Comparative study of foraminiferal biofacies along the east and west coast of India

Thesis

Submitted in partial fulfillment of the requirement for the degree of

Doctor of Philosophy

By

Dipankar Buragohain

Index no. 179/15/Geol.Sc./24

DEPARTMENT OF GEOLOGICAL SCIENCES

JADAVPUR UNIVERSITY

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যাদবপুর বিশ্ববিদ্যালয়
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JADAVPUR UNIVERSITY
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FACULTY OF SCIENCE : DEPARTMENT OF GEOLOGICAL SCIENCES

CERTIFICATE FROM THE SUPERVISOR

This is to certify that the thesis entitled ***"Comparative study of foraminiferal biofacies along the east and west coast of India"*** submitted by **Shri Dipankar Buragohain,** who got his name registered on 13.10.2015 for the award of **Ph.D (Science)** of **Jadavpur University**, is a piece of research work absolutely based upon his own work under the supervision of **Dr. Anupam Ghosh** and that neither this thesis nor any part of it has been submitted for either any degree/diploma or any other academic award anywhere before.

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List of Publications

Journal Papers:

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Das, I., Ghosh, A. and *Buragohain, D.* (2019) A study of microhabitat of intertidal foraminifera from Chandipur coast, Odisha; J. Pal.Soc. India. 64(1) 49-51.

Dutta, S., Das, I., *Buragohain, D.* and Ghosh, A. (2021) A study of Marsh foraminifera microhabitat in Harshad, Gujarat. J. Pal.Soc. India. 66 (2), 346-356.

Das, I., *Buragohain, D.* and Ghosh, A. Recent foraminiferal biofacies in the Bakhali region, West Bengal. Zoological Society of India (Under Review).

Conference Papers:

Bhattacharya, K., *Buragohain, D.* and Ghosh, A. (2017) A study on foraminiferal diversity along the Saurashtra coast, Western India using Scanning Electron Microscope. GEOCON.Abstract Volume. 21-22.

Buragohain, D., Bhattacharya, K. and Ghosh, A. (2017) A study of recent benthic foraminifera along the Saurashtra coast, western India. XXVI Indian Colloquium on Micropaleontology and Stratigraphy (ICMS).Abstract Volume. 38-39 (Poster presentation).

Buragohain, D. and Ghosh, A. (2018) Seasonal differences in benthic foraminiferal assemblages: A brief discussion from the Saurashtra coast, Gujarat. Geosymposium. Abstract Volume. 3-4 (poster presentation).

Buragohain, D. and Ghosh, A. (2018) A comparative study of the Recent Benthic Foraminiferal assemblages in the east and west coast of India. 3RD Regional Science and Technology Congress. Abstract Volume. 112 (Oral presentation).

Das, I., *Buragohain, D.*and Ghosh, A. (2017) A study of microhabitat of intertidal foraminifera from Chandipur coast, Odisha. XXVI Indian Colloquium on Micropaleontology and Stratigraphy (ICMS).Abstract Volume. 40-41.

Das, P. and *Buragohain, D.*, (2018) Ghosh, A. Seasonal variations in benthic foraminiferal assemblages along the east coast of India. Geosymposium. Abstract Volume. 18-19.

Dutta, S., Das, I.and *Buragohain, D.*, and Ghosh, A. (2019) A study of marsh foraminifera microhabitat in Harshad, Gujarat. XXVII Indian Colloquium on Micropaleontology and Stratigraphy (ICMS).Abstract Volume. 45.

Ghosh, S., *Buragohain, D.* and Ghosh, A. (2017) Chaudhuri, S. A study of benthic foraminiferal assemblages along the coastal tracts of Chandipur, east coast of India. XXVI Indian Colloquium on Micropaleontology and Stratigraphy (ICMS).Abstract Volume. 60.

Ghosh, A., Das, I., Ghosh, S. and *Buragohain, D.*(2017) A study of population dynamics of Marsh Foraminifera ofStresses Mangrove Ecosystem along the coastal regions of India. Humboldt Kolleg (Earth and Material Sciences for Sustainable Societal Developments). AbstractVolume. 30.

ABSTRACT

The present study examines the taxonomy, abundance and diversity of the foraminiferal population along India's east and west coast. Surface sediment samples were collected from fifteen stations over a year from both the regions. A total of eighteen species from the east coast and thirty five species from the west coast have been identified. The east coast is dominated by *Haynesina germanica*, *Cribroelphidium* spp., *Asterorotalia trispinosa*, *H. depressula*, and *Ammonia tepida.* The most dominant species of the west coast are *Rotalidium annectens*, *Elphidium crispum*, *Pararotalia nipponica*, *Eponides repandus*, *Quinqueloculina seminulum*, *Cibicides refulgens*, *Nonion* cf. *commune* and *Ammonia tepida*. The taxonomic comparison of both the coasts shows that only seven species are common. They are *Rotalidium annectens*, *Haynesina depressula*, *Quinqueloculina seminulum*, *Prarotalia nipponica*, *Ammonia tepida*, *Ammonia beccarii* and *Elphidium advenum.*

Total Foraminiferal Number (TFN) shows an overall higher abundance of foraminiferal assemblage in the west coast compared to the east coast. The test size of the benthic foraminifera is larger in diameter in the west coast (>125 µm) than east coast (<125). The abundance and diversity of the foraminiferal assemblages are lower in the east coast. Abiotic factors such as salinity and temperature are correlated with the foraminiferal assemblages. The salinity is lower in the east coast ($22\%_0$-$30\%_0$) compared to the west coast (35.99 ‰ -36.64 ‰). Two distinct foraminiferal biofacies zones are proposed for both coastal regions.

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Chapter-1

Introduction

1.1 Introduction:

Microfossils are becoming an integral part of the newly developed part of palaeoceanographic and palaeoenvironment studies. Foraminifera are the most important group of microfossils due to their stratigraphic significance and their value as good indicators of palaeoenvironment. They are the most widely used Protists or fossil organisms for biostratigraphy, age dating and correlation of sediments and palaeoenvironmental interpretation (Murray, 2006). The study of foraminifera has emerged as the prime information carrier in various branches of natural science, especially in biology, geology and oceanography. Due to their wide distribution of benthic foraminifera both in space and geological time and their rapid response to ecological changes make them the best microfossil group for studying benthic processes (Murray, 2006).

The microorganisms have a short life cycle (3 years to 2 years, Murray, 1991) and respond to changes in environment rapidly. They generally change in diversity and species population. Sometimes deformed test structures develop due to increasing anthropogenic pressure (e.g., Banerjee, 1974). Such adaptive responses have been observed in response to various abiotic factors such as organic matter (e.g., Altenbach and Sarnthein, 1989; Corliss and Emerson, 1990; Corliss, 1991; Herguera and Berger, 1991; Rathburn and Corliss, 1994; Jorissen *et al*., 1995, 1998; De Rijk *et al*., 2000), Oxygen conditions (e.g., Sengupta and Machain-Castillo, 1993; Gooday, 1994; Jorissen *et al*., 1995), pH, salinity and temperature (e.g., Murray, 2006) and sediment grain size (e.g., Basso and spezzaferri, 2000; Celia Magno *et al*., 2012).

Thus, the study of foraminifera makes an interesting tool for biomonitoring studies of anthropogenic impact (e.g., Alve 1995; Nigam *et al*., 2006; Frontalini and Coccioni, 2008).

An outline of the application of foraminiferal research is given below in Table-1.1

Biology/Ecology	Geology/Earth history	Contemporary issue
Molecular Biology	Plate tectonics	Economic Geology
Cell Biology	Palaeogeography	Environmental Assessment
Biomineralization	Palaeoclimatology	Environmental Change
Population Biology	Sedimentology	Biodiversity
Community Ecology	Geochemistry	Coastal Processes
Marine Biology/Ecology	Palaeoecology	Global Carbon Budget
Estuarine & Neritic	Stratigraphy	Global Climate Change
Pelagic & Deep Sea	Palaeoceanography	
Coral Reef Ecology		Pollution study
Evolution	Evolution	

Table-1.1: Applications of foraminiferal research (after, Chaturvedi, 2000)

1.2 Background of the problem:

The coastal regions of India house a range of contemporary marine ecosystems varying from estuaries, cliffs, coral reefs, sand flats, mud flats, intertidal flats and marshes. Each of these ecosystems has its own characteristic biotic communities and understanding of coastal ecosystem is very vital for its management and foraminifera can be used as a biological proxy to capture the response of the ecosystem with the changes of environmental conditions. Various works on foraminifera is being carried out in Indian waters by different research organization. The pioneer work on foraminiferal study from the Indian waters started by Chapman (1895), Hofker (1927, 1930) and Stubings (1939a, b).

In the Saurashtra coast, Sastry and Pant (1960) investigated *Operculina* rich sand from the sub recent deposits and foraminifera from miliolitic limestone, Desai & Pandya (1982) on microfauna of the coastline sediments of the Saurashtra coast and Bhalla & Lal (1985) in Okha beach sand. Bhalla & Nigam (1988) had worked on the cluster analysis of foraminifera from the six beaches of west and east coast including Bhogat beach of Saurashtra coast. Similar works carried out by Pandya (1985) in Saurashtra coast, K. Kameswara Rao & M. Srinath (2002) on beach sands of Saurashtra coast, Talib and Farooqui (2007) on littoral sediments of Dwarka beach.

In the east coast, Bhatia and Bhalla (1959) have illustrated 14 recent benthic foraminiferal species from beach sand of Puri, Ghosh (1966) briefly illustrated *Asterorotalia trispinosa* from Digha beach, Kathal (1989) has made a comprehensive research work on recent benthic foraminiferal assemblages from the 16 beaches of east coast of India, Rao *et al.* (2002) described 69 foraminiferal assemblages from Chilika lake, Ghosh *et al.* (2014) examined the marsh zones of Sunderban coast and correlated modern benthic marsh foraminiferal assemblages with the typical mangrove vegetation.

But the available literature on seasonal variation of the benthic foraminifera from the west coast and east coast of India and comparative biofacies distribution of both the coasts of

India has not been studied. Therefore, the present work aims to explore recent benthic foraminiferal assemblages from both east and west coast of India, their abundance, seasonal variation and comparison of the foraminiferal biofacies along both the coastal stretch of India.

1.3 Objectives:

The present study emphasizes regional biofacies characterization of the coastal tracts of east and west coast of India with following objectives-

1. To identify the benthic foraminiferal assemblages in two different Indian coasts
2. To document the seasonal variation of benthic foraminiferal assemblages along both the coasts
3. To understand the role of abiotic factors and foraminiferal populations
4. To prepare the biofacies map for the better understanding of abundance of foraminiferal assemblages for both the coasts

1.4 Physiographical settings of the east coast:

To the geographers, the east coast of India has been known for a long time as a low-lying stretch of land bordered on the west by mountains which stretch from near Cape Comorin on the south to the Ganges plain on the north (Cushing, 2006). Our study area in the east coast covers the places of West Bengal and Odisha state of India. On the eastern bottleneck of India, West Bengal stretches from the Himalayas in the north to the Bay of Bengal in the south. With Bangladesh, which lies on its eastern border, the state forms the ethnolinguistic region of Bengal, having a total area of 88,752 square kilometres. A part of the district of Purba Medinipur along the Bay of Bengal constitutes the small coastal region in the extreme south of the state. The Sundarbans delta is the largest mangrove forest in the world, lies at the mouth of the Ganges and is spread across areas of Bangladesh and West Bengal, India (Figure-1.1).

About a third of the Odisha has a green cover and physiographically consists of coastal plains, central plateaus, central hilly regions, flood plains, and uplands (Figure-1.2). The coastal plain region stretches from the Subarnarekha basin in the north to the Rushikulya basin in the south. The centre of the state occupied by mountainous highlands and plateau regions. Northwestern and western portions consist of rolling uplands. The middle mountainous and highlands region comprises the hills and mountains of the Eastern Ghats which rise sharply in the east and slope gradually to the eroded plateaus in the west running from the north-west (Mayurbhanj) to the south-west (Malkangiri). Mainly, the plateaus are part of the western slopes of the Eastern Ghats. The western rolling uplands are lower in elevation than the plateaus and heights varying from 153 metres to 305 metres. The major flood plains of Odisha are Baripada flood plain, Anandapur flood plain, Talcher flood plain and Malkangiri flood plain etc.

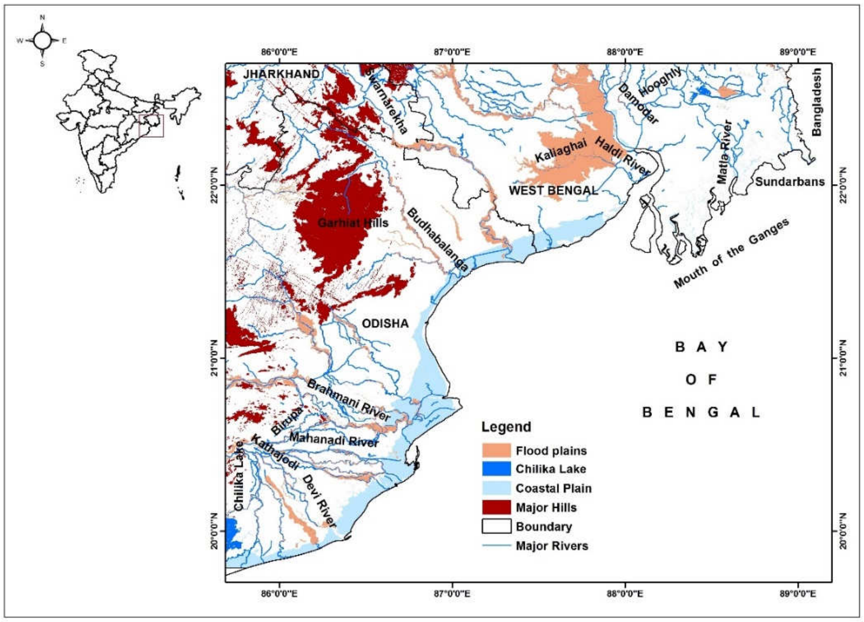


Figure-1.1: Physiographic divisions in and around the study area of the east coast

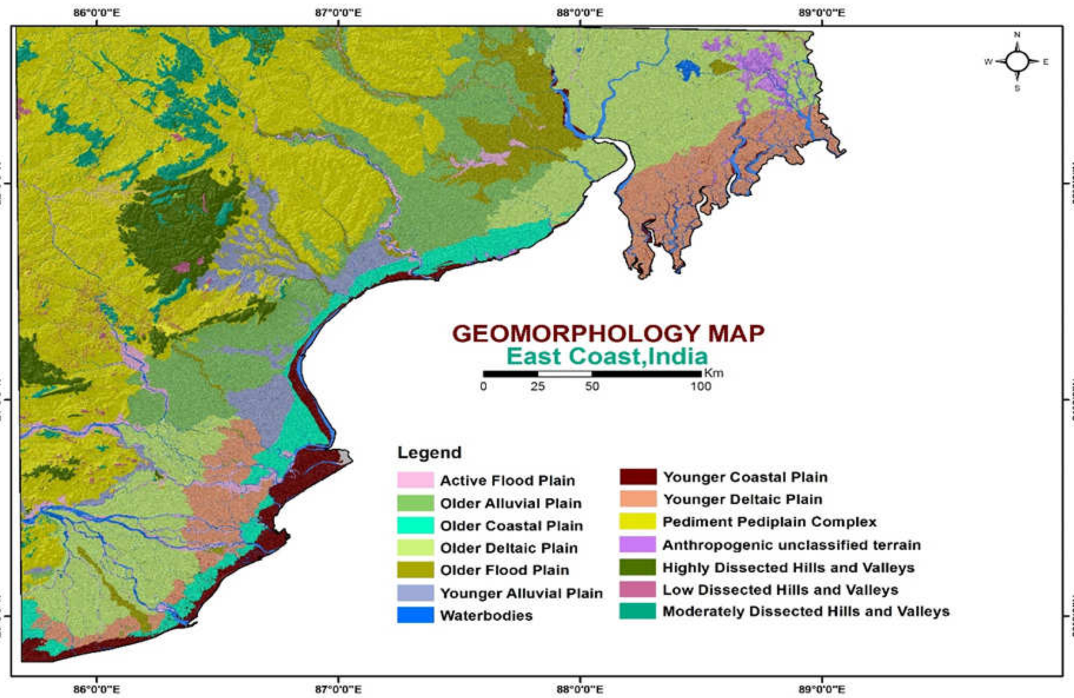


Figure-1.2: Geomorphology map in and around the study area of the east coast

1.5 Geological settings of the east coast:

The evolution of the east coast of India from the Permian up to the end of the Cretaceous has been traced by Sastri *et al.*, 1981. The researchers stated that the east coast basins (Mahanadi Godavari--Krishna, Palar and Cauvery Basins) are pericratonic. The entire Bengal basin is largely covered with the sub recent alluvium, bounded on the west by the Indian Peninsular Shield, with its Archaean complex and E-W trending intracratonic Upper Carboniferous to Lower Triassic Gondwana basin, on the south by the Bay of Bengal, and on the east by the Bangladesh plains covered by Recent alluvium (Kaila *et al.*, 1996).

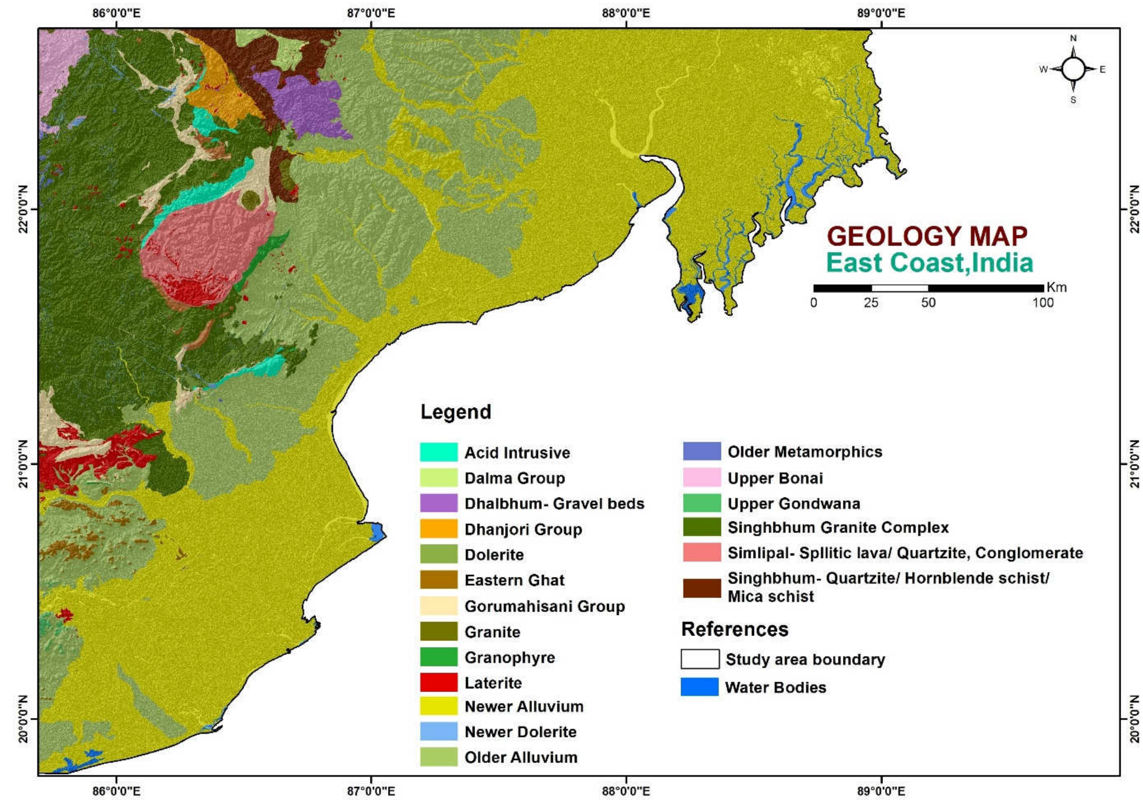


Figure-1.3: Geology map in and around the study area of the east coast

Odisha state is a part of three cratonic blocks called North Orissa Craton, the West Orissa Craton and Eastern Ghats Granulite Belt considered as a 'mobile belt' during the middle Proterozoic Era. The second oldest rocks on the planet were found in Champua, Kendujhar (Chaudhuri *et al.*, 2018). The North Orissa Craton is characterized by extensive banded iron formations, granite intrusives, and undeformed volcano-sedimentary assemblages belonging to the Archaean to-early Proterozoic times (Mahalik, 1996). The West Orissa Craton is underlain by occurrences of granites of the Archaean age and minor occurrences of Archaean banded iron formations and greenstones. The Eastern Ghats Granulite Belt or mobile belt is composed of Khondalite formations and moderately extensive charnockites, granites, migmatites, and local pegmatites formations. Gondwana basins are also found in

Odisha and the Mahanadi Master Basin holds a major part of the Gondwana basins of Odisha (Figure-1.3). The Quaternary sediments of Odisha are composed of laterites and unconsolidated clays, silts, sands, and gravels (Vaidyanadhan and Ghosh, 1993).

1.6 Drainage of the east coast:

The east coast of India consists of major river systems (Figure-1.4). In West Bengal, Ganges enters near Rajmahal and then flows in a south-easterly direction. The Bhagirathi-Hoogly is the main river in West Bengal, which drains the water into the Bay of Bengal near Sagar Island in the South 24 Parganas. The main tributaries of the Hoogly river are Haldi, Rosulpur and Pichaboni etc. The sorrow of West Bengal, Damodar is controlled by the Damodar Valley Project. The Sundarbans delta lies at the mouth of the Ganges, covered by numerous estuaries and streams, mainly distributaries of main rivers.

