcareous foraminifera comprises of the forms *Ammonia beccarii, Ammonia dentata, Ammonia tepida, Asterorotalia trispinosa, Cribroelphidium poeyanum, Haynesina depressula, Haynesina germanica* and *Quinqueloculina seminulum.* Agglutinated foraminifera consists of the forms *Trochammina inflata, Miliammina fusca* and *Haplophragmoides wilberti.*

The Chandipur foraminiferal assemblage mostly contains calcareous forms with some occurences of agglutinated forms near the swampy areas.

Down the core, the population of rotaliids decrease at the expense of the miliolids, which clearly indicates change in environmental settings.

Low diversity of foraminifera (α = 1 – 2) is recorded in this region.

Bivariate plots of Shannon Index (H) and Fisher's alpha diversity indicate there might have been a change of environment from brackish marginal marine to normal marine conditions.

All three cores show one or more downcore maxima, which might be attributed to dissolved oxygen and food availability.

Occurrence of good amounts of *Asterorotalia trispinosa* throughout the cores suggests high sedimentation rate prevalent in Chandipur.

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