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Research Article
Foraminiferal Assemblages from Recent Coastal Sediments of Chandipur, East Coast India

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Abstract

Background and Objective: The study area, being in close proximity of the estuarine and river mouth, is vulnerable to potential mixing and distribution of pollutants along with the sediment load into the ecologically sensitive tidal flat microhabitat. This study was conducted for investigating foraminiferal assemblages from recent coastal sediments of Chandipur, India. **Materials and Methods:** Total ten perforated and agglutinated foraminiferal species have been identified under scanning electron microscope. Their systematics and morphologies have been documented. **Results:** Dominant species are *Ammonia beccarii*, *Ammonia tepida*, *Haynesina germanica* and *Quinqueloculina seminulum*, mostly found in sand flats. Habitat and substrate preferences of various foraminiferal species have been established from the studied foraminiferal assemblages. **Conclusion:** Study shows great abundance of low diversity, epifaunal to infaunal foraminifera's assemblages in Chandipur sand flats, muddy tidal flats and marshlands.

Key words: Foraminifera, Chandipur coast, microhabitat, ecological sensitivity, estuarine

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Foraminifera are single celled protozoa living on sea floor (benthic) or floats in the upper water column (planktonic)[1-4]. These have thread like anastomosing pseudopodia enclosed within a calcareous test, which differentiates them from other protists. They can be unilocular or multilocular based on the number of the chambers. These tests (shells) are preservable in fossil record. Foraminifera lived from early Cambrian to recent times, with acme reached during Cenozoic[5,6]. Their ecology embraces planktonic and benthonic modes, although planktonic forms generally inhabit the open ocean and seldom live in coastal waters in any abundance, while benthonic foraminifera exist on substrates from abyssal plains to high intertidal areas[7-9]. The intertidal mudflat of Chandipur is an exclusive coastal ecosystem which hosts red crabs, endangered horseshoe crabs, sea turtles and varied intertidal benthic fauna. This ecosystem is under threat because of amplified tourism activities. The other part of this coastline is controlled by Indian Army as an integrated test range. Chandipur coastline belongs to one of the identified "Important Coastal and Marine Biodiversity Area" (ICMBA) for the better management of coastal and marine flora and fauna. Characterization of foraminiferal assemblage and tracking their behavior as well as morphology with time proves to be important to figure out any presence of potential pollutants regionally or locally (i.e., chemicals, heavy metals, sewage etc.). Abundance of these type of pollutants affect morphologies and population dynamics of the foraminiferal assemblages (lowered diversity, aberrant or deformed tests). Many researchers[10-14] have identified foraminifers as potential bioindicators for coastal pollution.

Eastern Indian coastline offers great abundance of benthic foraminiferal community and many researchers have worked on their habitat characterization from Gosthani estuary[15], Godavari-Krishna[16], Araniar river estuary[17], Chilka lake[18], Palar[19], Nagavali river estuary[20], Palk strait[21], Uppanar estuary[22], along the coastline. These studies indicate *Ammonia beccarii, Ammonia tepida, Quinqueloculina seminulum* are the most abundant in various east coast brackish water river estuaries. The main purpose of this study was to investigate the foraminiferal assemblage from present day coastal sediments of Chandipur, India.

MATERIALS AND METHODS

Study area: The study area, Chandipur is situated in Balasore district, Orissa, eastern coast of India (Fig. 1). The coastal