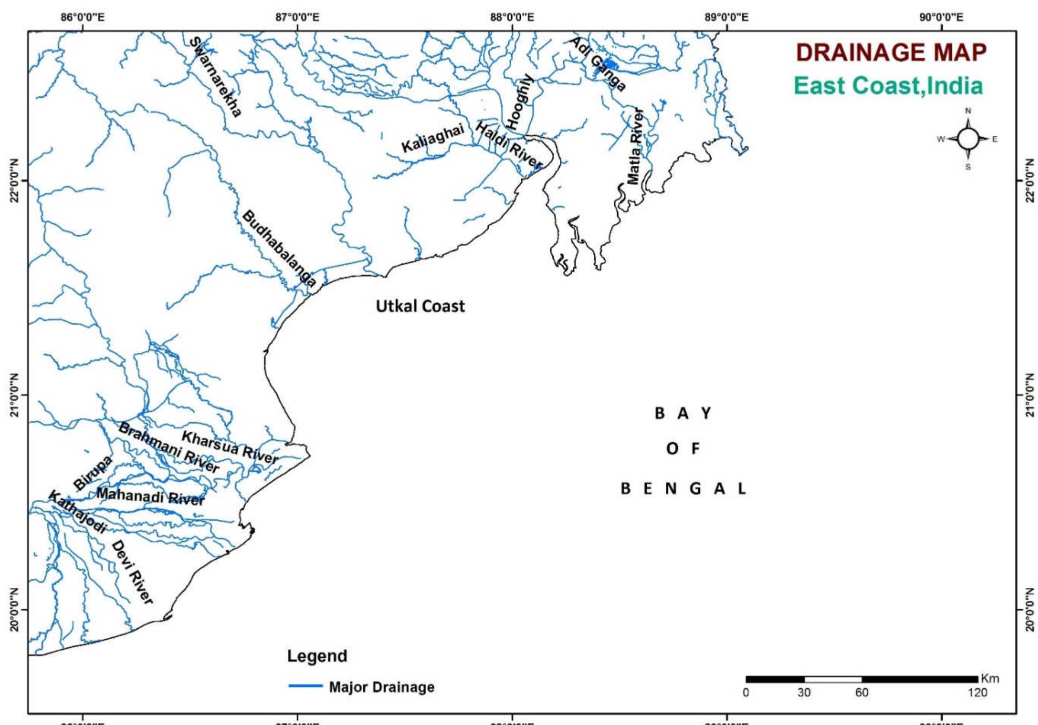


Figure-1.4: Drainage pattern in and around the study area of the east coast

Odisha also has numerous major river systems like Mahanadi basin, Brahmani-Baitarani basin, Subarnarekha basin and Budhabalanga river basin. Mahanadi is the sixth largest in India and the biggest river in Odisha, where Brahmani is the 2nd largest in Odisha. Brahmani flows through the Eastern Ghats in Sundargarh, Deogarh, Dhenkanal, and Jajpur districts. The Baitarani enters into the Bay of Bengal after joining the Brahmani River at the Dhamara mouth near Chandbali, Bhadrak. River Subarnarekha originates near the Chhotanagpur plateau of Jharkhand, flows across West Bengal state and joins the Bay of Bengal at Kirtania Port in Odisha. The Budhabalanga originates from the eastern slopes of the Similipal mountain range, flows through Mayurbhanj and Balasore Districts and ultimately drains into the Bay of Bengal near Balaramgadi**.**

1.7 Physiographical settings of the west coast:

Based on the physiographic condition, Gujarat can be divided into three distinct geographical units:

(a) Mainland Gujarat

(b) Saurashtra peninsula and

(c) Kutch.

Mainland Gujarat extends from Umbergaon (Maharashtra border) in the south to Mt. Abu (Rajasthan) in the north, Rann in the west, comprises a vast alluvial plain covering nearly 83,528 sq. km with a hilly terrain in the east bounded by Aravalli, Vindhyan, Satpura, and Sahyadri hill ranges. This agriculturally rich alluvial basin of Gujarat is mainly formed by the rivers Indus, Sabarmati, Mahi, Narmada and Tapi.

Saurashtra peninsula is situated in the southwestern side of Gujarat which lies between the latitude 20°41' N-23°26' N and longitude 65°05' E-72°20' E. The total length of the Saurashtra coastline traversing east, west and south is about 540 km with an inland width of 5 to 30 km (Pappu and Marathe, 1977). Along the coast, there is infringement of saline wastes, mangrove swamps, tidal flats and at some places bordered with dunes and bars (Pappu and Marathe, 1977). Saurashtra coast almost covers about one-third of the state of Gujarat**.** The E-W trending northern coast (Jamnagar-Okha) of Saurashtra shows a crenulated rocky shoreline with the sub-tidal zone consisting of channels, shoals, submerged islands, sand-bars, coral reefs and mangroves. Jamnagar – Diu (southwest coast of Saurashtra) faces the Arabian Sea and from Dwarka to Veraval, the coast shows characteristically straight NW-SE trend with sandy beaches. Veraval and Diu (E-W) are identical to those occurring along the Dwarka and Veraval coast. A transition from open sea to gulf environment can be seen in the coastal segment to the east of Diu to Bhavnagar.

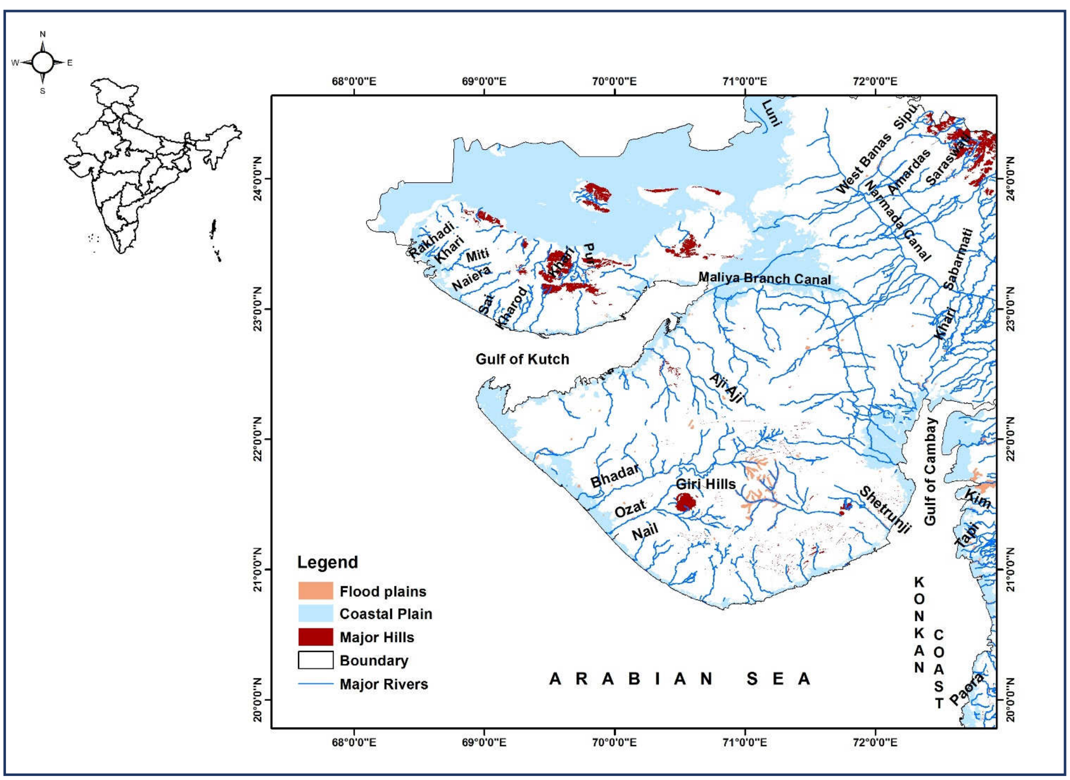


Figure-1.5: Physiographic divisions in and around the study area of the west coast

The mainland of Kutch is isolated on the north and east by the Great Rann, Little Rann on the SE, Gulf of Kutch on the south and the rest by the Arabian sea. The Gulf of Kutch is approximately aligned as E-W trending (Figure-1.5). The Rann is basically a dry bed of the remnant of the sea, which earlier connected the Narmada rift with Sind, and later separated.

1.8 Geological settings of the west coast:

Saurashtra peninsula is relatively flat and low-lying, largely covered by the Deccan lavas (Figure-1.6) except along its fringes where Tertiary and Quaternary sediments (limestone and alluvium) cover the Deccan rocks. It is located in the north western Deccan continental flood basalt province (India), notable for compositionally diverse volcano-plutonic complexes and abundant rhyolites and granophyres (Sheth *et al.*, 2011). Mesozoic sedimentary rocks are exposed in the northern part. No pre-Mesozoic rocks are known in this Saurashtra region from outcrops, borings, or xenoliths (Sheth *et al.*, 2011).

The rock formations of the Gujarat State have been tabulated below (Table-1.2):

GROUP	**SYSTEM**	**ROCK TYPE**	**LOCALITIES**	**AGE (MY)**
Quaternary	Recent and sub recent	Alluvium, blown sand, Silts of Rann and Banni, Tidal flats and raised beaches.	Alluvial plains of Gujarat, Rann, Banni & Coastal deposits.	0.01
	Pleistocene	Miliolites	(i) Saurashtra coast from Gopnath northwards extending beyond Porbandar. (ii) Kutch area.	1
Tertiary	Pliocene	Dwarka beds, Manchhar beds,	Dwarka, Okha, Piram Island, Kutch.	12

		Gypsiferous clays and sandy foraminiferal limestones.		
	Miocene	Gaj beds - Highly fossiliferous clays and limestones. Agate bearing conglomerates. Kand formations.	Saurashtra coast, Kutch.	25
	Oligocene	Tarkeshwar clays.	Tarkeshwar (District:Surat) and Kutch.	40
	Eocene	Nummulitic limestones and clays.	Tarkeshwar area and Kutch	60
	Paleocene	Madh series- Supratrapean.	Kutch	
Mesozoic	Cretaceous Eocene	Deccan traps with inter trappeans.	Parts of Sabarkantha, Panchmahals, Baroda, Broach, Surat and major part of Bulsar and Dangs Districts. Major part of Saurashtra and small part of Kutch.	
	Cretaceous	Himatnagar sandstones, Lameta (limestones). Bagh beds (sandstones, Limestones and shales). Songir sandstones, Nimar sandstones, Wadhavan sandstone (Infratrappeans), Bhuj and Umia series sandstones	Himatnagar, Kapadvanj, Balasinor, Parabia, Dohad, Gabat, Narmada valley, Gora, Surpan Vanji, etc. Songir. Near pavagadh. Wadhavan, Dhrangadhra, Bhuj etc.	110
	Jurassic	Katrol series, Chari series, Patcham series (sandstones, shales and limestones).	Kutch.	150

	Purana (Algonkian & Part of Cambrian)	Rinpura granite (Post-Delhi).	Palanpur, Danta, Idar, Modasa, Taranga, Dharoi, Virpur, Wanakbori, Godhra, etc	1500
		Delhi System-Alwar quartzites, schists, and calc-gneisses, calc-schists of Ajabgarh series.	Parts of Sabarkantha and Banaskantha, and Mehsana Districts.	
Archaean		Aravali System-Mica-schists, Phyllites, quartzites, etc.	Sabarkantha, Panchmahals, Baroda, Banaskantha.	4000
		Banded gneissic complex.	Baroda District.	

Table-1.2: Rock formation of Gujarat (after Kulkarni, 1985)

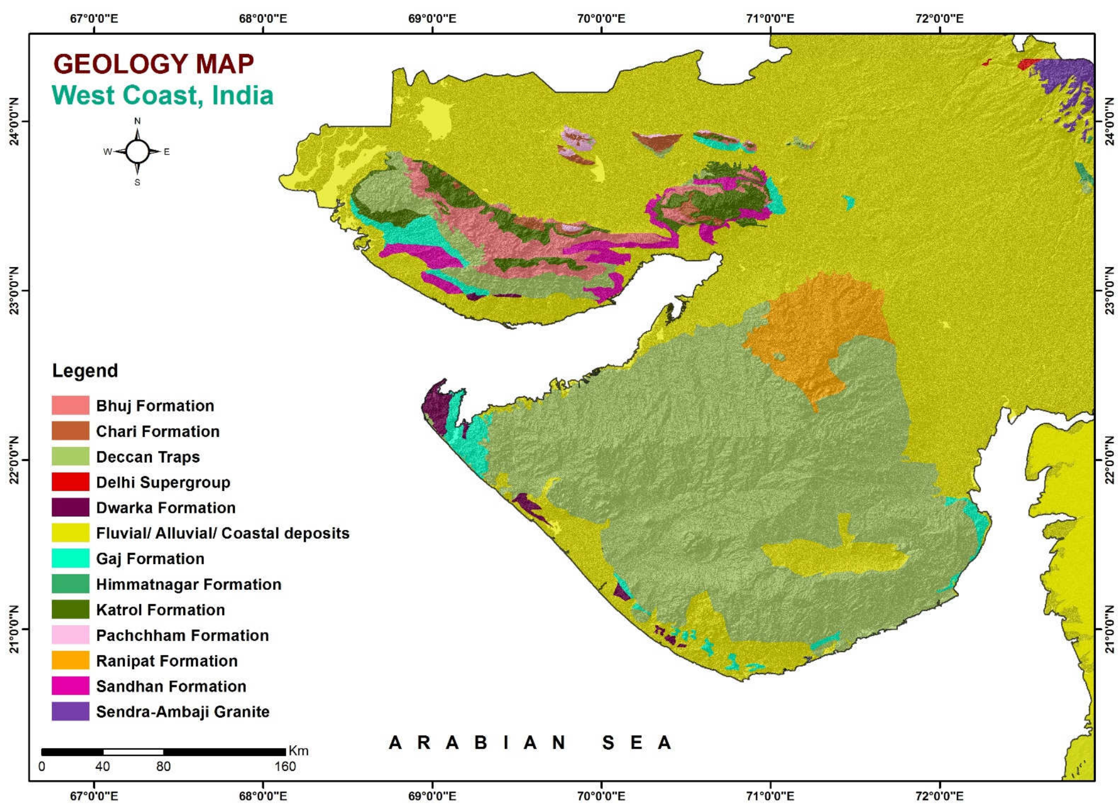


Figure-1.6: Geology map in and around the study area of the west coast

1.9 Drainage of the west coast:

Drainage is a reflection of the terrain characteristics, which is controlled by physiography, climate and tectonic framework (S. K. Chaturvedi, 2000). The drainage system of Saurashtra is characterized by a radial pattern (Marathe, 1981) with the rivers flowing out in all directions from the central highland. The two major hill ranges, viz., the Manda range near Rajkot (383 m above msl) and the Gir range in the southern Saurashtra (higher than 390 m above MSL),

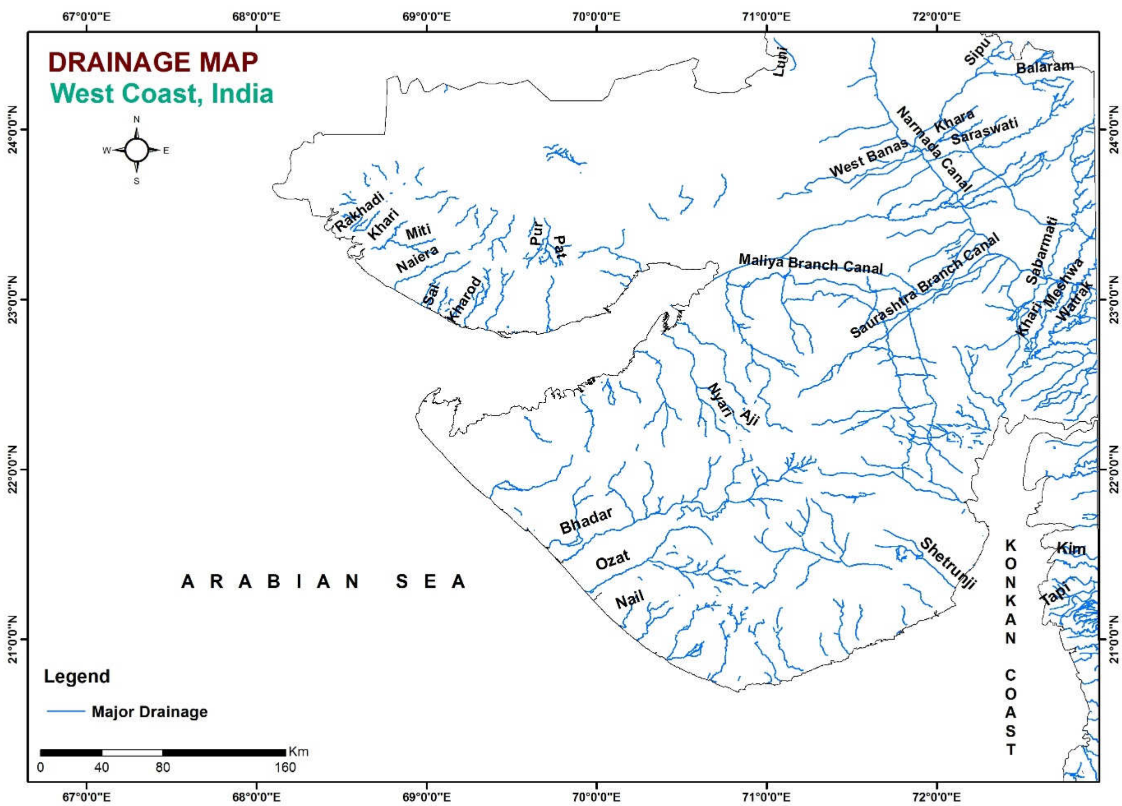


Figure-1.7: Drainage pattern in and around the study area of the west coast

controlling the drainage pattern and are linked by tortuous, narrow neck of highland (Pappu and Marathe, 1977). With its source at Jasdan, the Bhadar is the largest westerly flowing river with a course of 193 km. Shetrunji river flows towards east to merge with Gulf of Cambay. Apart from these major rivers, there are a large number of small rivers with length varying from 20 to 80 km. Except the Bhadar and Shetrunji, none of the rivers can be called perennial. Porbandar to Kodinar, having a straight coastline, indented by a number of rivers forming tidal creeks with lagoons. The most prominent of these are the Vartu, Bhadar, Megal, Heran and Suran rivers (Chamyal *et al*. 2003). Ojat and Saraswati, show a characteristic deflection in their courses so that they flow parallel to the coast before meeting the sea (Mehr, 1995). With developing a wide alluvial plain, the Shetrunji meets the sea near Bhavnagar (Sant, 1999). The Bhadar and the Shetrunji, the two largest rivers of the Saurashtra peninsula, flow in opposite directions (Figure-1.7) passing through plains formed by the alluvial deposits of these rivers (Marathe, 1981).

1.10 Organization of the Thesis:

This thesis is organized into five chapters. The present chapter gives an idea about foraminifera, the main objectives and problem identified in the thesis and describes the geological settings of east and west coast India. Chapter 2 deals with the methodology that have been followed in this research. Chapter 3 describes detailed systematics of the foraminifera and its relation with abiotic factors along the east coast. Chapter 4 describes the systematics of the foraminifera and its relation with physical attributes along the west coast. This thesis concludes with the final Chapter 5 which discusses the comparative analysis on the distribution and biofacies of both coastal foraminiferal assemblages.

Chapter-2

Materials and Methodology

2.1 Introduction

For a successful micropaleontological investigation, reliable sample acquisition is an essential prerequisite. Different sampling strategies need to be carried out for different substrates and in different environments. After a literature survey on the standard methodology, a flow chart has been created as in Figure-2.1. It provides a summary of the methodology adopted during the research work.

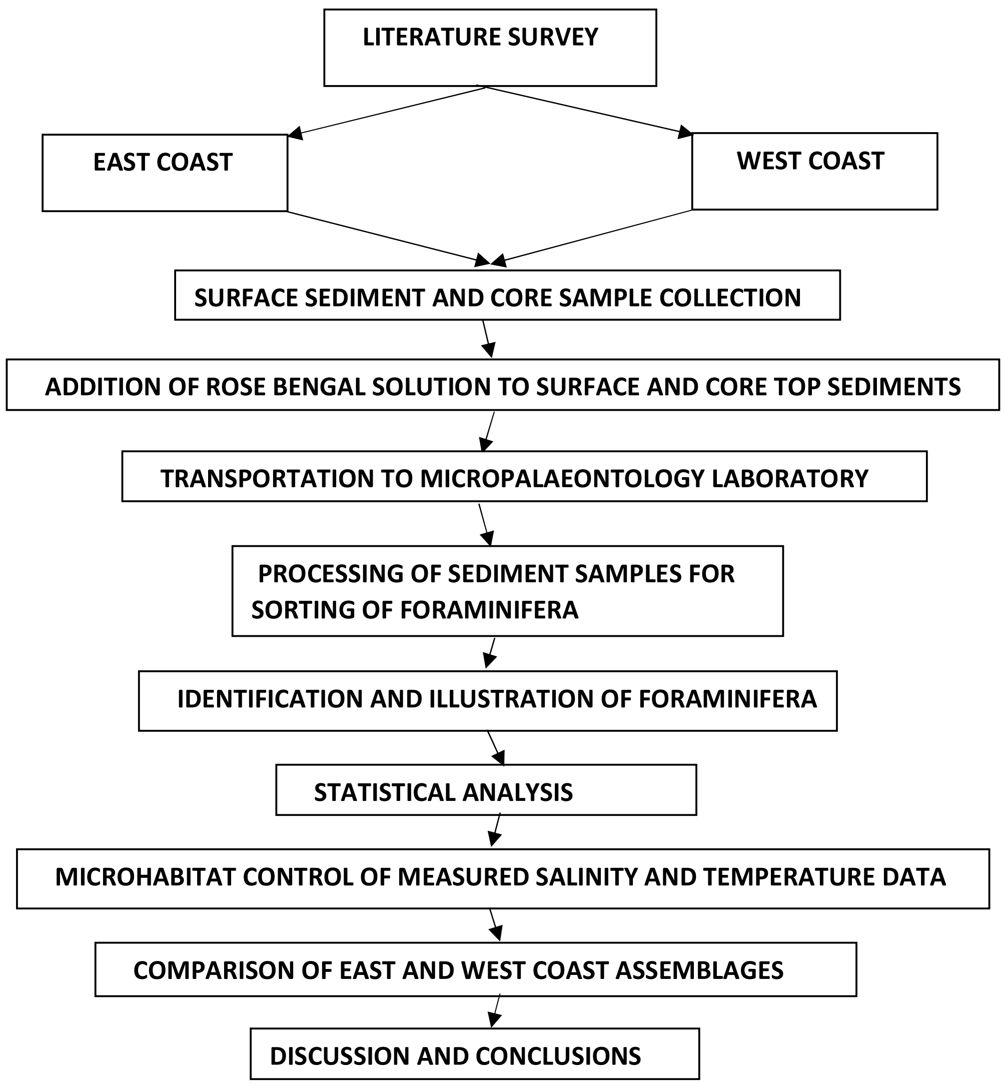


Figure-2.1: Flow chart of the work planned for the present study

The sampling stations of the east coast are from the northern to the southern region, i.e. from Rasulpur, West Bengal to Dosinga, Odisha. It includes fifteen stations (Figure-2.2), namely Rasulpur, Junput, Pichaboni, Mandarmani, Digha, Dagara, Jambhirei, Kasafals, Bagada, Chandipur, Gudu, Khadu, Mandanapur, Chandimal and Dosinga (Table-2.1), stretching 256 km.

Sampling stations	Latitude	Longitude
Rasulpur	22°14.111'N	87°3.638'E
Junput	22°43.038'N	87°49.194'E
Pichaboni	22°02.249'N	87°3.638'E
Mandarmani	21°39.822'N	87°42.684'E
Digha	21°37.317'N	87°32.317'E
Dagara	21°33.071'N	87°04.916'E
Jambhirei	21°32.569'N	87°14.635'E
Kasafals	21°30.728'N	87°08.324'E
Bagada	21°16.721'N	87°3.638'E
Chandipur	21°27.523'N	87°3.638'E
Gudu	21°24.40'N	86°59.174'E
Khadu	21°24.227'N	86°59.921'E
Mandanapur	20°54.564'N	87°3.638'E
Chandimal	20°53.033'N	87°3.638'E
Dosinga	20°50.185'N	87°3.638'E

Table-2.1: Sampling location details of the east coast

The sampling stations of the west coast are from the northern to the southern region, i.e. from Dwarka to Sutrapada. It includes fifteen stations (Figure-2.3), namely Dwarka, Okhamadhi, Kuranga, Harshad, Porbandar, Rangbai, Navi Bandar, Gorsar, Madhavpur, Mangrol, Chorward, Adri, Veraval, Somnath, and Sutrapada (Table-2.2). The total coastline covered was about 266 kilometres. Few field photographs have been shown in Figure-2.4 (a-h) and Figure-2.5 (a-h).

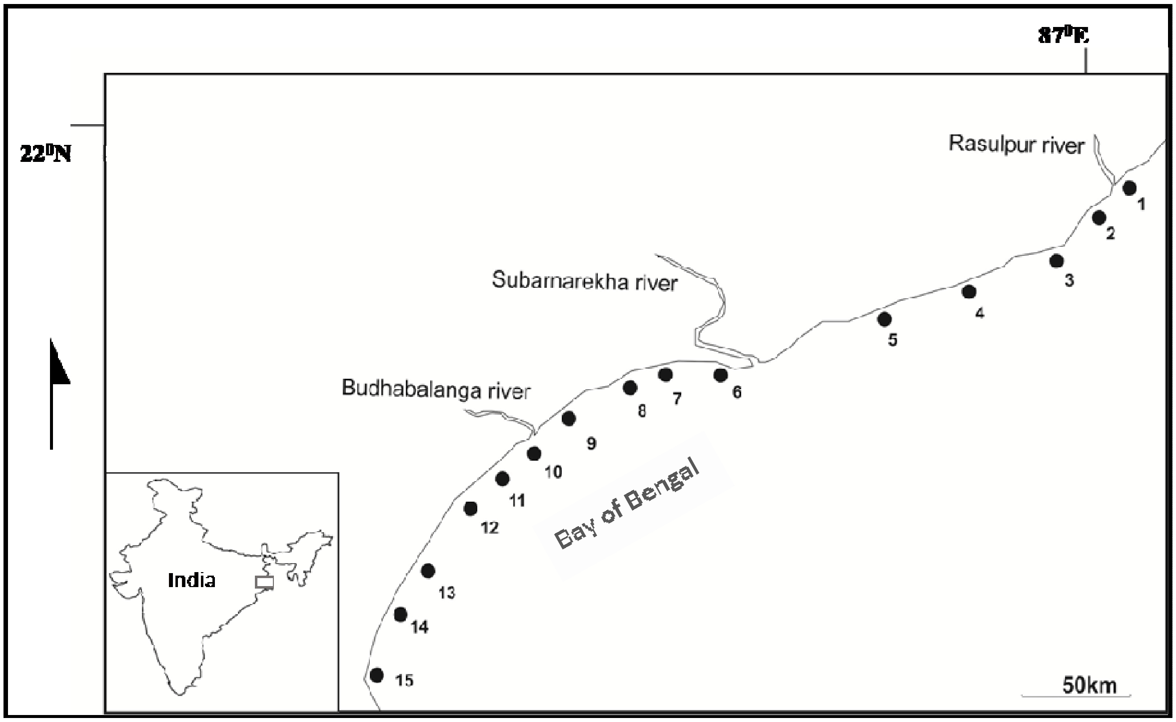


Figure-2.2: Location map showing the sampling stations of the east coast
(Legends: 1-Rasulpur, 2-Junput, 3-Pichaboni, 4-Mandarmani, 5-Digha, 6-Dagara, 7-Jambhirei, 8-Kasafals, 9-Bagada, 10-Chandipur, 11-Gudu, 12-Khadu, 13- Mandanapur, 14-Chandimal and 15-Dosinga)

Sampling stations	Latitude	Longitude
Dwarka	22°14.111'N	68°57.950'E
Okhamadhi	22°05.452'N	69°05.723'E
Kuranga	22°02.249'N	69°09.249'E
Harshad	21°50.059'N	69°21.963'E
Porbandar	21°37.795'N	69°36.594'E
Rangbai	21°33.046'N	69°41.313'E
Navibandar	21°27.055'N	69°47.015'E

Gorsar	21°29.899'N	69°44.414'E
Madhavpur	21°16.721'N	69°56.125'E
Mangrol	21°06.217'N	70°06.411'E
Chorward	21°00.075'N	70°13.496'E
Adri	20°57.562'N	70°16.711'E
Veraval	20°54.564'N	70°21.155'E
Somnath	20°53.033'N	70°24.416'E
Sutrapada	20°50.185'N	70°28.815'E

Table-2.2: Sampling location details of the west coast

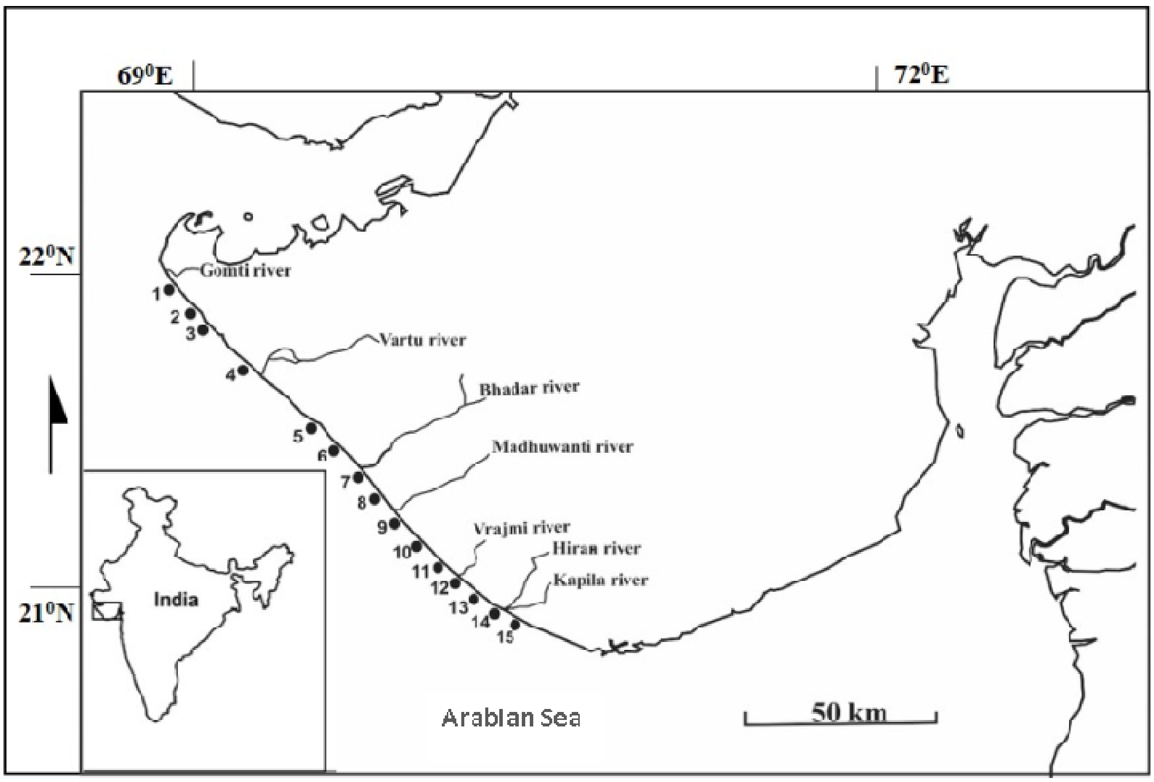


Figure-2.3: Location map showing the sampling stations of the west coast

(Legends: 1-Dwarka, 2-Okhamadhi, 3-Kuranga, 4-Harshad, 5-Porbandar, 6-Rangbai, 7-Navibandar, 8-Gorsar, 9-Madhavpur, 10-Mangrol, 11- Chorward, 12-Adri, 13- Veraval, 14-Somnath and 15-Sutrapada)

2.2 Sample collection

The surface sediment samples were collected from 15 stations each from both the coasts of India within the same latitude (20^0N – 22^0N). Surface sediment samples of 100 cm^3 (10cm X 10cm X 1cm) were collected in 250 ml plastic container. For preservation and identification of living foraminifera, Rose Bengal Solution was added to the samples. Rose Bengal Solution was made using a concentration of 2g Rose Bengal powder per litre ethanol. After the addition of Rose Bengal Solution to the samples, samples were shaken gently until the solution reached every corner of the sampling bottle.

Sampling was carried out on a seasonal basis during October 2016 (post-monsoon) and April, 2017 (pre-monsoon). Also, a core sample of 15 cm long was collected from Chandipur, east coast and another from Harshad, west coast to compare the vertical distribution of foraminiferal assemblages in intertidal areas. The cores were sub-sampled at 1 centimeter. The sediment samples of both the cores were kept in fifteen different wide, tight-mouthed plastic containers for each core, corresponding to the layers of both the cores obtained. The GPS coordinates were recorded at each sampling station and lithology, sedimentary features and biologic features were noted in field notebook. Each of the stained samples was labelled properly and brought back to the Micropaleontology Laboratory, Department of Geological Sciences, Jadavpur University for processing. The standard method described by FOBIMO was followed in the micropalaeontological investigation.

2.3 Sample processing technique

The sediments were washed on a 63 μm sieve to eliminate clay and silt particles within 14 days of the storing in the laboratory, with a slow shower and low water pressure to prevent foraminiferal tests from breakage. The washed samples were oven-dried under 50^0C. These dried sediments were transferred into a small transparent plastic tube for sorting.

2.4 Sorting and identification

One gram of dried sediment was separated from each of the washed oven-dried residue using the micro splitter. The micro splitter was used to separate >63 μm fraction of the selected samples into smaller portions. This one gram dried sediment of each sample was separated into different size fractions, i.e. >500 μm, >125 μm and >63 μm, to observe the size variation of the benthic foraminiferal assemblages along the sampling locations. The measured sediments were transferred into a micropalaeontological gridded tray and examined under a stereo zoom microscope (Nikon SMZ-1000), and foraminifera were picked using a fine #000 brush. The picked foraminifera were placed on a pre-glued, labelled micro faunal slides (24 chambered and double punch) for identification and statistical analyses. The best-preserved foraminifera were photographed using the Scanning Electron Microscope (Carl Zeiss EVO-18, Jadavpur University, Kolkata) for finer identification and illustration. The taxa were mainly identified following the papers published by Loeblich and Tappan (1964), Rao and Srinath (2002), Talib and Farooqui (2007) and Ghosh (2008). In our present study, the classification given by Loeblich and Tappan (1964) has been followed for the taxonomic study. Analysed samples of east and west coast India were stored in Micropalaeontology Laboratory, Department of Geological Sciences, Jadavpur University.

2.5 Physical parameters

The physical parameters such as salinity and temperature were not recorded during the sampling process, but the data were received from the National Institute of Oceanography-Data Centre (NIODC) on request and statistical plots were carried out.

2.6 Statistical analyses

The data generated from the study is represented by various statistical analyses for meaningful environmental interpretations, including Total foraminiferal number (TFN), Murray's triangular plot of the foraminiferal wall structure, Fisher's α diversity index plot, bivariate plot of Fisher's α and Shannon diversity index (H), Foraminiferal test size variation, Q-mode and R-mode cluster analyses to correlate with the abiotic factors such like salinity, temperature and sedimentation.

TFN gives the Total number of foraminiferal species along the sampling locations. Murray's triangular plot was used to observe the relative percentages of agglutinated, porcelaneous and hyaline test types of the foraminifera. Fisher's α diversity index was plotted to describe the relationship between the number of species and the number of individuals in each sampling station mathematically. The Bivariate plot of Fisher's α and Shannon diversity index (H) was performed to understand the different environments of the foraminiferal assemblages. The foraminiferal test size variation graph was plotted to observe the sizes of the foraminiferal species.

Paired group (UPGMA) and Jaccard Q-mode cluster analysis was plotted to understand the spatial variation of the foraminiferal assemblages among the sampling stations and Paired group (UPGMA) and Morisita cluster analysis was performed to assess the similar characteristics of the foraminiferal assemblages.

2.4 a. Rasulpur

2.4 b. Junput

2.4 c. Mandarmani

2.4 d. Bagada

2.4 e. Jambhirei

2.4 f. Chandipur

2.4 g. Gudu

2.4 h. Mandanapur

Figure-2.4 (a-h): Field photographs of a few sampling stations from the east coast

2.5 a. Dwarka

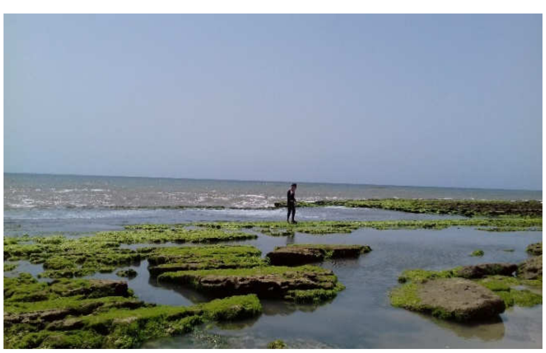
2.5 b. Okhamadhi

2.5 c. Harshad

2.5 d. Porbandar

2.5 e. Rangbai

2.5 f. Navibandar



2.5 g. Chorward

2.5 h. Veraval

Figure-2.5 (a-h): Field photographs of a few sampling stations from the west coast

Chapter-3

Foraminiferal Assemblages of the East Coast

3.1 Historical resume:

Recent Benthic Foraminiferal assemblages of coastal sediments are being studied worldwide. In the Indian context, a lot of research papers have been published on Recent benthic foraminifera from both east and west coast of India. As our main study represents the marginal marine environment, a detailed account of research work done by the earlier researchers on foraminiferal studies on beaches/estuaries and mud flat regions along the east coast of India has been tabulated in Table-3.1.

S.No.	YEAR	AUTHOR	AREA	REMARKS
1	1964	Bhatia & Bhalla	Beach sand of Puri (Orissa)	described 14 species of recent foraminifera.
2	1966	Ghosh	Digha beach Southern Bengal	*Asterorotalia trispinosa* (Thalmann) a spinose rotalid.
3	1966	Rao & Rao	Visakhapatnam	Living foraminifera from tidal creek near Pudimadka.
4	1968	Bhalla	Visakhapatnam	Recent foraminifera and its relation to foramogeographical province in Indian Ocean.
5	1969	Ramanathan	Vellar estuary, Madras	Abundance of Rotalids, Miliolids, Nonionoides and arenaceous foraminifera
6	1970	Bhalla	Marina beach (Madras)	Identified 15 species of foraminifera including 4 intermediate species. Of these 4 species are recorded for the first time
7	1970	Ramanathan	Vellar estuary, Tamil Nadu	Foraminiferal ecology and foraminiferal relationship.
8	1973	Ameer Hamsa	Palk Bay, Gulf of Mannar	12 species have been described and illustrated along with the list of 34 species from the beach sands.
9	1973	Reddy	Pennar estuary	Ecology of recent foraminifera.

10	1974	Reddy *et al.*	Pennar estuary	Out of total, 45 species identified only 21 have living representatives, most of the species are benthic.
11	1978	Reddy & Rao	Pennar estuary	Size distribution among recent foraminifera.
12	1979	Reddy *et al.*	Pennar estuary	Foraminiferal and substrate relationship Pennar estuary.
13	1980	Reddy & Reddy	Pennar estuary	Recent *Textularia* and *Miliolina*.
14	1980	Reddy & Rao	Pennar estuary	45 foraminiferal species identified.
15	1981	Narappa *et al.*	Gautami and Nelareu estuaries of river Godavari	Living population is interpreted in view of ecological factors.
16	1982	Narappa *et al.*	Godavari and Krishna river estuary	90 species found of which 59 are found in living condition.
17	1982	Reddy & Reddy	Araniar estuary Tamilnadu	44 benthonic foraminifera.
18	1983	Naidu	Vamsadhara estuary and Bendi lagoon	Foraminifera from the Sanidanigedda Machilsm back water.
19	1983	Reddy & Rao	Pennar estuary, Andhra Pradesh	Spatial and temporal distribution of recent foraminiferal species.
20	1983	Reddy & Rao	Pennar estuary, Andhra Pradesh	Reported 45 foraminiferal species.
21	1984	Reddy & Rao	Pennar estuary, Andhra Pradesh	A total of 45 foraminiferal species were identified. Rotaliina is the dominant suborder, Miliolina occur less frequently and Textulariina are rare.
22	1987	Naidu	Vamsadhara estuary	56 foraminiferal species were identified, out of which Textularids 10, Miliolids 18, Rotalids 28.
23	1990	Kumar *et al.*	Thamirabarani river estuary	Benthic foraminiferal abundance ans species diversity.
24	1994	Reddy & Reddy	Araniar River estuary, SE coast of India.	Recorded 46 foraminifer species. Among various ecological parameters salinity, pH and calcium have close bearing on distribution and abundance of foraminifera in estuary.
25	1994	Rao *et al.*	Alikuppam and Kuvatturpettai back	Recorded 21 species of foraminifera.

			water, Tamil Nadu	
26	1996	Kathal & Bhalla	East coast of India	Reported 56 foraminiferal species from 16 beaches and assigned the assemblages as 'Indo-Pacific' upto Vedranniyam and further south upto Kanniyakumari as 'Mixed zone' of foramgeographical province of the world.
27	1998	Kathal & Bhalla	Palk Strait & Kakinada Bay	Presented the taxonomic observations of *Rotorboides granulosum.*
28	1998	Jayaraju *et al.*	Pulicat Lake	Q-mode factor analysis of 23 foraminiferal genera and presented 6 assemblages for each season within Pulicat Lake.
29	2000	Jayaraju *et al.*	Pulicat lake	Q-mode factor analysis of relative abundance of 35species.
30	2002	Kathal	16 stations along East coast	54 recent and one relict benthic species from 96surface samples from 0 to 3 m depth.
31	2002	Gandhi *et al.*	Palk Strait	Taxonomy and distribution of 102 benthic foraminifera
32	2004	Kumar and Srinivasan	Coleroon River Estuary, Tamil Nadu	Factor analysis of 56 foraminiferal species.
33	2007	Satyanarayana *et al.*	Karaikal-Nagore-Nagapattinam	Presence of long spines of *Asterorotalia trispinosa* and *Ammonia dentata* indicates no reworking of oceanic sediments due to tsunami in the region.
34	2008	Jayaraju *et al.*	Nellore Coast	Relation of foraminifera with heavy metal pollution
35	2010	Kathal and V.K.Singh	East coast	First report on twelve recent benthic foraminifera
36	2014	Ghosh *et al.*	Sunderban marsh	benthic marsh foraminiferal assemblages and correlated with the typical mangrove vegetation
37	2019	Sreenivasulu *et al.*	Beypore estuary	Biodiversity, Benthic foraminifera and ecological stress
38	2019	Das *et al.*	Chandipur coast	Investigated vertical distribution of the benthic foraminifera and identified eleven foraminiferal species

Table-3.1: Major research work carried out on beaches/estuaries/Marsh and mud flats region along Eastern Indian coast (Modified after Khare *et al.*, 2007)

3.2 Foraminiferal assemblages

Surface sediments were collected from the fifteen stations of this coast in both pre (April) and post-monsoon (October). In this present study, a total of 18 species of foraminifera were identified from the study area of the east coast. The characteristic calcareous assemblages are *Haynesina germanica, Cribroelphidium poeyanum*, *Asterorotalia trispinosa*, *Quinqueloulina seminulum*, *Cribroelphidium excavatum*, *Ammonia tepida*, *Rotalidium annectens*, *Haynesina depressula, Pararotalia nipponica, Ammonia beccarii*, *Ammonia parkinsoniana*, *Nonionella* sp., *Pseudononion japonicum, Elphidium advenum* and *Bolivina* sp. and the agglutinated assemblages are *Trochammina inflata and Haplophragmoides* sp., and *Miliammina fusca.*

3.3 Systematics

The species identified from the east coast has been described as follows-

Order **Foraminiferida Eichward, 1830**
Suborder **Textularina Delage and Hèrouard, 1896**
Superfamily **Lituolacea de Blainville, 1825**
Family **Trochamminidae Schwager, 1877**
Subfamily **Trochammininae Schwager, 1877**
Genus ***Trochammina* Parker & Jones, 1859**

***Trochammina inflata* Montagu**
(Plate-1, Figs. 1 & 2)

Remarks: It is present in surface samples collected from Mandanapur and Chandimal and core sample of Chandipur.

Family **Haplophragmoididae Maync, 1952**

Subfamily Haplophragmoidinae Maync, 1952

Genus *Haplophragmoides* Cushman, 1910

***Haplophragmoides* sp.**

(Plate-1, Fig. 3)

Remarks: It is present in both surface and core sample collected from Chandipur.

Superfamily Rzehakinacea Cushman, 1933

Family Rzehakinidae Cushman, 1933

Genus *Miliammina* Heron-Allen and Earland, 1930

***Miliammina fusca* Brady**

(Plate-1, Fig. 4)

Remarks: It is present in Chandimal.