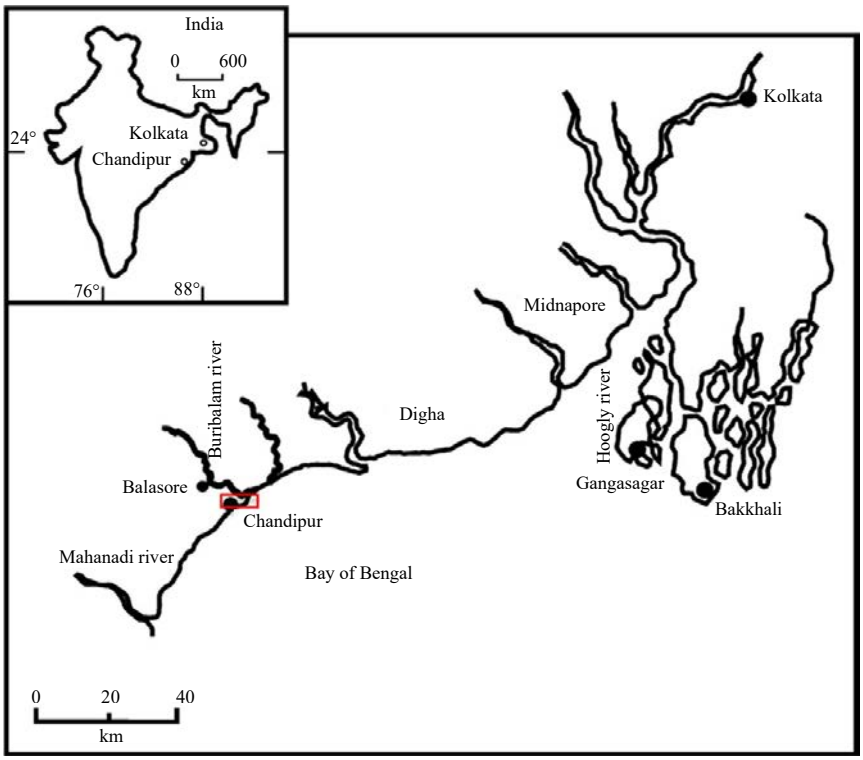

Fig. 1: Study area in Chandipur, marked by red square along the east coast, India

Table 1: Location coordinates of the sampling stations in the study area

Stations	Distance from coastline (m)	Distance from estuary mouth (m)	Latitude	Longitude
L-1	100	1995	21 27'9.24"N	87 02'34.90"E
L-2	330	1195	21 27'3.44"N	87 02'39.27"E
L-3	650	695	21 26'57.73"N	87 02'42.84"E
L-4	110	1990	21 27'17.07"N	87 02'47.05"E
L-5	340	1190	21 27'10.86"N	87 02'51.48"E
L-6	645	690	21 27'6.21"N	87 02'54.84"E
L-7	105	2000	21 27'28.02"N	87 03'03.97"E
L-8	335	1200	21 27'22.50"N	87 03'08.64"E
L-9	640	700	21 27'18.32"N	87 03'12.57"E
L-10	40	22	21 28'26.53"N	87 03'36.43"E
L-11	1035	20	21 28'01.49"N	87 04'16.27"E

sediments belong to Quaternary fluviomarine origin developed during post-glacial Flandrian transgression (6.5 Ka onwards) during the Holocene[23]. The Chandipur coastal area has broadly 2 geomorphologically distinct zones, land part (away from sea) is characterized by the fluvial processes from the Buribalam river, seaward part is a long beach, parallel to the coastline of the Bay of Bengal[11]. Beach has distinctive dune field and a very low dipping (<3°) silty intertidal flat[24], along with a shore parallel, sandy longitudinal bar at Buribalam estuary mouth[23,24]. The intertidal flat is quite wide, approximately 1-4 km. The intertidal mudflat of Chandipur is an exclusive coastal ecosystem which hosts red crabs, endangered horseshoe crabs, sea turtles and varied intertidal benthic fauna. This ecosystem is under threat because of amplified tourism activities. The other part of this coastline is controlled by Indian Army as an integrated test range. Chandipur coastline belongs to one of the identified "Important Coastal and Marine Biodiversity Area" (ICMBA) for the better management of coastal and marine flora and fauna. The study area lies between 21° 44′ N-21° 47′ N and 87° 02′ E-87° 07′ E, covering a stretch along NE trending Chandipur coastline, ending at Buribalam river estuary mouth see Table 1. Groundwater is saline here and fresh water is available in discontinuous patches. Shelf has a gentle slope. Overall climate remains dry and humid with seasonal cyclones. This study was conducted from December, 2016-January, 2019.