Order Foraminiferida Eichward, 1830

Suborder Miliolina Delage and Hirouard, 1896

Superfamily Miliolacea Ehrenberg, 1839

Family Miliolidae Ehrenberg, 1839

Subfamily Hauerinidae Schwager, 1876

Genus *Quinqueloculina* d'Orbigny, 1826

***Quinqueloculina seminulum* Linnaeus**

(Plate-1, Fig. 5)

Remarks: It is highly abundant in Junput followed by both surface and core sample of Chandipur.

Suborder Rotaliina Delage and Hirouard, 1896

Superfamily Rotaliacea Ehrenberg, 1839

Family Rotaliidae Ehrenberg, 1839

Subfamily Ammoninidae Schwager, 1876

Genus *Rotalidium* Asano, 1936

***Rotalidium annectens* Parker and Jones**

(Plate-1, Fig. 6)

Remarks: It is present in all the sampling stations except Rasulpur.

Genus *Asterorotalia* Hofker, 1950

***Asterorotalia trispinosa* Thalman**

(Plate-1, Fig. 7)

Remarks: It is mainly abundant in Junput and Jambhirei.

Superfamily Nonionacea Schultze, 1854

Family Nonionidae Schultze, 1854

Subfamily Nonioninae Schultze, 1854

Genus *Haynesina* Banner and Culver, 1978

***Haynesina germanica* Ehrenberg**

(Plate-1, Fig. 8)

Remarks: It is highly abundant in Chandipur, Khjadu, Gudu, Mandanapur and Chandimal.

***Haynesina depressula* Walker & Jacob**

(Plate-1, Fig. 9)

Remarks: It is mainly present in Junput, Chandipur and Chandimal.

Genus *Pseudononion* Asano, 1936

***Pseudononion japonicum* Asano**

(Plate-2, Fig. 1)

Remarks: It is present only in Pichaboni and Chandipur and the abundance is very low.

***Nonionella* sp.**

(Plate-2, Fig. 2)

Remarks: It is present in Bagada, Chandipur and Chandimal

Family **Elphidiidae Galloway, 1933**

Subfamily **Elphidiinae Galloway, 1933**

Genus ***Cribroelphidium* Cushman and Brönniman, 1948**

Cribroelphidium poeyanum

(Plate-2, Fig. 3)

Remarks: It is highly abundant in Chandipur, Mandanapur and Chandimal followed by Pichaboni and Mandarmani.

Cribroelphidium excavatum

(Plate-2, Fig. 4)

Remarks: It is highly abundant in Chandipur, Mandanapur and Chandimal followed by Pichaboni and Mandarmani.

***Elphidium advenum* Cushman**

(Plate-2, Fig. 5)

Remarks: It is present only in Mandanapur and junput and the abundance is very low.

Subfamily Rotaliinae Ehrenberg, 1839

Genus *Ammonia* Brunnich, 1972

***Ammonia tepida* Cushman**

(Plate-2, Fig. 6)

Remarks: It is mainly abundant in Chandipur and Gudu.

***Ammonia beccarii* Linneus**

(Plate-2, Figs. 7 & 8)

Remarks: It is present in Junput and pichaboni with low abundance.

***Ammonia parkinsoniana* d'Orbigny, 1839**

(Plate-2, Fig. 9)

Remarks: It is present in Dagara, Gudu and Khadu with low abundance.

Subfamily Pararotaliinae Reiss, 1963

Genus *Pararotalia* Y. Le Calvez, 1949

***Pararotalia nipponica* Asano**

(Plate-2, Fig. 10)

Remarks: It is present in Junput, Pichaboni, Kasafals, Bagada and Khadu.

Superfamily Bolivinacea Glaessner, 1937

Family Bolivinidae Glaessner, 1937

Genus *Bolivina* d'Orbigny, 1839

***Bolivina* sp.**

(Plate-2, Fig. 11)

Remarks: It is present only in Rasulpur with very low abundance.

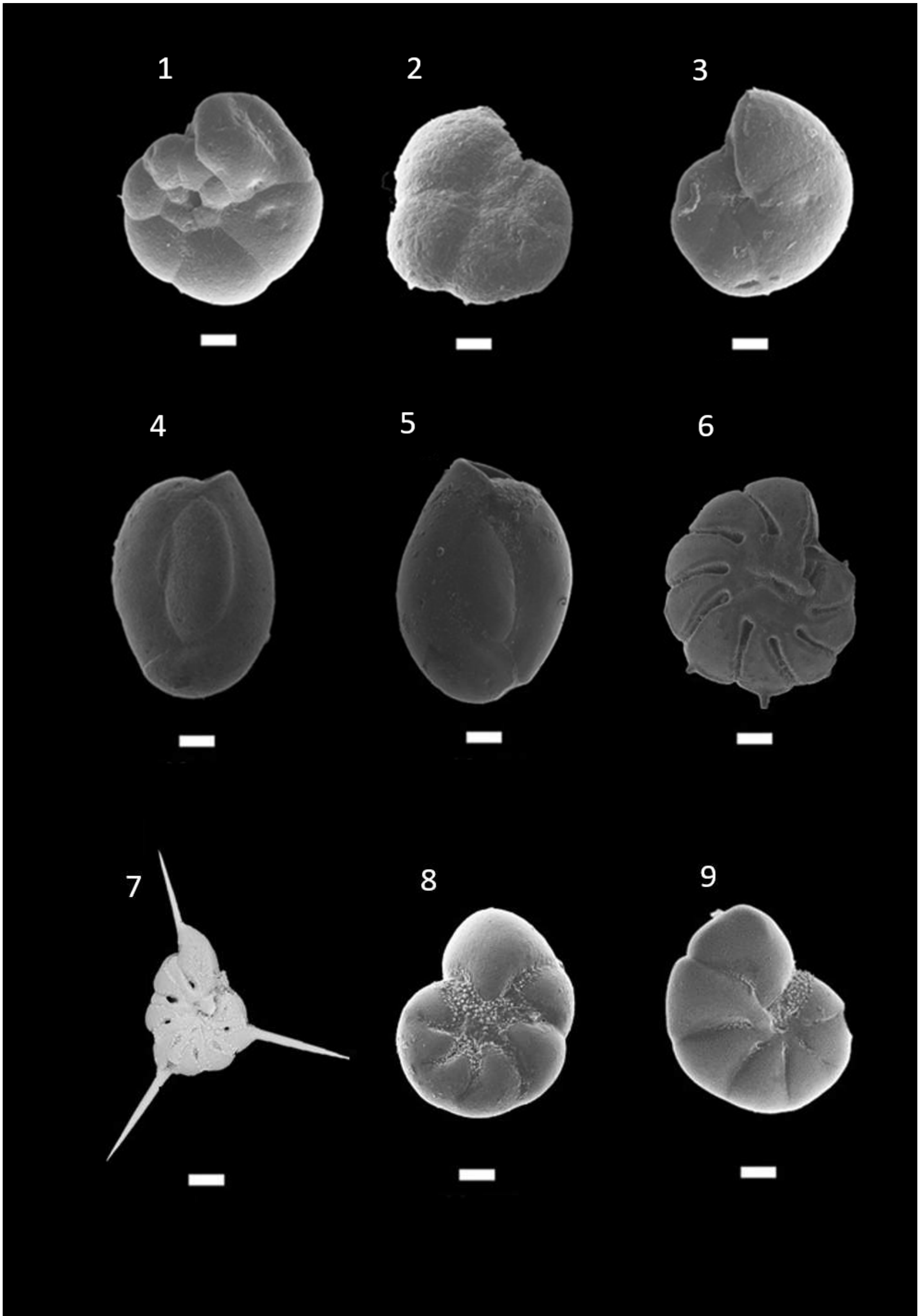


Plate-1: Scanning Electron Microphotographs of 1) *Trochammina inflata* (S) 2) *Trochammina inflata* (U) 3) *Haplophragmoides* sp. (U) 4) *Miliammina fusca* (Si) 5) *Quinqueloculina seminulum* (Si) 6) *Rotalidium annectens* (Si) 7) *Asterorotalia trispinosa* (U) 8) *Haynesina germanica* (U) 9) *Haynesina depressula* (U) All scale bar measures 60 microns.

Legends: S- Spiral side, Si- Side view, Ap- Apertural view, U- Umbilical view

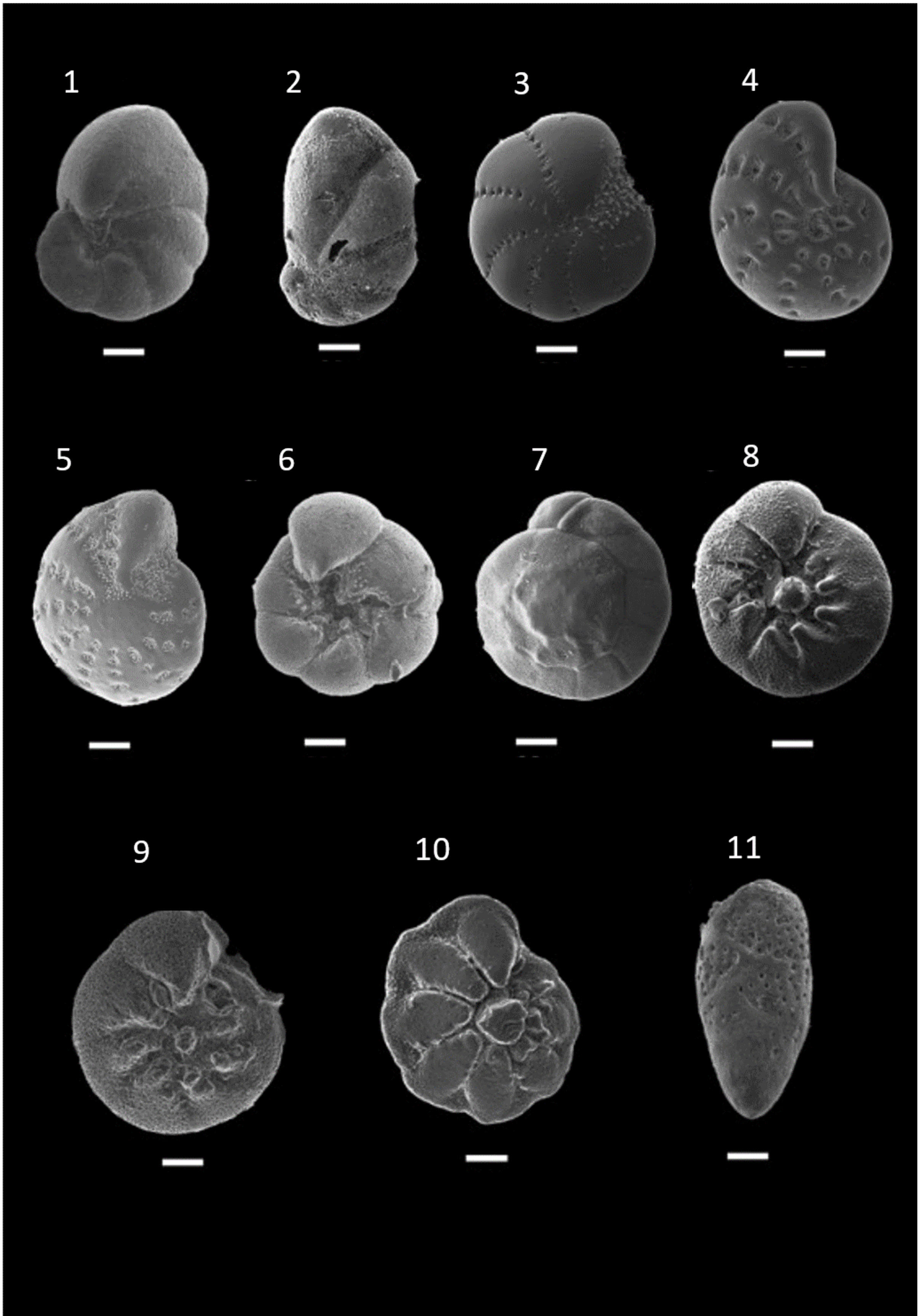


Plate-2: Scanning Electron Microphotographs of 1) *Pseudononion japonicum* (U) 2) *Nonionella* sp. (U) 3) *Cribroelphidium poeyanum* (Si) 4) *Cribroelphidium excavatum* (Si) 5) *Elphidium advenum* (Si) 6) *Ammonia tepida* (U) 7) *Ammonia beccarii* (S) 8) *Ammonia beccarii* (U) 9) *Ammonia parkinsoniana* (U) 10) *Pararotalia nipponica* (U) 11) *Bolivina* sp. (S). All scale bar measures 60 microns

Legends: S- Spiral side, Si- Side view, Ap- Apertural view, U- Umbilical view

3.4 Results

3.4.1 Surficial distribution of foraminiferal assemblages

The Total Foraminiferal Number (TFN) is plotted across the sampling stations of the east coast for both pre (April) and post-monsoon (October) seasons (Figure-3.1). The TFN includes the total benthic foraminiferal (dead and living forms) population. The TFN in pre-monsoon month varies between 5 to 193 individuals and in post-monsoon it ranges between 4 to106 forms. The highest abundance of foraminifera was found in Chandipur, i.e. 193 and the lowest was in Rasulpur, i.e. 4. The sediment weight of 1 gram was considered for all analyses. From the TFN bar diagram, we can see here that the southern part of our sampling stations such as Chandipur, Gudu, Khadu, Mandanapur and Chandimal, having higher foraminiferal abundances as compared to the northern part of our sampling locations such as Bagada, Kasafals, Dagara, Digha and Mandarmani. The data from the Rasulpur was not included in other statistical analyses due to the low

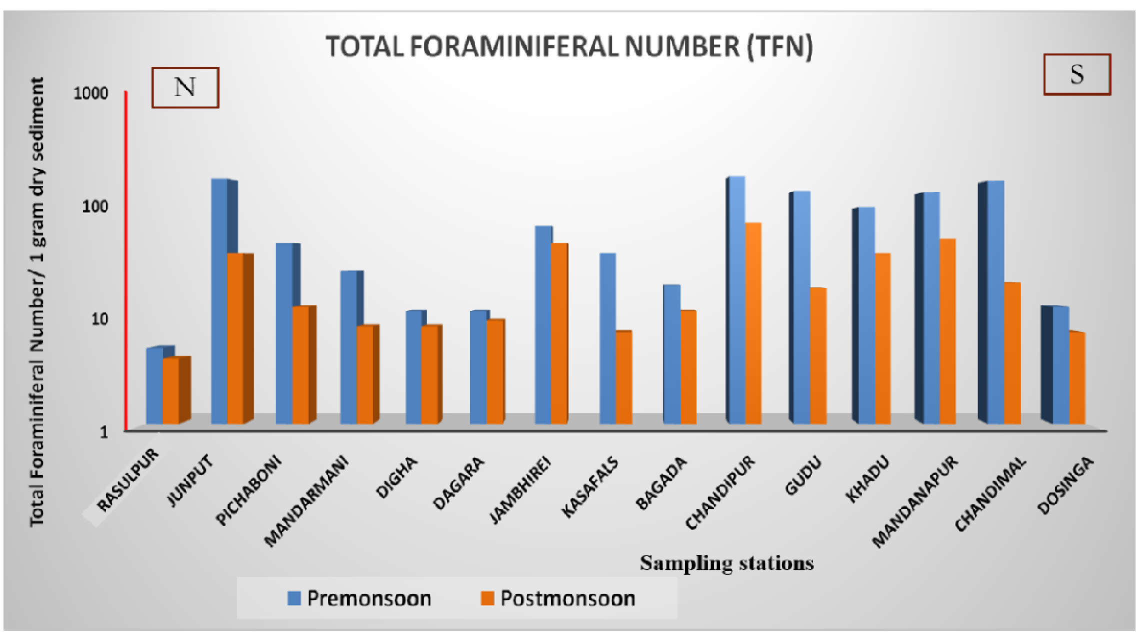


Figure-3.1: Total Foraminiferal Number (TFN) across the sampling stations of the east coast abundance of the foraminiferal species (6/gram).

The size variations of the foraminifera are shown in Figure-3.2(a-b). There is a dominance of size ranges from 63-125 μm. Hence, the foraminiferal test is of small size along the east coast.

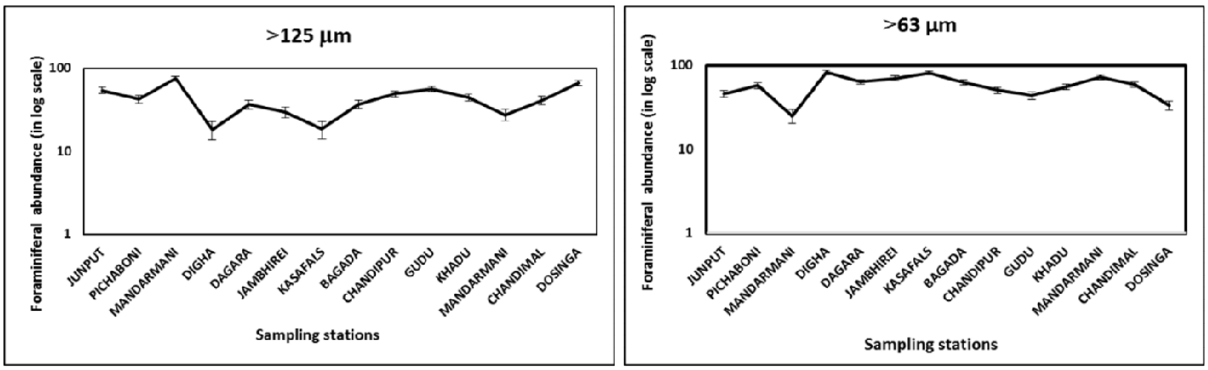


Figure-3.2: Foraminiferal test diameter along the sampling stations (in log scale). **(a)** >125 μm. **(b)** >63 μm

Murray's Ternary diagram (Figure-3.3) shows the dominance of the calcareous hyaline test in both the seasons. The agglutinated species were found in Chandipur, Mandanapur and Chandimal (southern stations) only. The porcelaneous forms in pre-monsoon are higher in number as of post-monsoon month.

The Fisher's α diversity index shows that moderately high diverse assemblages were recorded in pre-monsoon (α=1-3) than post-monsoon (α=1) (Figure-3.4). This indicates that pre-monsoon are favourable months for the growth of the foraminiferal population. The cross plot of Fisher's α diversity and information function shows that the foraminiferal assemblages are of marginal to normal marine environment. The correlation coefficient is 0.677 (Figure-3.5)

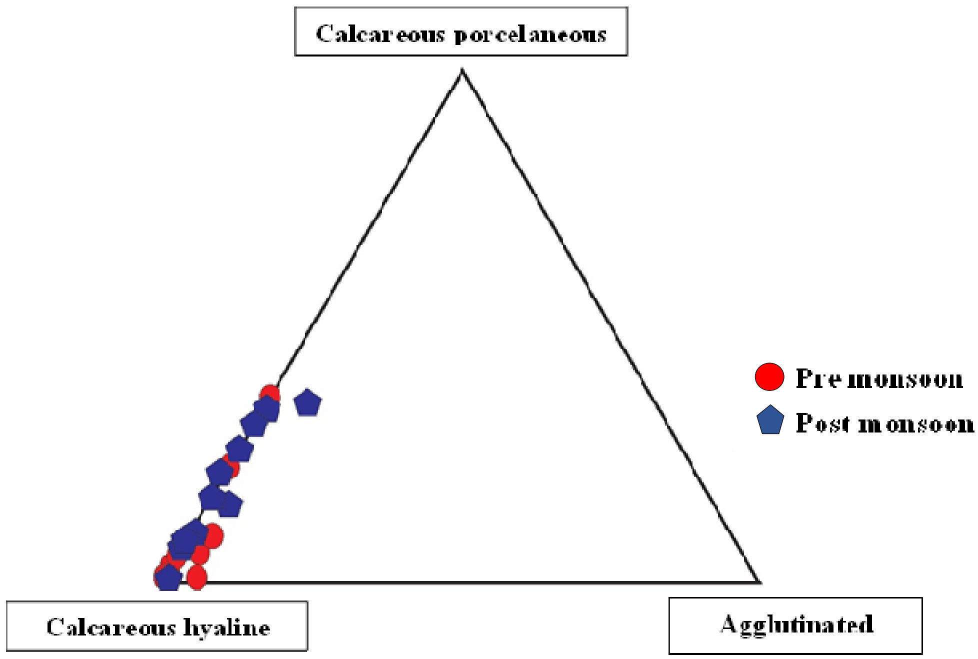


Figure-3.3: Murray's Ternary plot of the east coast foraminiferal samples

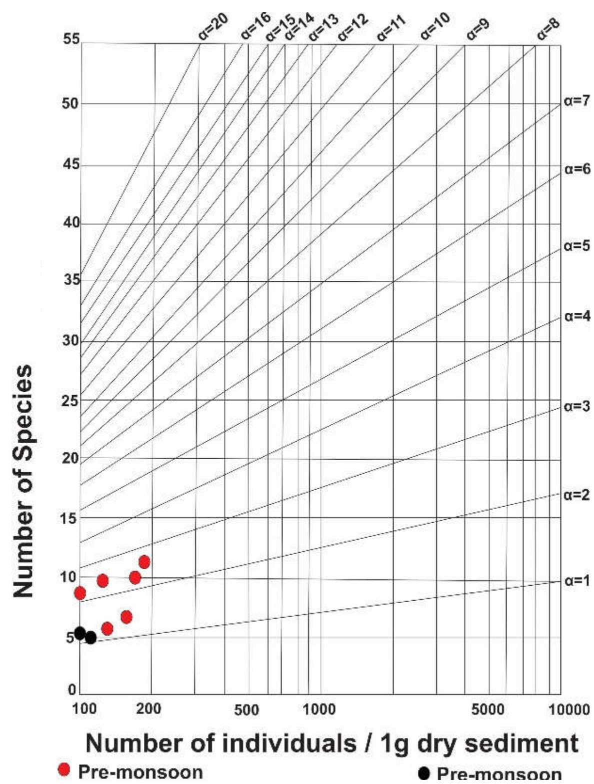


Figure-3.4: Fisher's α diversity index plot for the east coast foraminiferal samples

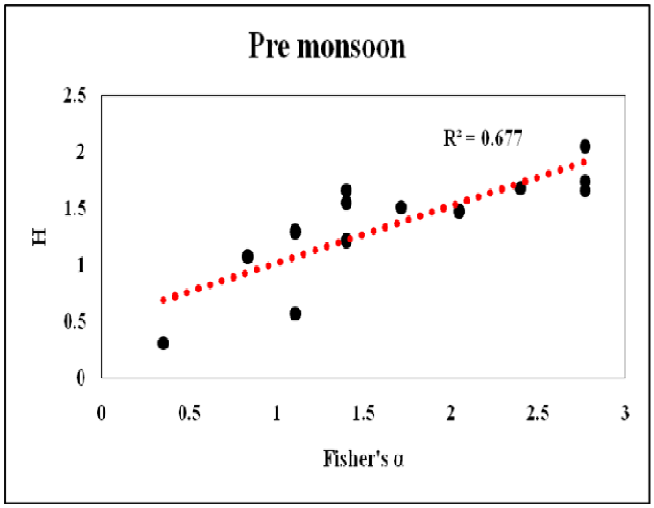


Figure-3.5: Cross plot of Fisher's α and H-index for benthic foraminiferal assemblage

Due to some limitations, salinity and temperature data were not recorded during the sampling process. However, an attempt was made to correlate these with data downloaded from the National Institute of Oceanography- Data Center (NIODC). The data set of salinity and temperature shows a drop in salinity and temperature in post-monsoon months. Overall, the salinity (Figure-3.6) plot along the East coast over the year shows little variation of salinity values along the stations ($22\‰_0$-$30\‰_0$). The temperature plot (Figure-3.7) shows the highest value during the peak summer and the low during the winter (24.8^0C- 27.5^0C).

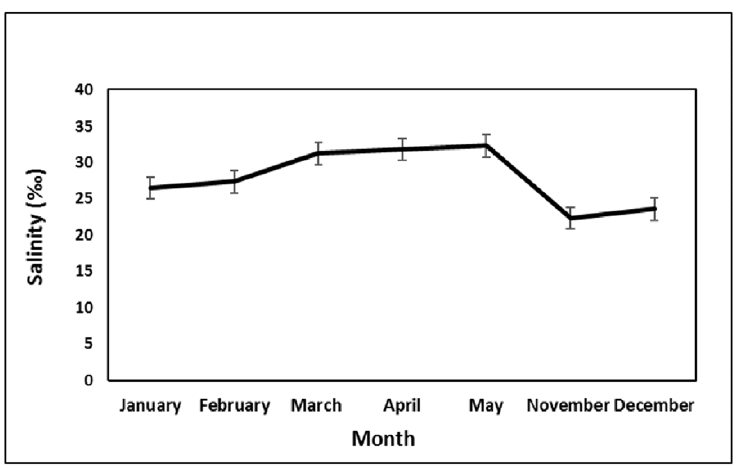


Figure-3.6: Salinity variation along the east coast (source: NIODC)

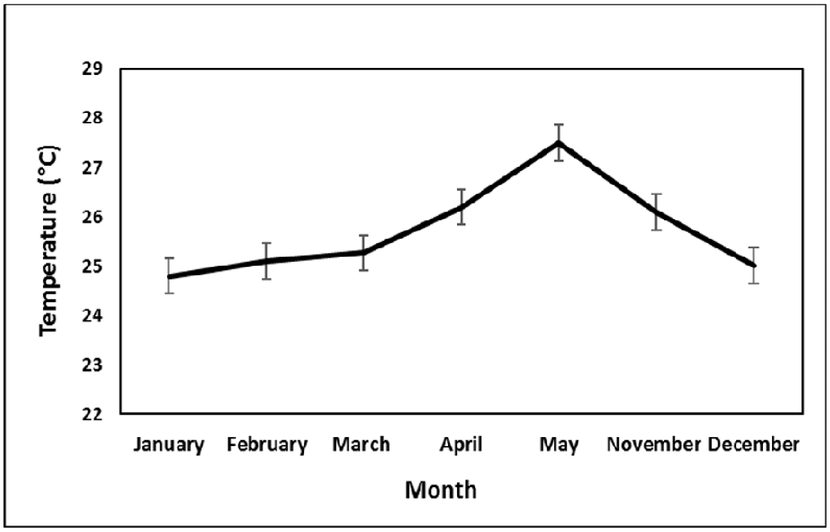


Figure-3.7: Temperature variation along the east coast (source: NIODC)

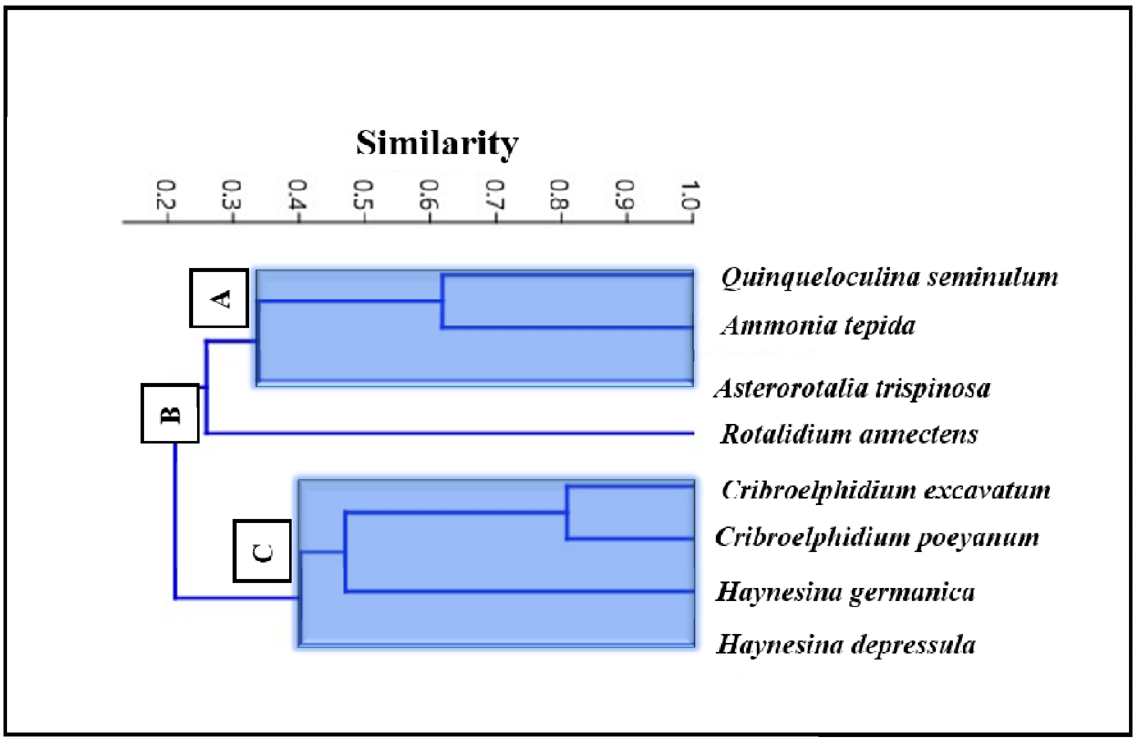


Figure-3.8: Paired group (UPGMA) and Morisita R-mode cluster analysis showing the similarities between the foraminiferal assemblages

To assess the similar characteristics of the foraminiferal assemblages, Paired group (UPGMA) and Morisita cluster analysis was performed. Here, the species were selected, only those have 4% or greater abundance of the total specimen of the single sampling location. Three different clustered groups were observed (Figure-3.8). Group A is dominated by the species those are the characteristics of clay-silt rich sediment, Group B consists of only one species which is the characteristics of sandy substratum and present in all the sampling stations of the east coast and the foraminiferal assemblage dominant in clay-sand rich sediments are clustered in Group C.

Group A – *Quinqueloculina seminulum, Ammonia tepida* and *Asterorotalia trispinosa*

Group B – *Rotalidium annectens*

Group C – *Cribroelphidium excavatum, Cribroelphidium poeyanum, Haynesina germanica* and *Haynesina depressula*

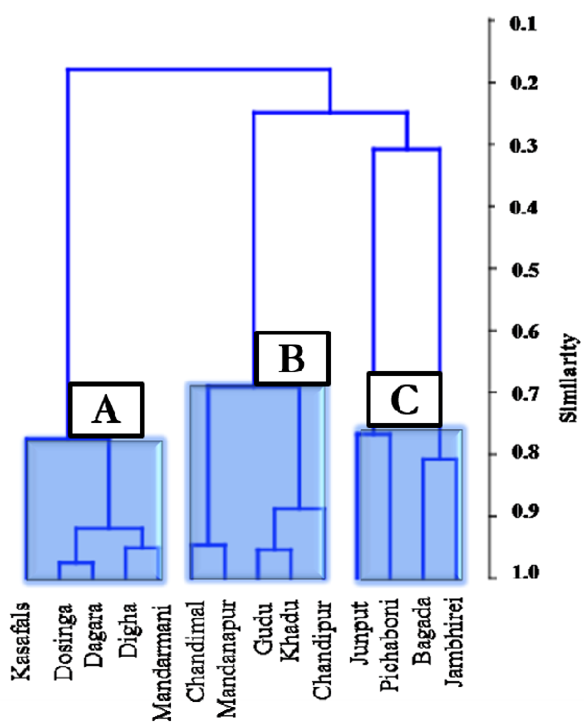


Figure-3.9: Dendrogram of the results of the Paired group (UPGMA) and Jaccard Q-mode cluster analysis

To understand the spatial variation of the foraminiferal assemblages, paired group (UPGMA) and Jaccard Q-mode cluster analysis (Figure-3.9) was performed. Three distinct clusters, Cluster A and B and C were observed. Cluster-A includes five sampling stations (Kasafal, Dosinga, Dagara, Digha and Mandarmani), Cluster-B also consists of five sampling stations (Chandimal, Mandanapur, Gudu, Khadu and Chandipur) and Cluster-C consists of four stations (Junput, Pichaboni, Bagada and Jambhirei). Here, stations with low foraminiferal abundance and diversity are clustered in Group A. Their common species are *Ammonia tepida* and *Rotalidium annectens*. Cluster- B consists of the sampling stations where diversity is relatively high than in other stations and abundance of *Haynesina germanica* is high. Cluster-C consists of the sampling stations where foraminiferal abundance and diversity are moderate with a distinct abundance of *Asterorotalia trispinosa*.

The distribution pattern of the few dominant foraminiferal species along the sampling stations has been shown below-

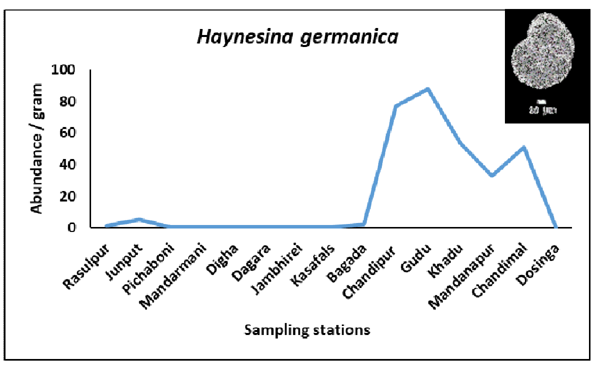


Figure-3.10: Distribution pattern of *Haynesina germanica* along the east coast

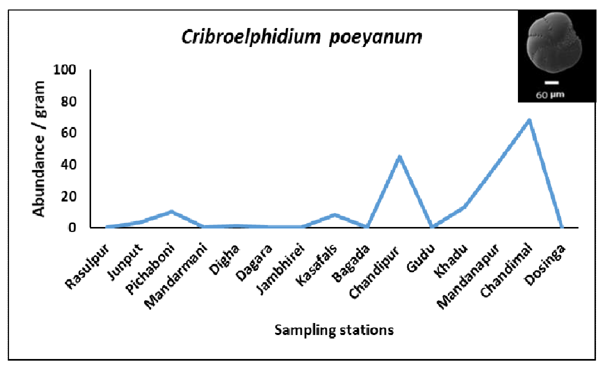


Figure-3.11: Distribution pattern of *Cribroelphidium poeyanum* along the east coast

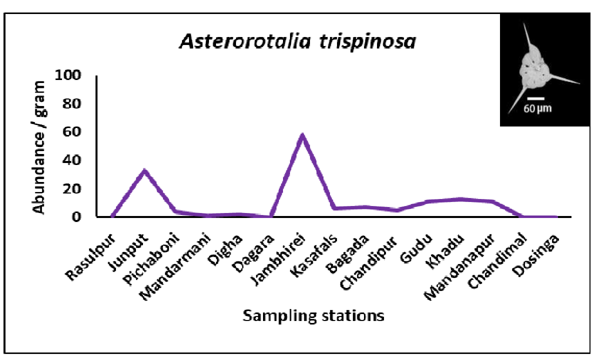


Figure-3.12: Distribution pattern of *Asterorotalia trispinosa* along the east coast

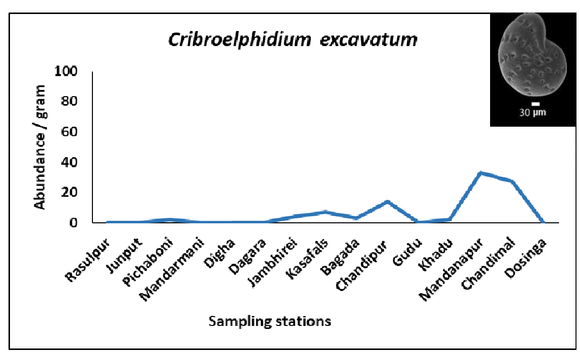


Figure-3.13: Distribution pattern of *Cribroelphidium excavatum* along the east coast

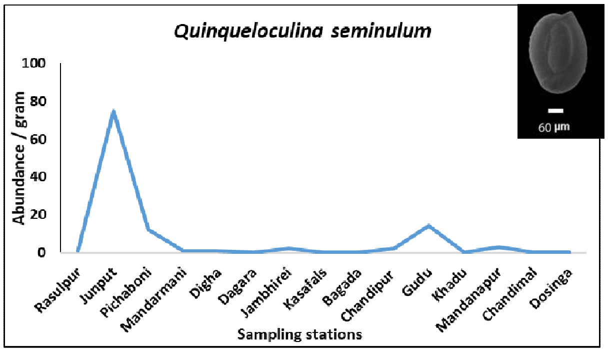


Figure-3.14: Distribution pattern of *Quinqueloculina seminulum* along the east coast

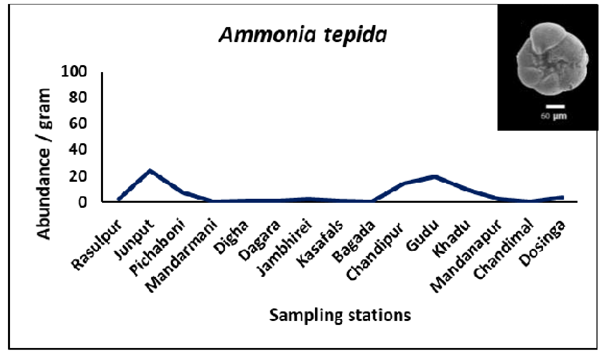


Figure-3.15: Distribution pattern of *Ammonia tepida* along the east coast

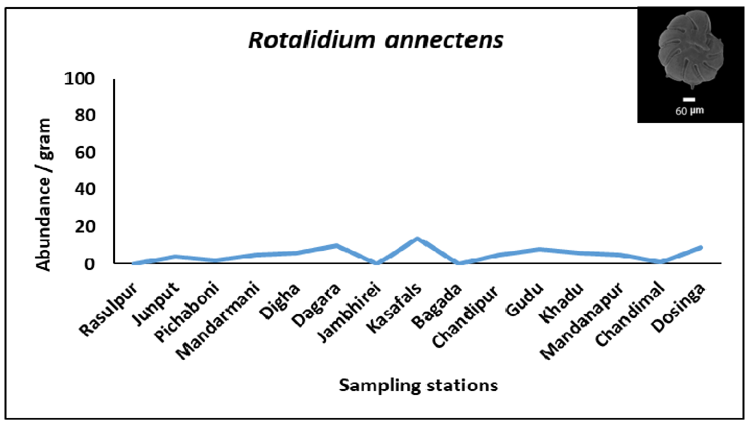


Figure-3.16: Distribution pattern of *Rotalidium annectens* along the east coast

Based on the species plot graph (Figure-3.12-3.16), it is evident that forms such as *Haynesina germanica*, *Cribroelphidium poeyanum* and *Cribroelphidium excavatum* show a habitat preference of southern stations, whereas *Quinqueloculina seminulum* and *Asterorotalia trispinosa* ae found in northern stations. *Ammonia tepida* and *Rotalidium annectens* have a moderate distribution in all the locations of the east coast. The species preference may be correlated with substrate type. The southern stations are a more clay dominated region as compared to the northern part.

3.4.2 Vertical distribution of foraminiferal assemblages

A total of 7 species have been identified from the 15 cm long core collected from the Chandipur marsh area. *Ammonia tepida* is the most dominant species followed by *Asterorotalia trispinosa, Cribroelphidium excavatum, Cribroelphidium poeyanum, Haynesina germanica, Quinqueloculina seminulum* and *Trochammina inflata.*

The vertical distribution of the Total Foraminiferal Number (TFN) is plotted for the Chandipur core sample (Figure-3.17). The Foraminiferal population varies from 23 to 67 specimens per gram of dry sediment. The abundance of the foraminifera is high at the top (0-1cm) and 9cm and shows declining trend in the rest part of the core.

This vertical distribution pattern is similar to the D-type profile described by Sengupta, 2003. This type of profile shows a combination of a surface maximum with one or several maxima deeper in the sediment where the species apparently find suitable environments at the sediment surface as well as deeper part of the sediment. Based on Murray's ternary diagram, a dominance of calcareous hyaline and agglutinated forms were observed in the core (Figure-3.18). Agglutinated forms are mostly abundant in 0-2cm and 9cm depth in the core.

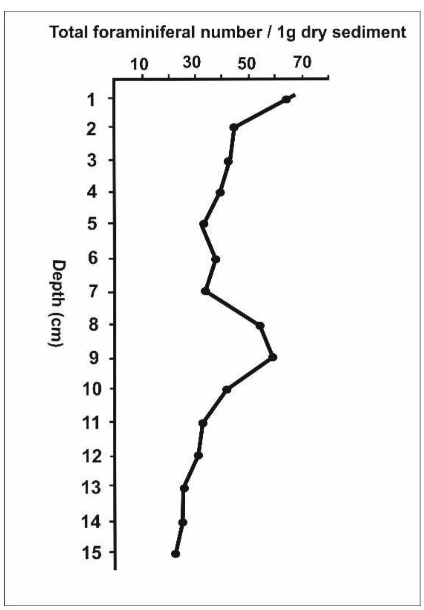


Figure-3.17: Downcore variation of Total Foraminiferal Number (TFN) in Chandipur region

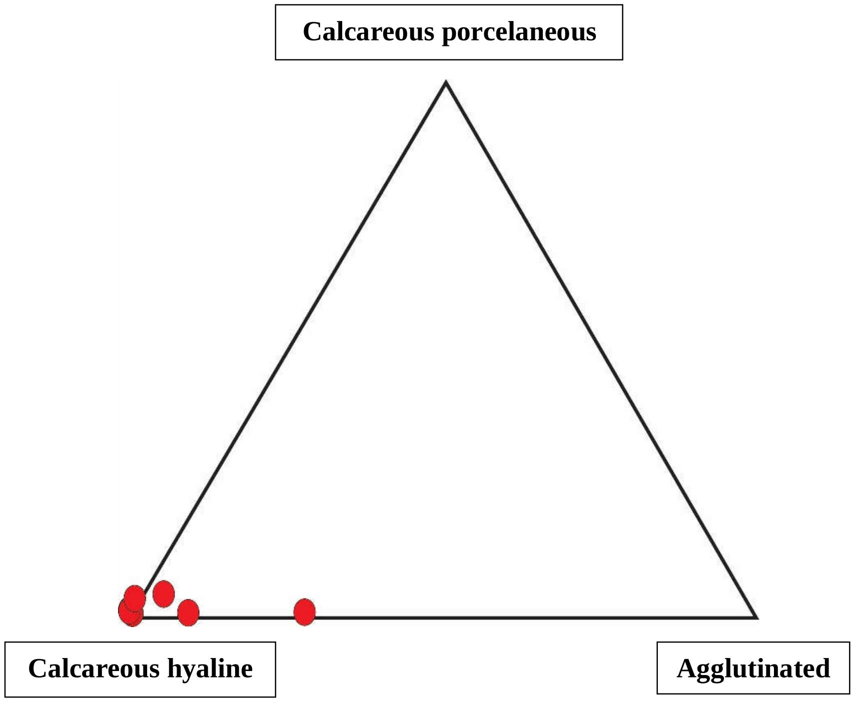


Figure-3.18: Murray's Ternary plot showing the wall type of foraminifera in the core sample

3.4.3 Biofacies zone

We have studied the distribution pattern of individual taxa constituting the biofacies zone along the east coast. Two biofacies zones were identified (Figure-3.19).

Biofacies zone 1 includes *Ammonia tepida, Asterortalia trispinosa* and *Quinqueloculina seminulum.* Biofacies zone 2 consists of *Ammonia tepida, Asterortalia trispinosa, Haynesina germanica* and *Cribroelphidium* spp..