Sample collection and processing: Collection of foraminifera sample required initial observation regarding the presence of macro-organisms as they usually consume micro-organisms as food, which helps in identifying the areas of potentially maximum occurrence of foraminifera. Surface sediment samples (of 100 cm^3) from estuary mouth and tidal flat regions were collected and stored into wide mouth plastic bottle. Rose Bengal solution was prepared by dissolving 2 g of rose Bengal in one liter of ethanol (ethyl alcohol). When this solution is poured on the collected sample, living organisms show pink color, thus it helps distinguishing living organisms from dead ones. The rose Bengal stained s ample was transferred to 63 micron (µm) sieve and washed over by using a jet of water. The 63 µm sieve is used to eliminate all the silt and clay particles, leaving fine sand and larger fraction (i.e., the fraction that includes size range of most foraminifera). The washed sample was then transferred into porcelain bowl and then kept in a hot oven for about 30 min for drying. The temperature of the oven was set at 50°C. The bowl was removed from the oven when it was totally dried and then transferred into a Tarson plastic tube for sorting and identification.

Separation of foraminifera from sediments needs some accessories i.e., finest stable hair brush (#000), faunal slides made up of card board with glass slide and aluminum case (24 chambered, double punched and single punched slide used according to their importance), micropalaeontological tray (which are marked by grids), micropalaeontological needle etc. Different types of faunal slides are available for specific purposes. Round punch is used to store skeleton of same species and rectangle punch is used to store type specimens of one species/all species of a single sample or type specimens of all the species from a single stratigraphic level. Firstly, each sample was transferred from Tarson plastic tube to picking tray containing gridlines. The sample is thinly scattered in the tray. Then, from each sample, 300 foraminifera were picked with the help of a fine water moistened (#000) brush while observing under stereo zoom microscope (Nikon SMZ 1000). The picked foraminifera were placed on 24 chambered micropalaeontological slides.

Clean foraminifera specimens were studied using scanning electron microscope (SEM). Specimens were mounted in a required orientation on a metallic stub, inserted inside the microscope to acquire high resolution images (magnification ranging from 20X to approximately 30,000X, spatial resolution of 50-100 nm). SEM images facilitate

identification of morphological features of tests (aperture, shell architecture, orientation, suture etc.). The taxa were then identified with the help of reported references[1,25-50].

RESULTS

Collected foraminifera samples were studied under SEM and systematics were documented. Systematics deals with the classification and nomenclature of organisms. Physical appearances play important role in identification process. Taxonomic description of the foram samples found in the coastal sediment of study area has been presented below.

***Haynesina germanica*:**

Phylum	:	Foraminifera
Class	:	Globothalamea
Order	:	Rotaliida
Superfamily	:	Nonionoidea
Family	:	Nonionidae
Subfamily	:	Nonioninae
Genus	:	*Haynesina*
Species	:	*Haynesina germanica*

These were abundantly present in ripple flat zone. The planispiral test of this species has 6-12 chambers per whorl, with rounded periphery. Surface is perforated. This species does not have any sutural bridge. Symmetrically almost completely involute, each umbilicus is narrow and depressed and may be reduced to a lunate form, being then only about one-half of a whorl of the incised, inner spiral suture. The primary aperture is almost interiomarginal, a single, low arch, symmetrical about the equatorial plane, it may be obscure externally by tuberculation. The primary septal aperture is similar but may be enlarged by resorption. The posterior lateral walls of each chamber are sharply inflected and inward extensions are distally fused to the preceding anterior septal face, forming a narrow, laterally situated, intercameral lacuna which may extend virtually for the whole height of the septum. Externally, the intercameral sutures are, in consequence, deeply and narrowly incised proximally (i.e., from their umbilical ends) to the distant limit of the intercameral lacuna. Internally the anterior wall of the lacuna is penetrated by an interiomarginal, latero-umbilical supplementary aperture, connecting the chamber lumen latero-posteriorly with the exterior of its umbilical margin (Fig. 2a).