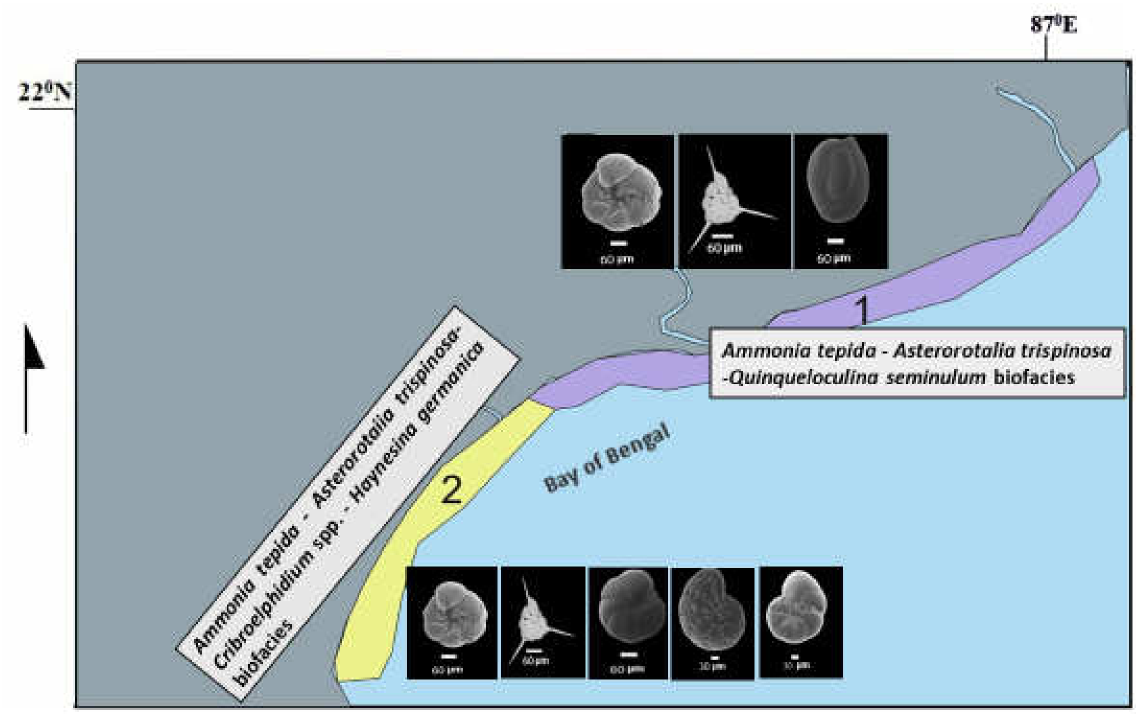


Figure-3.19: Biofacies zones of foraminiferalmassemblages along the east coast

Chapter-4

Foraminiferal Assemblages of the West Coast

4.1 Historical resume

A detailed account of research work done by the earlier researchers on foraminiferal studies on beaches/estuaries and mud flat regions along the west coast of India have been tabulated in Table-4.1.

S.No.	YEAR	AUTHOR	AREA	REMARKS
1	1954	Chaudhury & Biswas	Juhu Bombay	12 species of perforate foraminifera.
2	1956	Bhatia	Juhu, Bhogat & Chaupatty	Reported 46 species.
3	1960	Sastry & Pant	Saurashtra	Investigated *Operculina* rich sand from the sub recent deposits.
4	1960	Sastry & Pant	Saurashtra	Foraminifera from miliolitic limestone.
5	1964	Rocha & Ubaldo	Diu, Gogola & Simbor	52 species were reported out of which 22 were already known from this area. The absence of agglutinated forms suggests low input of terrigenous sediment.
6	1964	Rocha & Ubaldo	Jampor and Baga (Goa)	24 species reported.
7	1972	Setty & Wagle	Goa coast	A brief list of foraminifera with other microfauna is given from beach rock.
8	1978	Jain & Bhatia	Mandvi, Kutch	37 species including one new species *Pararotalia boltovskoy*.
9	1979	Bhalla & Nigam	Calangute, Goa	36 species identified. Fauna was compared with eastern beaches.
10	1980	Bhalla & Nigam	Calangute, Goa	Planktic foraminifera and their paleoclimatic significance.
11	1980	Bhalla & Raghav	Malabar coast	Reported 25 species and suggested that salinity is the chief governing factor.

12	1982	Desai & Pandya	Saurashtra, Gujarat	Foraminifera of the coastline sediments.
13	1982	Desai & Shringarpure	Saurashtra, Gujarat	Used Recent foraminifera to study the impact of sedimentation on onshore environment.
14	1984	Badve *et al.*	Raigad district, Maharashtra	A small portion foraminiferal content of beach rocks.
15	1984	Setty *et al.*	Miramar, Caranzalem, Goa	44 benthic and one planktic species of foraminifera from the intertidal area.
16	1984	Srivastava *et al.*	Veraval, Saurashtra	26 species of benthic and one species of planktic foraminifera.
17	1985	Bhalla & Lal	Okha, Gujarat	18 species of recent foraminifera, compared with the fauna of other beaches of west coast.
18	1985	Pandya	Gujarat	Segment wise distribution is given which is controlled by various off shore and littoral processes.
19	1985	Pandya	Saurashtra	95 species including 3 planktic, ecological control on the foraminiferal diversity.
20	1986	Bhalla & Nigam	Velsao Beach, Goa	Abnormal *Ammonia* as indicator of pollution
21	1987	Bhalla & Gaur	Colva, Goa	Detailed systematic study of 29 species.
22	1988	Bhalla & Nigam	West and east coast of India	Cluster analysis of published foraminiferal data from six beaches to study foramgeographical provinces.
23	1988	Nigam	Lothal	Utilized foraminifera to prove large rectangular structure at Lothal (a Harappan settlement) as a dockyard.
24	1988	Shareef & Venkatachalapathy	Bhatkal & Devagad island	40 species from Bhatkal and 41 species from Devagad island, a checklist is provided.
25	1994	Talib & Farooqui	Dwarka Beach, Gujarat	Reported 26 species of benthic foraminifera.
26	1996	Nigam *et al.*	Dias Beach, Goa	Studied the effect of different media, food, and antibiotic

				drug on *Rosalina leei* in the laboratory culture experiments.
27	1996	Nigam *et al.*	Dias Beach, Goa	Laboratory culture experiments on *Rosalina leei*
28	1997	Raj & Chamya	Mahi Valley, Gujarat	Based on foraminiferal studies concluded that sediments of Mahi Formation was deposited in an estuarine to marginal marine environment.
29	1998	Raj & Chamyal	Mahi Valley, Gujarat	Identified 25 genera of foraminifera from the mud unit of Midto Late Holocene age.
30	2000	Kathal *et al.*	West and east coast of India	Q-Mode cluster analysis of 160 foraminiferal species to separate two different foramgeographical realms for west andeast coasts.
31	2002	Nigam *et al.*	Mandovi Estuary, Goa	Effect of Mining pollution on TFN from 10 surface samples
32	2003	Saraswat *et al.*	Dias Beach, Goa	Applied molecular genetic analysis to differentiate three species of Pararotalia
33	2004	Saraswat *et al.*	Dias Beach, Goa	Effect of varying concentration of mercury on *Rosalina leei*
34	2005	Panchang *et al.*	Zuari Estuary, Goa	Comparison of time series foraminiferal data, to infer mining impact
35	2005	Nigam	West coast of India	Review of foraminiferal studies
36	2005	Nigam *et al.*	Mandovi Estuary, Goa	Comparison of time series foraminiferal data, to infer mining impact
37	2006	Nigam *et al.*	Dias Beach, Goa	Effect of changing salinity on *Pararotalia nipponica* under laboratory culture
38	2007	Talib & Farooqui	Dwarka Beach	Identified 26 foraminiferal species
39	2008	Ghosh *et al.*	Gulf of Cambay	Examined the extent of sea-level change in estuarine settings using foraminifera as an analogue
40	2012	Ghosh	Gulf of Cambay	Discussed the systematics and distribution of the Foraminiferal species in the macrotidal estuaries of the Gulf of Cambay

41	2021	Patel & Desai	Mandvi coast, Gujarat	Post-mortem transportation of foraminiferal assemblages, identified 21 foraminiferal species
42	2020	Ravichandran *et al.*	Anthakara Nazhi Beach, Kerala	Identified 21 benthic foraminiferal species and correlated them with palaeo productivity
43	2021	Buragohain & Ghosh	Saurashtra coast	Identified 35 benthic foraminiferal species correlated with abiotic factors like salinity and temperature
44	2021	Dutta *et al.*	Harshad, Saurashtra coast	Vertical Distribution of benthic foraminiferal assemblages

Table-4.1: Major research work carried out on beaches/estuaries/Marsh and mud flats regions along Western Indian coast (Modified after Bhalla *et al.*, 2007)

4.2 Foraminiferal assemblages

Surface sediments were collected from the fifteen stations of this coast in both pre and post-monsoon. In this present study, a total of 35 species of foraminifera belonging to 17 genera, 12 families and 2 suborders were identified from the study area of the west coast. The most dominant calcareous forms are *Rotalidium annectens*, *Elphidium crispum* and *Pararotalia nipponica*, *Eponides repandus*, *Quinqueloculina seminulum*, *Cibicides refulgens*, *Nonion* cf. *commune* and *Ammonia tepida.* Characteristically, two shallow larger benthic foraminifera *Nummulites venosus* and *Amphistegina radiata* were observed.

4.3 Systematics

The species identified from the west coast have been described as follows-

Order **Foraminiferida Eichward, 1830**

Suborder **Miliolina Delage and Hirouard, 1896**

Superfamily **Miliolacea Ehrenberg, 1839**

Family **Miliolidae Ehrenberg, 1839**

Subfamily **Hauerinidae Schwager, 1876**

Genus ***Quinqueloculina* d'Orbigny, 1826**

***Quinqueloculina seminulum* Linnaeus**
(Pl. 3, Fig. 1)

Quinqueloculina seminulum (Linnaeus)- Talib and Farooqui, 2007, pl. 1, figs. 9a-b

Remarks: Its abundance is high in Porbandar and presents in all other stations except Kuranga, Adri and Somnath.

***Quinqueloculina sulcata* d'Orbigny**
(Pl. 3, Fig. 2)

Quinqueloculina sulcata d'Orbigny- Kathal, 2002, p. 121, figs. 9a-b

Remarks: It is present in Porbandar, Madhavpur and Rangbai. It is different from *Quinqueloculina seminulum* being larger in size and having a more flattened chamber and long neck.

***Quinqueloculina pseudoreticulata* Parr**
(Pl. 3, Fig. 3)

Quinqueloculina pseudoreticulata Parr- Talib and farooqui, 2007, pl. 1, figs. 8a-b

Remarks: It is mainly present in Dawrka, Okhamadhi, Porbandar, Rangbai, Madhavpur, Chorward and Veraval.

Quinqueloculina cf. _pseudoreticulata_ Parr
(Pl. 3, Fig. 4)

Remarks**:** The difference between *Quinqueloculina pseudoreticulata* and *Quinqueloculina* cf. *pseudoreticulata* is that the later one is a little bit longer and has a long neck than the former and reticulations are more prominent and less pitted. It is present in Dwarka, Okhamadhi and Adri.

Quinqueloculina laevigata d'Orbigny
(Pl. 3, Fig. 5)

Quinqueloculina laevigata d'Orbigny- Cushman, 1918, pl. 4, fig. 3a-c

Remarks: Difference between *Quinqueloculina laevigata* and *Quinqueloculina sulcata* is that the base of the last chamber of the former are wider and latter has carination. It is present in Porbandar, Gosa and Somnath.

Quinqueloculina cf. _echinata_ d'Orbigny
(Pl. 3, Fig. 6)

Quiqueloculina echinata (d'Orbigny)- Gandhi et. al, 2013, pl. 2, fig. 5

Remarks: Our specimens are different from *Quinqueloculina echinata*, having less prominent conical spines and short neck. This species is present in Porbandar and Gosa.

Quinqueloculina polygona d'Orbigny
(Pl. 3, Fig. 7)

Quinqueloculina polygona d'Orbigny- Debenay, p. 125

Remarks: It is present only in Porbandar.

Quinqueloculina costata **d'Orbigny**
(Pl. 3, Fig. 8)

*Quinqueloculina costata (*d'Orbigny) Cushman, 1918, pl. 3, fig. 7a-b

Remarks: It is present in Dwarka, Okhamadhi and Porbandar.

Subfamily Miliolinellinae Vella, 1957

Genus Triloculina d'Orbigny, 1826

Triloculina trigonula **Lamark**
(Pl. 3, Fig. 9)

Triloculina trigonula (Lamark), Kathal, 2002, p. 127. figs. 4. 10a-b

Triloculina trigonula Lamark- Talib and Farooqui, 2007, pl. 1, figs. 16a-b

Remarks: It is the dominant species of triloculine form in our specimens and present in all the sampling locations except Kuranga, Somnath and Sutrapada.

Triloculina tricarinata **d'Orbigny**
(Pl. 3, Figs. 10, 11)

Triloculina tricarinata d'Orbigny- Kathal, 2002, p. 127. figs. 4. 8a-b

Remarks: It is present in Dwarka, Okhamadhi, Porbandar, Gosa, Navibandar, Madhavpur, Mangrol and Somnath.

Triloculina terquemiana **Brady**
(Pl. 3, Fig. 12)

Triloculina terquemiana Brady- Talib and Farooqui, pl. 1, figs. 15a-b

Remarks: It is present in Dwarka, Okhamadhi and Somnath.

***Triloculina insignis* Brady**
(Pl. 3, Fig. 13)

Triloculina insignis (Brady) Cushman, 1917, p. 72, pl. 27, fig. 3a

Remarks: It is present in Porbandar, Navibandar, Mangrol and Chorward.

***Triloculina rotunda* d'Orbigny**
(Pl. 3, Fig. 14)

Triloculina rotunda d'Orbigny- Devi and Rajashekhar, 2009, p. 26, image 4, fig. j

Remarks: It is present in Navibandar and Somnath.

Family Spiroloculinidae Wiesner, 1920

Genus *Spiroloculina* d'Orbigny, 1826

***Spiroloculina depressa* d'Orbgny**
(Pl. 3, Fig. 15)

Spiroloculina depressa D'Orbigny- Akimoto et al., 2002, p. 46, pl. 10, fig. 3a

Remarks: It is present in Porandar and Chorward.

***Spiroloculina indica* Cushman and Todd**
(Pl. 3, Fig. 16)

Spiroloculina indica Cushman and Todd- Kathal, 2002, p. 121, figs. 3, 4a-b.

Remarks: This species occurs in Dwarka, Porbandar, Chorward and Somnath.

Suborder Rotaliina Delage and Hirouard, 1896

Superfamily Rotaliacea Ehrenberg, 1839

Family Rotaliidae Ehrenberg, 1839

Subfamily Ammoninidae Schwager, 1876

Genus ***Rotalidium*** **Asano, 1936**

Rotalidium annectens **Parker and Jones**
(Pl. 4, figs. 1, 2)

Rotalidium annectens (Parker and Jones)- Talib and Farooqui, 2007, pl. 1, figs. 23a-b

Remarks: This is the most abundant and widely distributed among the all species we have identified and present in all the sampling stations.

Subfamily **Pararotaliinae Reiss, 1963**

Genus ***Pararotalia*** **Y. Le Calvez, 1949**

Pararotalia nipponica **Asano**
(Pl. 4, figs. 3, 4)

Pararotalia nipponica Asano- Kathal, 2002, pl. 7, figs. 2a-c

Remarks: It is present in all the sampling stations except Kuranga, Rongbai and Adri.

Family **Elphidiidae Galloway, 1933**

Subfamily **Elphidiinae Galloway, 1933**

Genus ***Elphidium*** **de Montfort, 1808**

Elphidium crispum **Linnaeus**
(Pl. 4, fig. 5)

Elphidium crispum (Linnaeus)- Talib and Farooqui, 2007, pl. 1, figs. 25a-b

Remarks: This species occurs in good abundance in all the sampling stations except Kuranga and Sutrapada.

Elphidium advenum Cushman
(Pl. 4, fig. 6)

Elphidium advenum Cushman- Devi and Rajashekhar, 2009, image 12. C

Remarks: *E. advenum* differs from *E. crispum* having less number of chambers and being little lobulated than the former. This species occurs in Porbandar, Gosa, Navbandar, Madhavpur and Mangrol.

Elphidium craticulatum Fitchel and Moll
(Pl. 4, fig. 7)

Elphidium craticulatum Fitchel and Moll- Talib and Farooqui, 2007, pl. 1, figs. 24a-b

Remarks: *E. craticulatum* differs from *E. crispum*, being more circular and having straight sutures. This species occurs in Dwarka, Porbandar, Rangbai, Navibandar, Mangrol,Chorward and Adri.

Superfamily Discorbacea Ehrenberg, 1838

Family Eponididae Hofker, 1951

Subfamily Eponidinae Hofker, 1951

Genus _Eponides_ Montfort, 1808

Eponides repandus Fichtel and Moll
(Pl. 4, figs. 8, 9)

Eponides repandus - Hottinger, 1991, pl. 1, fig. 1-8

Remarks: This species is found in all the locations except Kuranga and Sutrapada.

Superfamily Nonionacea Schultze, 1854

Family Nonionidae Schultze, 1854

Subfamily Nonioninae Schultze, 1854

Genus _Nonion_ de Montfort, 1808

***Nonion* cf. *commune* d'Orbigny**
(Pl. 4, fig. 10)

Nonion commune d'Orbigny- Singh and Kathal, 2011, (Pl. II, figs. 12a-b & Tab. 3, figs. 8a-b

Remarks: Our specimens are little bit wider than *Nonion commune* and found in Okhamadhi, Porbandar, Mangrol and Chorward.

***Nonion* sp.**
(Pl. 4, fig. 11)

Remarks: Chambers are more inflated as compared to *Nonion* cf. *commune*. It is found only in Navibandar.

***Nonionella stella* Cushman and Moyer**
(Pl. 4, fig. 12)

Nonionella stella (Cushman and Moyer)- Polovodova and Schoenfeld, 2015, v. 35, no. 2, pl. 1, fig. 9

Remarks: Rare occurrence of this species is found in Porbandar and Chorward.

Genus *Haynesina* Banner and Culver, 1978

***Haynesina depressula* Walker & Jacob**
(Pl. 4, fig. 13)

Remarks: This species is found only in Gosa.

Superfamily Nummulitacea de Blainville, 1827

Family Nummulitidae de Blainville, 1827

Genus *Nummulites* Lamarck, 1801

Nummulites venosus Fichtel and Moll
(Pl. 4, fig. 14)

Nummulites venosus (Fichtel and Moll)- Ghosh, 2008, pl. III, fig. 1

Remarks: This is a shallow benthic larger foraminifera and only the living species of Nummulitidae family in recent time. It is moderately abundant in Dwarka and Harshad and rarely present in Okhamadhi, Porbandar, Rangbai, Gosa and Madhavpur.

Superfamily Planorbulinacea Schwager, 1877

Family Cibicididae Cushman, 1927

Subfamily Cibicidinae Cushman, 1927

Genus _Cibicides_ de Montfort, 1808

Cibicides refulgens de Montfort
(Pl. 4, figs. 15, 16)

Cibicides refulgens de Montfort- Debenay, 2012, p. 191

Remarks: It is abundantly found in Okhamadhi, Porbandar and Gosa and moderately present in Harshad, Navibandar, Madhavpur, Mangrol, Chorward and Somnath.

Cibicides sp.
(Pl. 1, figs. 1, 2)

Remarks: It is found in Porbandar, Gosa, Navibandar, Mangrol, Adri and Somnath.

Subfamily Rotaliinae Ehrenberg, 1839

Genus _Ammonia_ Brunnich, 1972

Ammonia tepida Cushman
(Pl. 5, fig. 3)

Ammonia tepida Cushman- Debenay, 2012, p. 185

Ammonia tepida Cushman- Ghosh, 2008, pl. IV, fig. 10

Remarks: It is abundantly present in Porbandar and rare to moderately occurs in Okha, Navibandar, Mangrol, Chorward and Somnath.

***Ammonia beccarii* Linneus**
(Pl. 5, fig. 3)

Ammonia beccarii (Linnè)- Ghosh, 2008, pl. II, figs. 14-15, pl. IV, figs. 13-14

Remarks: Rare occurrence of this species is found in Porbandar.

Superfamily Asterigerinacea d'Orbigny, 1839

Family Amphisteginidae Cushman, 1927

Genus *Amphistegina* d'Orbigny, 1826

***Amphistegina radiata* (Fichtel and Moll)**
(Pl. 5, fig. 4)

Amphistegina radiata (Fichtel and Moll)- Debenay, 2012, p. 216

Remarks: This is another shallow benthic larger foraminifera and occurs moderately in Dwarka and shows the rare occurrence in Okhamadhi, Harshad, Gosa, Navi, Madhavpur, Mangrol and Somnath.

Superfamily Asterigerinacea d'Orbigny, 1839

Family Bagginidae Cushman, 1927

Genus *Cancris* de Montfort, 1808

***Cancris oblongus* Williamson**
(Pl. 5, fig. 5)

Cancris oblongus Williamson- Ghosh, 2008, pl. 1, fig. 14

Remarks: Rare occurrence of this species is found in Porbandar and Gosa only.

***Cancris* sp.**
(Pl. 5, fig. 6)

Remarks: The specimens differ from *Cancris oblongus*, having carinated periphery in the whole test more prominently and less broad. It is found only in Porbandar with a very rare occurrence.

Superfamily Glabratellacea Loeblich and Tappan, 1964

Family Glabratellidae Loeblich and Tappan, 1964

Genus *Glabratella* Dorren, 1948

***Glabratella patelliformis* Brady**
(Pl. 5, figs. 7, 8)

Glabratella patelliformis Brady- Kathal, 2002, p. 139, fig. 6, 2a-c

Remarks: Very low occurrence of this species found only in Gosa.

Superfamily Bolivinacea Glaessner, 1937

Family Bolivinidae Glaessner, 1937

Genus *Brizalina* Costa, 1856

***Brizalina* sp.**

Remarks: Very low occurrence of this species found only in Porbandar.

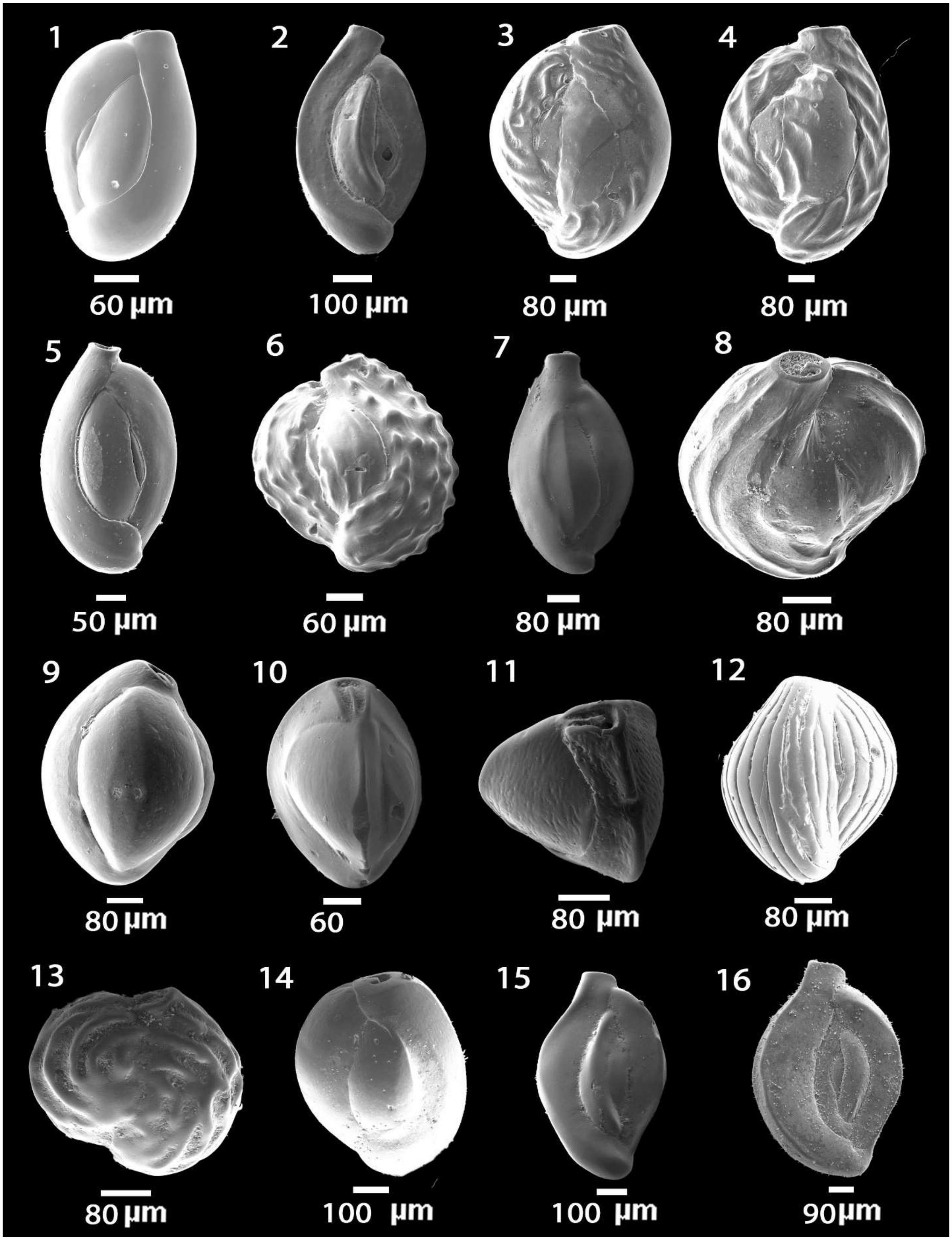


Plate 3: Scanning Electron Microphotographs of 1) *Quinqueloculina seminulum* (Si) 2) *Q Quinqueloculina sulcata* (Si) 3) *Quinqueloculina pseudoreticulata* (Si) 4) *Quinqueloculina* cf. *pseudoreticulata* (Si) 5) *Quinqueloculina laevigata* (Si) 6) *Quinqueloculina* cf. *echinata* (Si) 7) *Quinqueloculina polygona* (Si) 8) *Quinqueloculina costata* (Si) 9) *Triloculina trigonula* (Si) 10) *Triloculina tricarinata* (Si) 11) *Triloculina tricarinata* (Ap) 12) *Triloculina terquemiana* (Si) 13) *Triloculina insignis* (Si) 14) *Triloculina rotunda* (Si) 15) *Spiroloculina depressula* (Si) 16) *Spiroloculina indica* (Si).

Legends: Si- Side view, Ap- Apertural view

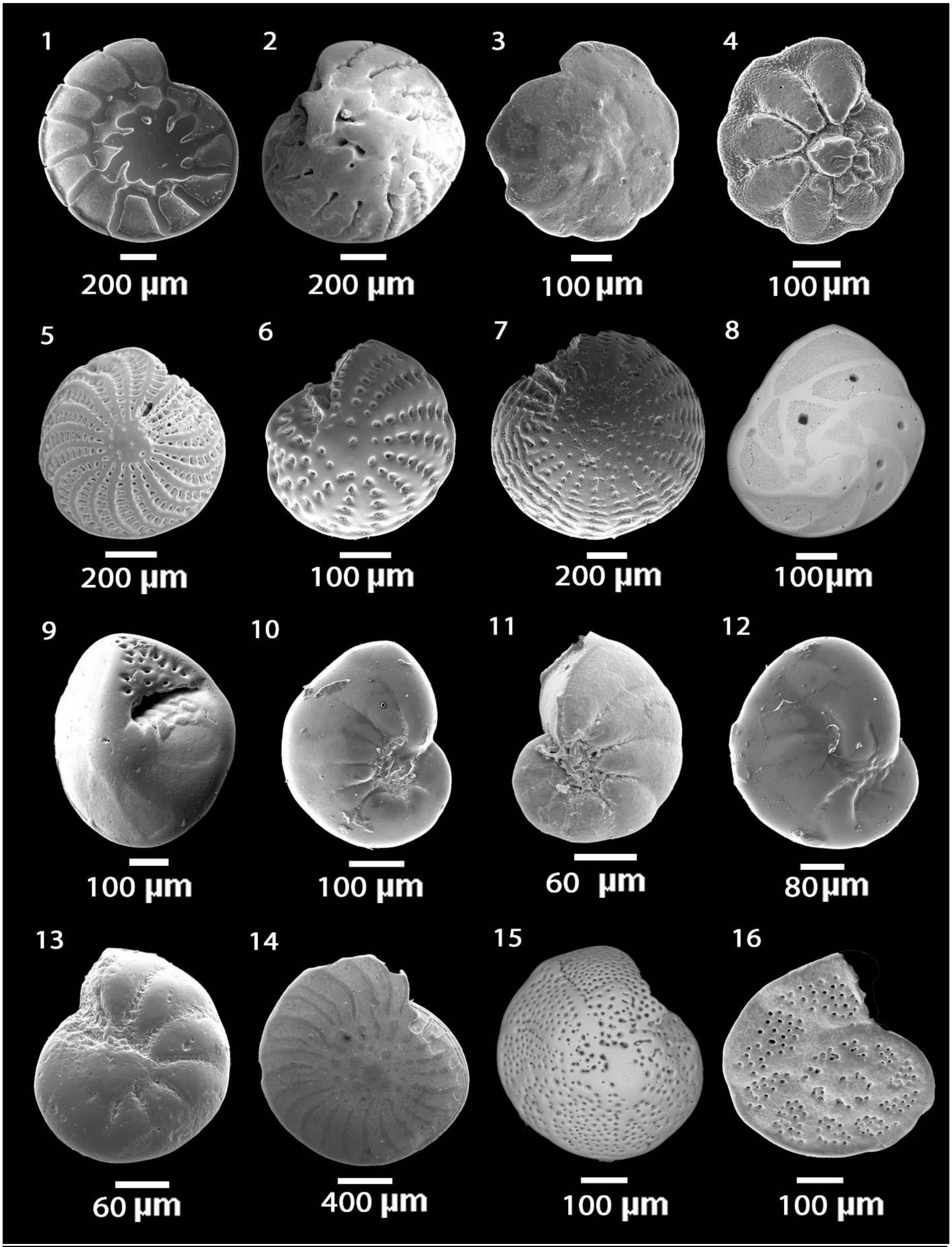


Plate 4: Scanning Electron Microphotographs of 1) *Rotalidium annectens* (S) 2) *Rotalidium. annectens* (U) 3) *Pararotalia nipponica* (S) 4) *Pararotalia nipponica* (U) 5) *Elphidium crispum* (Si) 6) *Elphidium advenum* (Si) 7) *Elphidium. craticulatum* (Si) 8) *Eponides repandus* (S) 9) *Eponides repandus* (Ap) 10) *Nonion* cf. *commune* (Si) 11) *Nonion* sp. (Si) 12) *Nonionella stella* (Si) 13) *Haynesina depressula* (Si) 14) *Nummulites venosus* (S) 15) *Cibicides refulgens* (U) 16) *Cibicides refulgens* (S).

Legends: S- Spiral side, Si- Side view, Ap- Apertural view, U- Umbilical view

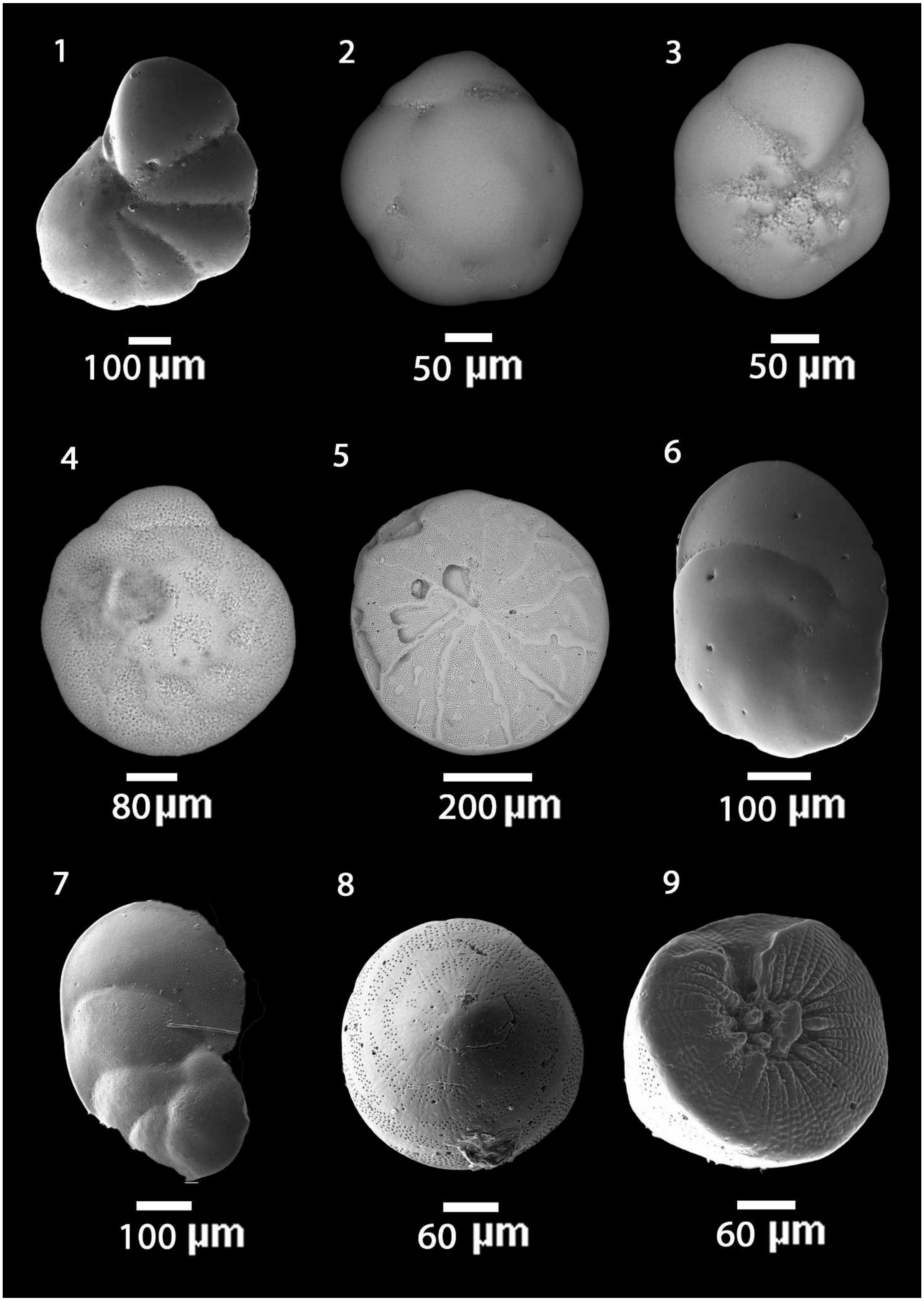


Plate 5: Scanning Electron Microphotographs of 1) *Cibicides* sp. (U) 2) *Ammonia tepida* (S) 3) *Ammonia tepida* (U) 4) *Ammonia beccarii* (S) 5) *Amphistegina radiata* (U) 6) *Cancris oblongus* (S) 7) *Cancris* sp. (S) 8) *Grabratella patelliformis* (S) 9) *Glabratella patelliformis* (U).

Legends: S- Spiral side, U- Umbilical view

4.4 Results

4.4.1 Surficial distribution of foraminiferal assemblages

The Total Foraminiferal Number (TFN) is plotted for both pre (April) and post-monsoon (October) seasons. The TFN is more during pre-monsoon (3-734/gram) than post-monsoon (5-365/gram) season (Figure-4.1). The highest abundance of foraminifera was found in Porbandar (734/gram during pre-monsoon) and the lowest was in Kuranga (3/gram during pre-monsoon). Kuranga is a tidal inlet with huge fresh water runoff. The population of the foraminifera is very low (3/gram). There is no such trend of abundance from north (N) to south (S) of the study area. The data from the Kuranga and Sutrapada were not included in other statistical analyses due to the low abundance of the foraminiferal species (<100).

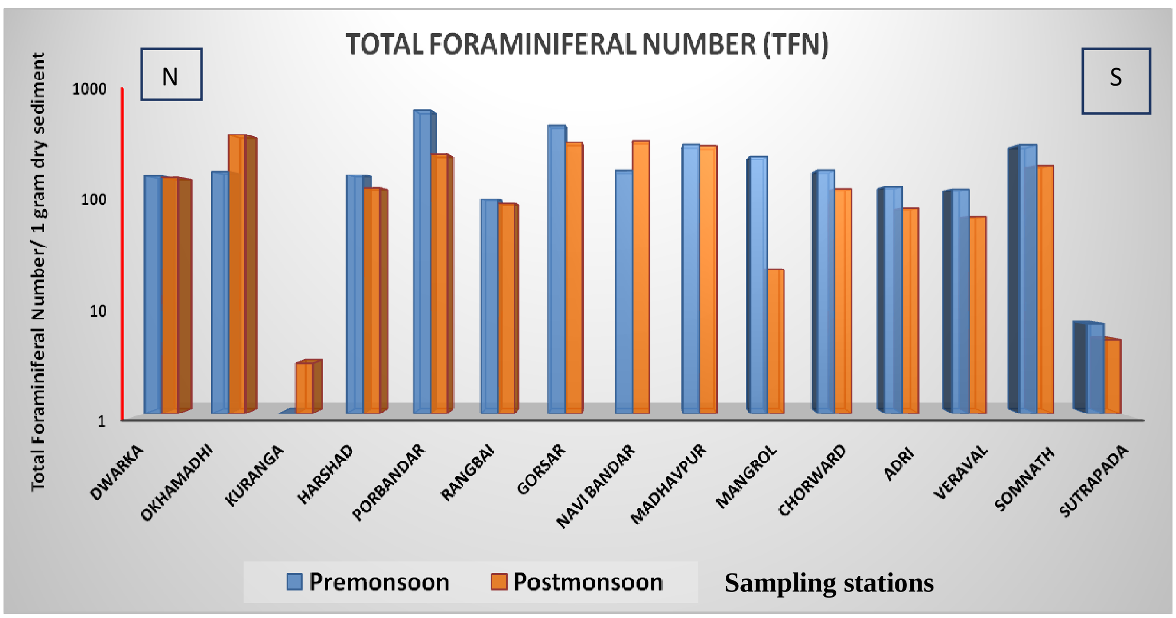


Figure-4.1: Total Foraminiferal Number (TFN) in log scale along the sampling stations of the west coast

All the foraminiferal assemblages are found greater than 125µm. We have not found foraminifera between 63-125 microns. The size variations of the foraminifera are shown in Figure-4.2 (a-b). It is evident that the foraminiferal test size is big in the west coast.

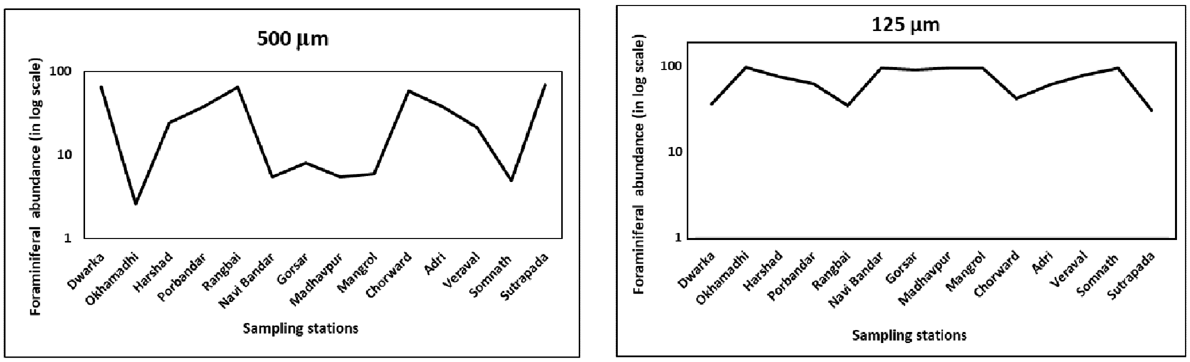


Figure-4.2: Foraminiferal test diameter along the sampling stations (in log scale). **(a)** >500 µm. **(b)** >125 µm

The Murray's Ternary diagram (Figure-4.3) shows the dominance of the calcareous hyaline test in both the seasons. No agglutinated species were found in this region. The calcareous porcelaneous forms of the pre-monsoon period are higher in number than post-monsoon.

The Fisher's α diversity index shows a high diverse assemblage in pre-monsoon (α=1-5) than post-monsoon (α=1-4) (Figure-4.4). The reproductive cycle does happen in this period; thus, a good count of good foraminiferal populations has been recorded.

The cross plot of Fisher's α diversity and information function H was performed to understand the different environments of the foraminiferal assemblages. Fisher's α diversity shows the value of α=5 and information function, H shows the value of < 2.5. A best fit line is drawn for both the plots. The correlation factor is good for pre-monsoon season. For pre-monsoon, R^2 shows a value of 0.9143 (Figure-4.5) and for post-monsoon it is 0.5757 (Figure-4.6). Both the diagram indicate the foraminiferal assemblages are of marginal to normal marine environment.

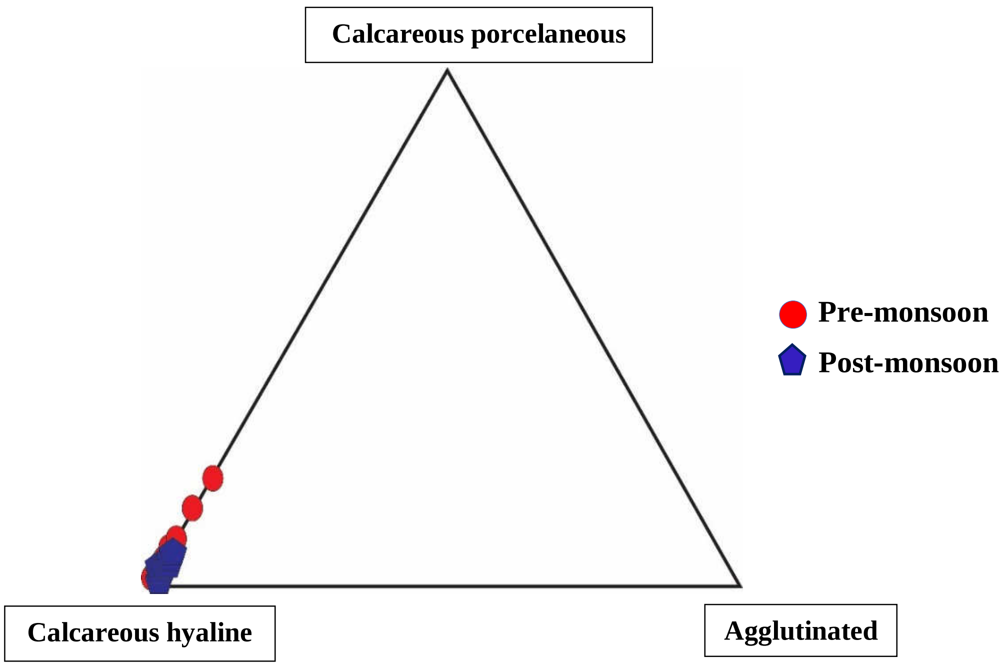


Figure-4.3: Murray's Ternary plot showing the wall type of foraminifera along the west coast

The data set of salinity and temperature (Source: NIODC) show a drop in salinity (Figure-4.7) and temperature (Figure-4.8) in post-monsoon months. Overall, the salinity and temperature plots along the Saurashtra coast over the year shows a little variation of salinity values along the stations (35.99 ‰ to 36.64 ‰). The temperature plot shows a higher value (26^0C-28^0C) during the peak summer (April to May) and a low value (24.8^0C-25^0C) during the winter (December to January).