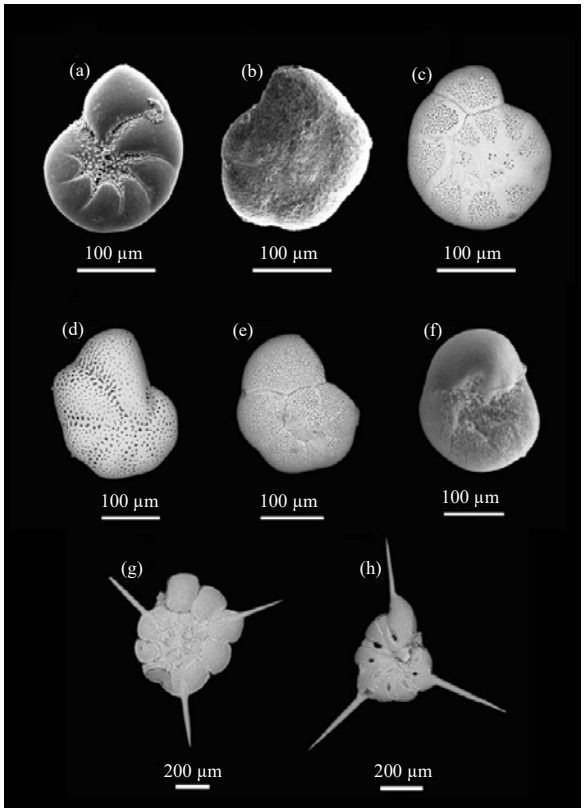

Fig. 2(a-h): SEM images of perforated foraminifer assemblages, (a) *Haynesina germanica*, (b) *Trochammina inflate*, (c) *Ammonia beccarii*, (d-f) *Ammonia tepida* and (g, h) *Asterorotalia trispinosa*

***Trochammina inflata*:**

Phylum	:	Foraminifera
Class	:	Globothalamea
Order	:	Lituolida
Suborder	:	Trochamminina
Superfamily	:	Trochamminoidea
Family	:	Trochamminidae
Subfamily	:	Trochammininae
Genus	:	*Trochammina*
Species	:	*Trochammina inflata*

This species has inflated trochospiral tests, with globular to ovate chambers displaying a gradual increase in size. Walls are agglutinated, sutures are depressed in general. Outer whorl has 5-6 chambers with deep umbilicus. Aperture is present on the umbilicus side at the base of final body chamber and it forms a narrow lip. This foraminifera taxa is typically found in tidal marsh lands (Fig. 2b).

***Ammonia beccarii*:**

Phylum : Foraminifera
Class : Globothalamea
Order : Rotaliida
Superfamily : Rotalioidea
Family : Ammoniidae
Subfamily : Ammoniinae
Genus : *Ammonia*
Species : *Ammonia beccarii*

It is characterized by its thick peripheral brim and short blunt spines on the peripheral portion. The umbilical side is characterized by granular surface and umbilical boss. The spiral shows the reticulate pattern of thickened calcite riblets over the central spiral area. The size varies from 0.2-0.4 mm with 7-9 chambers in the final whorl. Pore density is low and the pores are relatively larger. Also, irregular secondary calcification is prominent on the folia. Again this is another species which have been found quite abundant and dominant in sandy facies (Fig. 2c).

Systematics of *Ammonia tepida*:

Phylum : Foraminifera
Class : Globothalamea
Order : Rotaliida
Superfamily : Rotalioidea
Family : Ammoniidae
Subfamily : Ammoniinae
Genus : *Ammonia*
Species : *Ammonia tepida*

The test outline is smooth with no ornamentation and rounded periphery. The umbilical side is characterized by sharp, pointed folium as well as strong deeply notched proto foramen. The spiral side shows the development of raised thickened calcite along the radial sutures as well as over central spiral area. It is smaller (0.3-0.6 mm), has 7-9 chambers in the final whorl and has no plug or extraneous calcareous material in the umbilical area. Micro structurally, pore density is high, pores are regular and are present all throughout the test except at the pointed ends of folia. Tidal flats, estuary and lagoons are the preferred habitats for this species (Fig. 2d-f).

Systematics of *Asterorotalia trispinosa*:

Phylum : Foraminifera
Class : Globothalamea
Order : Rotaliida
Superfamily : Rotalioidea
Family : Ammoniidae
Subfamily : Ammoniinae
Genus : *Ammonia*
Species : *Asterorotalia trispinosa*

Test free, trochospiral, biconvex, with 3 prominent slender spines radiating from test and continuous through all whorls from earliest, margin carinate, septa with intraseptal passages, opening as series if pores in and along sutures of umbilical side, partly covered by thin plates with distal openings, wall calcareous, perforate radial in structure, each spine containing tubular radial canal, interiomarginal aperture is equatorial in position. These spines help them to gain buoyancy so that they can just stay above sediment-water interface (Fig. 2g-h).

Systematics of *Nonionella labradorica*:

Phylum : Foraminifera
Class : Globothalamea
Order : Rotaliida
Superfamily : Nonionoidea
Family : Nonionidae
Subfamily : Nonioninae
Genus : *Nonionellina*
Species : *Nonionella labradorica*

This species has equilateral smooth calcareous tests. Tests are trochospiral in early stages of life, later it becomes almost planispiral with inflated basal lobes at the umbilical end of the chamber, with a flared last chamber. This species is an important indicator of warming conditions after the last glaciation in North Atlantic shelf areas (Fig. 3a, b).

Systematics of *Haplophragmoides* sp.:

Phylum : Foraminifera
Class : Globothalamea
Order : Lituolida
Suborder : Lituolina
Superfamily : Lituoloidea
Family : Haplophragmoididae
Genus : *Haplophragmoides*
Species : *Haplophragmoides* sp.

These have planispirally coiled test, with agglutinated wall. Apertures have an equatorial interiomarginal slit. This species is abundantly found in marsh environment and intertidal areas (Fig. 3c).

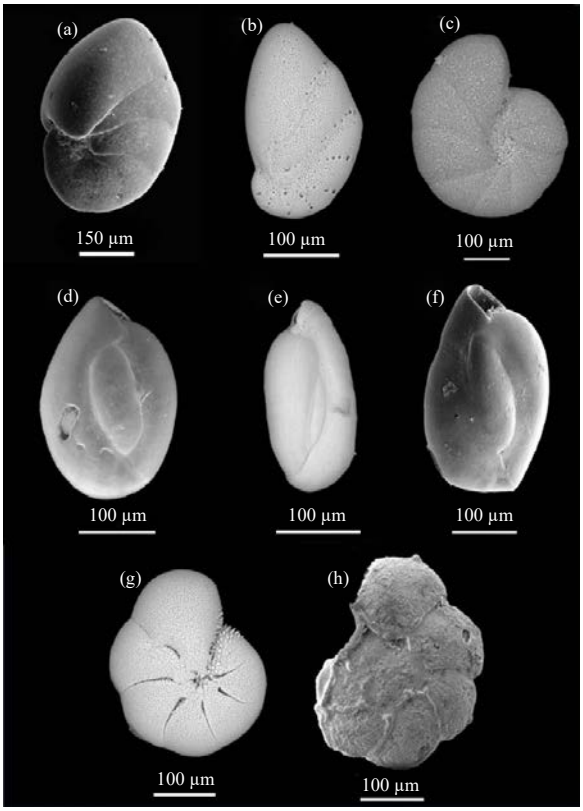

Fig. 3(a-h): SEM images of agglutinated foraminiferal assemblages, (a, b) *Nonionella labradorica*, (c) *Haplophragmoides* sp., (d-f) *Quinqueloculina seminulum* (S), 2. *Quinqueloculina seminulum* (S), (g) *Haynesina depressula* and (h) *Ammonia dentata*

Systematics of *Quinqueloculina seminulum*:

Phylum : Foraminifera
Class : Tubothalamea
Order : Miliolida
Superfamily : Milioloidea
Family : Hauerinidae
Subfamily : Hauerininae
Genus : *Quinqueloculina*
Species : *Quinqueloculina seminulum*

Test imperforate, porcelanous, with chambers coiled 72° apart but with successive chambers in planes 144° apart, so that characteristically four chambers are visible from one side and three from the other. Chambers have sub-rounded periphery and rounded aperture has thick rim. This very resilient species can be found virtually from marsh to shelf environments. This species have preferred habitat in inner shelf region as his study from northwest Europe and southeast Australia concludes (Fig. 3d-f).

Systematics of *Haynesina depressula*:

Phylum : Foraminifera
Class : Globothalamea
Order : Rotaliida
Superfamily : Nonionoidea
Family : Nonionidae
Subfamily : Nonioninae
Genus : *Haynesina*
Species : *Haynesina depressula*

These were distinguished from *Haynesina germanica* by the presence of the ridge lines on their body. These lines meet at a central point, it seems radiating from thee center. These were also found in the ripple flat zone (Fig. 3g).

Systematics of *Ammonia dentata*:

Phylum : Foraminifera
Class : Globothalamea
Order : Rotaliida
Superfamily : Rotalioidea
Family : Ammoniidae
Subfamily : Ammoniinae
Genus : *Ammonia*
Species : *Ammonia dentata*

This species is characterized by thick peripheral rim with short blunt peripheral spines. Umbilical surface is granular. Central spinal area has reticulated thick calcite riblets. Overall size varies between 0.2 and 0.4 mm. These have low pore density but average pore size is large. Also irregular secondary calcification is prominent on the folia. Abundantly found in tidal flat muddy sediments (Fig. 3h).

DISCUSSION

Broadly 2 types of foraminiferal assemblages could be distinguished from the coastal sediments collected from sandy beach, muddy tidal flat and estuary mouth-perforated and agglutinated. These reflect the substrate characteristics-coarser and finer respectively. Effect of substrate quality on the foraminiferal species assemblages have not been studied much in details[9]. Researchers concluded variation of test

morphology as a result of substrate character (rocky or muddy etc.)[10,50]. From current study area *Ammonia dentata*, *Nonionella* sp., *Quinqueloculina seminulum* have been found in muddy substrate. *Haynesina germanica* has been found across the various substrates-sandy beach to mixed sediment zone to muddy tidal flats, although their abundance was recorded from sandy beach facies.

Current study showed great abundance of low diversity, epifaunal to infaunal foraminifers' assemblages in Chandipur sand flats, muddy tidal flats and marshlands. Dominant species are *Ammonia beccarii*, *Ammonia tepida*, *Haynesina germanica* and *Quinqueloculina seminulum*, mostly found in sand flats. *Asterorotalia trispinosa* has been reported as endemic to the eastern coastline of India. Haslett *et al*.[48] have reported very limited distribution this species from various ecological settings which include littoral zones to beaches to estuarine and inner part of shelf areas. In our study area, these were found majorly in sandy beaches, also few were seen in tidal flat samples of the study area. *Quinqueloculina* has been commonly found in the muddy tidal flats and few were reported from active sediment mixing zone. This indicates their preference for muddy sediments because of favorable nutrient supply. Their fusiform test is suggestive of free living and probably infaunal behavior.

In coastal studies, foraminifera have been employed in a number of investigations as indicators of Quaternary sea-level change[48,49,51,52] for establishing coastal palaeoenvironments and sedimentary biofacies[51,52] as sediment transport indicators in tidal[12,36], wave-dominated[47,48] and aeolian environments and as monitors of coastal environmental pollution[2-8,44]. The value of foraminifera as sediment transport indicators in tidal environments has been realized and is being developed[29]. Foraminifera seldom live on beaches and their occurrence in these environments is due to post-mortem transport, therefore identified species with known ecologies can act as sediment provenance tracers and depending on their source area, can indicate transport processes[52]. Murray[41] summarized environmental and habitat information of various foraminifera from European and Australian coastal areas and we have here used that reference for interpreting the foraminiferal assemblages from Chandipur coastal area. Murray[41] distinguished two major clusters-one group inhabits phytal and/or sandy substrates, which generally represents non-turbid, clear water environments. Another group/cluster is characterized by specimens favoring muddy substrates.

CONCLUSION

Ten different species of foraminifera have been identified from the coastal sediments collected from sandy beach, muddy tidal flat and estuary mouth. Foraminifer's distribution and their substrate preference have been deciphered. A correlation between coastal sediment distribution and Foraminifera assemblages has been established. This study will help in the improved supervision of present foraminiferal assemblages in the coastal sediments and to identify any potential threat to their preferred habitats.

SIGNIFICANCE STATEMENT

This study identifies the dominant foraminiferal assemblages from the present day coastal sediments and establishes their habitat preferences in Chandipur, eastern India. Sediment transport from the Buribalam River estuarine can significantly introduce pollutants in these habitats. This study highlights a potential ecological damage risk, which can be taken cared by taking necessary corrective measures. A necessary measure can be taken to protect the identified micro-habitats and avoid ecological damage.

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