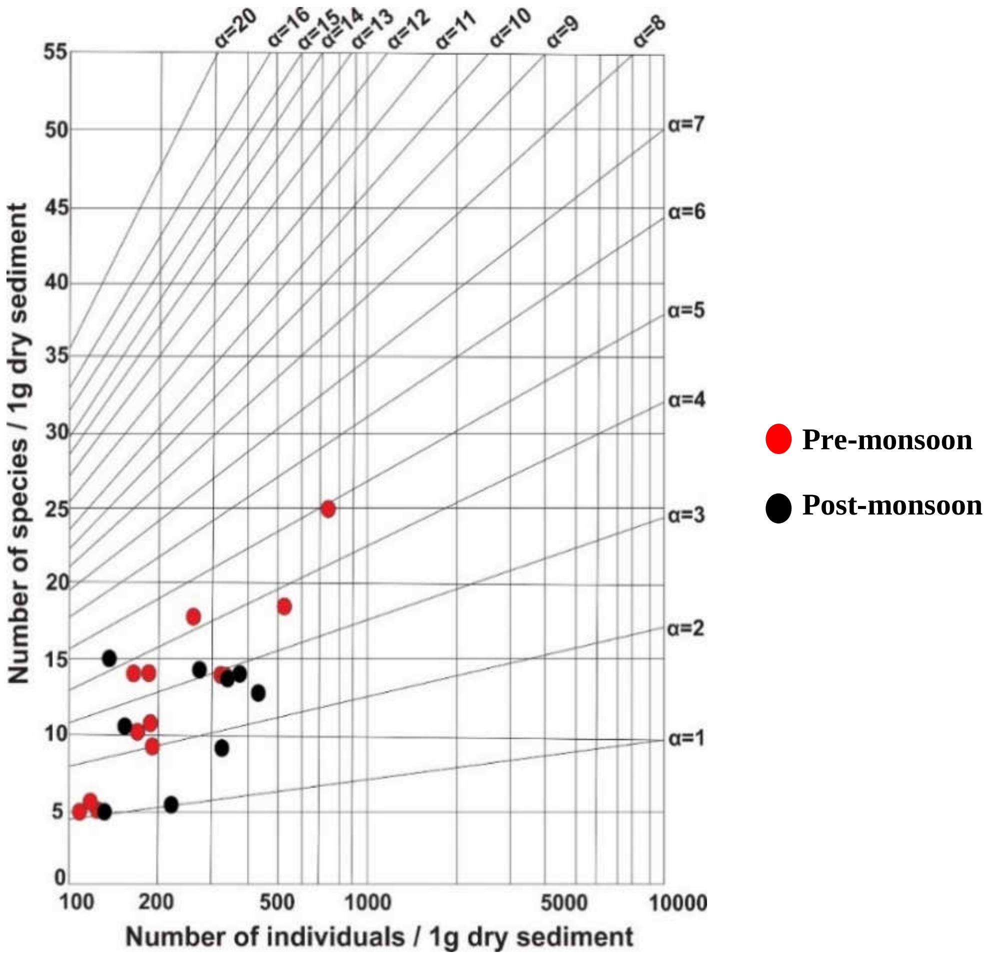
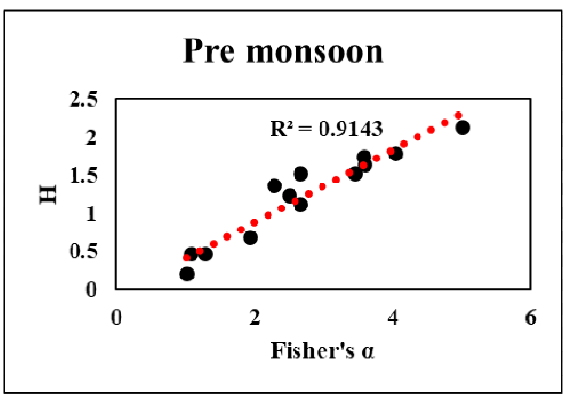


Figure-4.4: Fisher's α diversity index plot for sampling stations of the west coast



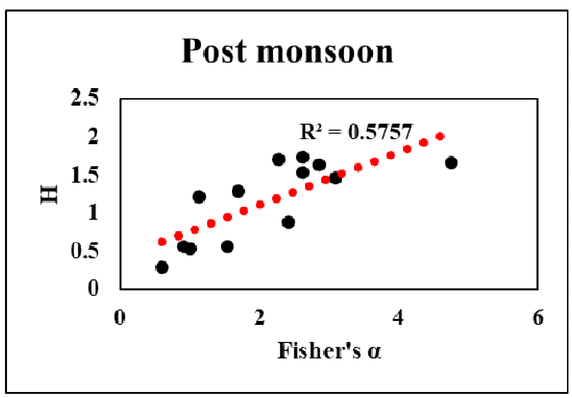


Figure-4.5: Cross plot of Fisher's α and H-index (pre-monsoon)

Figure-4.6: Cross plot of Fisher's α and H-index (post-monsoon)

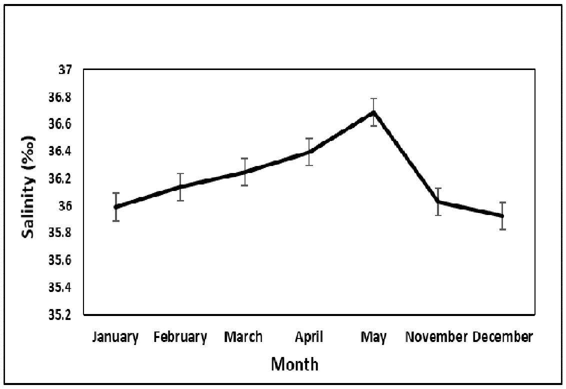


Figure-4.7**:** Salinity variation data from NIODC

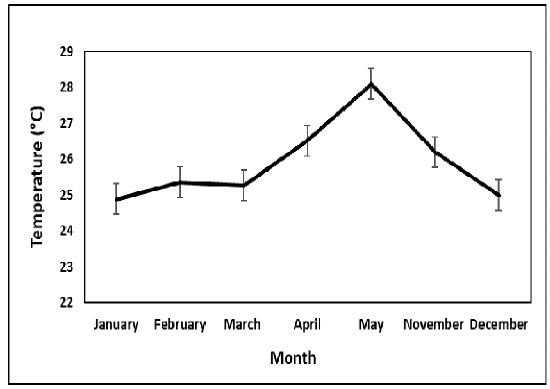


Figure-4.8: Temperature variation data from NIODC

To assess the similar characteristics of the foraminiferal assemblages, Paired group (UPGMA) and Morisita cluster analysis was performed. Here, the species were selected only those have 4% or greater abundance of the total specimens of the single sampling location. Three different clustered groups were observed (Figure-4.9). Group A is dominated only by larger benthic foraminifera, which is a transported form. Group B is dominated by the foraminiferal species, characteristics of sandy substratum and the foraminiferal assemblages dominant in clay-silt rich sediment are clustered in another group Group C.

Group A - *Nummulites venosus*

Group B - *Rotalidium annectens*, *Elphidium crispum*, *Pararotalia nipponica*, *Eponides repandus* and *Cibicides refulgens*

Group C - *Quinqueloculina seminulum*, *Ammonia tepida* and *Nonion* cf. *commune*

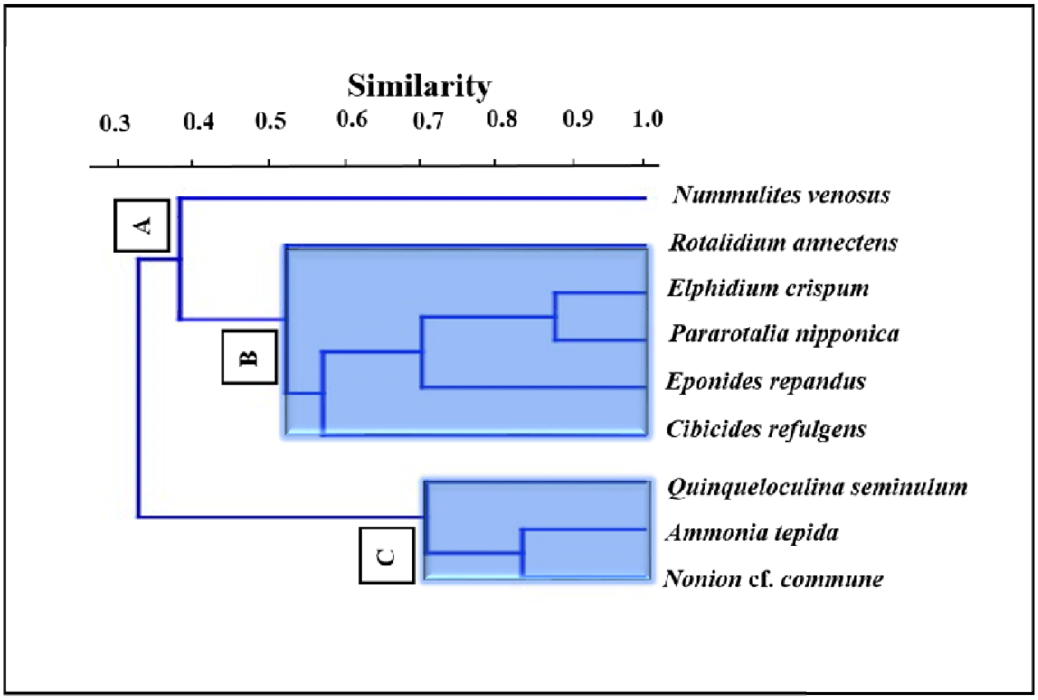


Figure-4.9: Paired group (UPGMA) and Morisita R-mode cluster analysis showing the similarities between the foraminiferal assemblages.

To understand the spatial variation of the foraminiferal assemblages, Paired group (UPGMA) and Jaccard Q-mode cluster analysis (Figure-4.10) was performed. Two distinct clusters, Cluster A and B were observed. Cluster-A includes five sampling stations (Chorward, Adri, Rangbai, Veraval, and Sutrapada) and Cluster-B consists of nine sampling stations (Porbandar, Dwarka, Mangrol, Navibandar, Gosa, Harshad, Madhavpur, Okhamadhi, and Somnath).

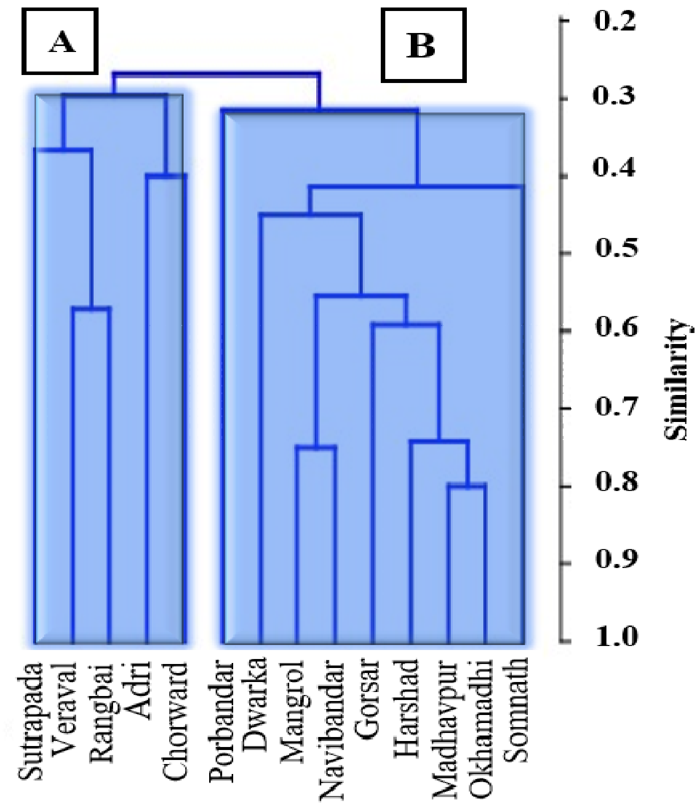


Figure-4.10: Dendrogram of the results of the Paired group (UPGMA) and Jaccard Q-mode cluster analysis

Here, stations (Chorward, Adri, Rangbai, Veraval, and Sutrapada) with low foraminifera diversity are clustered in one group (Cluster-A), and the most dominant species are *Rotalidium annectens*, *Elphidium crispum* and *Quinqueloculina seminulum.* Cluster-B includes the sampling stations where the diversity of foraminiferal assemblages is higher. It is characterized by *Rotalidium annectens*, *Elphidium crispum*, *Pararotalia nipponica*, *Eponides repandus*, *Nummulites venosus*, *Amphistegina radiata*, *Cibicides refulgens*, *Quinqueloculina seminulum*, *Ammonia tepida*, *Triloculina trigonula*, and *Triloculina tricarinata*.

The abundance of the dominant foraminiferal species along the sampling stations has been shown in Figure-4.11-4.17.

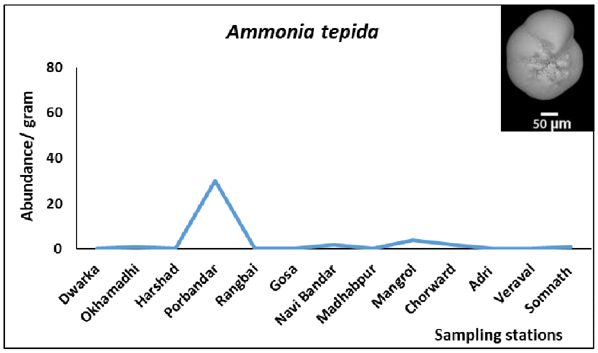


Figure-4.11: Distribution pattern of *Ammonia tepida* along the west coast

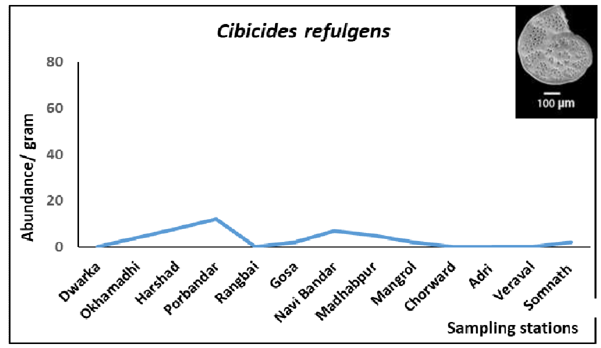


Figure-4.12: Distribution pattern of *Cibicides refulgens* along the west coast

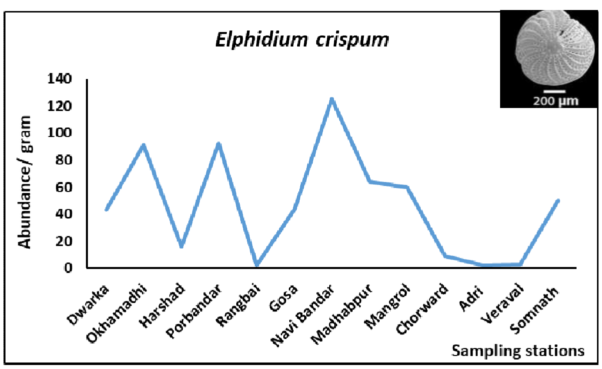


Figure-4.13: Distribution pattern of *Elphidium crispum* along the west coast

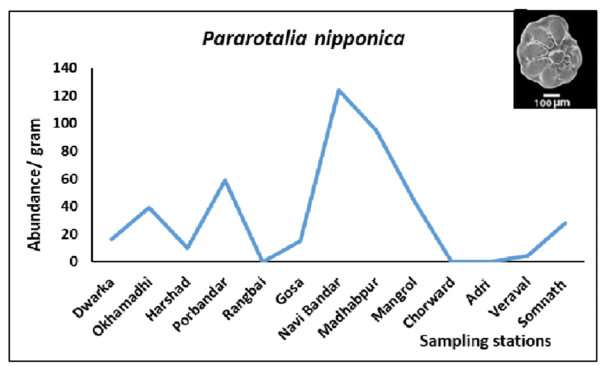


Figure-4.14: Distribution pattern of *Pararotalia nipponica* along the west coast

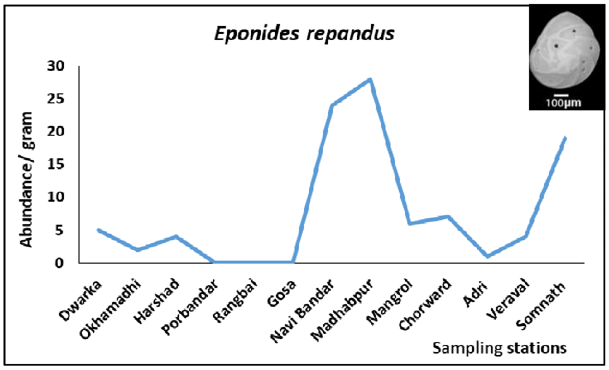


Figure-4.15: Distribution pattern of *Eponides repandus* along the west coast

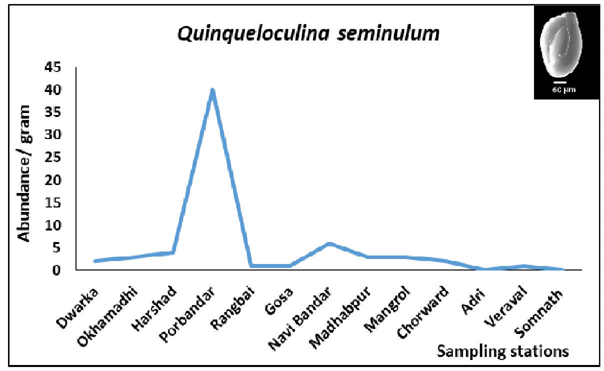


Figure-4.16: Distribution pattern of *Quinqueloculina seminulum* along the west coast

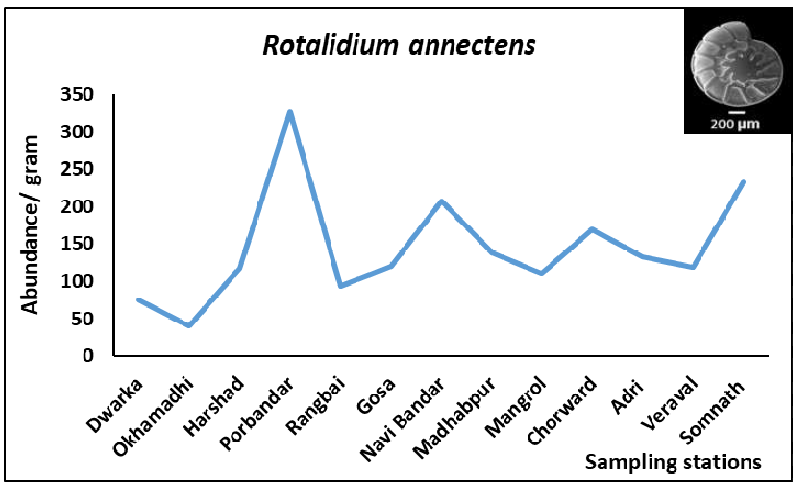


Figure-4.17: Distribution pattern of *Rotalidium annectens* along the west coast

Rotalidium annectens is the most dominant species in all the stations of the west coast. *Elphidium crispum, Quinqueloculina seminulum, Ammonia tepida* and *Cibicides refulgens* are in good abundance in the northern stations whereas *Pararotalia nipponica, Eponides repandus* are present in good numbers along the southern stations.

4.4.2 Vertical distribution of foraminiferal assemblages

A total of 16 species have been identified from the 15 cm long core collected from the Harshad marsh area. *Ammonia tepida* is the most dominant species contributing 60% of the total foraminiferal population followed by *Rotalidium annectens, Elphidium crispum, Pararotalia nipponica, Nonion cf. commune, Quinqueloculina seminulum, Quinqueloculina sulcata, Quinqueloculina pseudoreticulata, Cibicides refulgens, Eponides repandus, Elphidium craticulatum, Elphidium advenum* and *Triloculina trigonula.* Two larger benthic foraminifera, *Nummulites venosus* and *Amphistegina radiata* were identified. These two are not in-situ forms but transported in the Harshad marsh region.

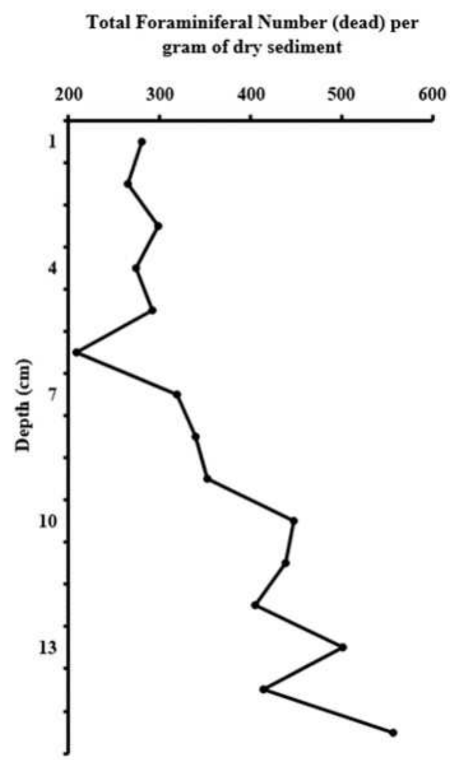


Figure-4.18: Downcore variation of Total Foraminiferal Number (TFN) in Harshad region

The vertical distribution of the Total Foraminiferal Number (TFN) is plotted for the Harshad core sample (Figure-4.18). The TFN shows that the Foraminiferal population varies from 209 to 557 specimens per gram of dry sediments. The abundance of the foraminifera shows an increasing trend in the lower part of the core, i.e. 7cm depth onwards. Thus, it indicates that ambient conditions such as salinity, temperature and nutrients were favourable for the high foraminiferal population at deeper depth.

This vertical distribution pattern is similar to the C-type profile described by Sengupta, 2003. This type of profile shows relatively low value in the top part and increasing trend in deeper part of the core.

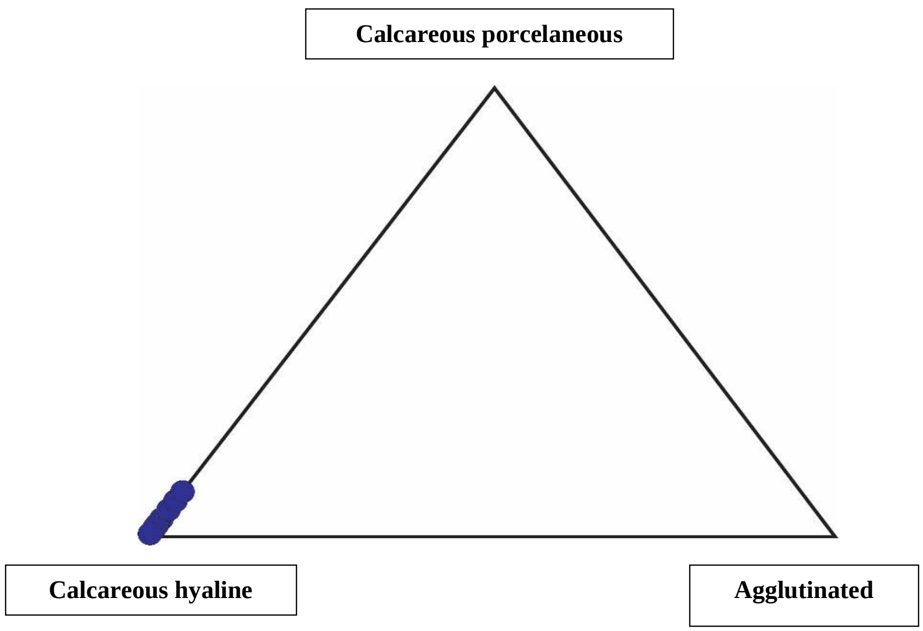


Figure-4.19: Murray's Ternary plot showing the wall type of foraminifera for core sample of the Harshad region

The Murray's Ternary diagram (Figure-4.19) shows the abundance of the calcareous hyaline tests in the core. A low population of porcelaneous foraminifera has been observed. No agglutinated forms were observed in the study area. The Fisher's α diversity index (Figure-4.20) shows a low to moderate diverse assemblage in the core (α=2-4). The abundance of the hyaline tests in the study area can be attributed to the high salinity conditions and based on assemblage diversity, the collected core is typical of the marsh environment.

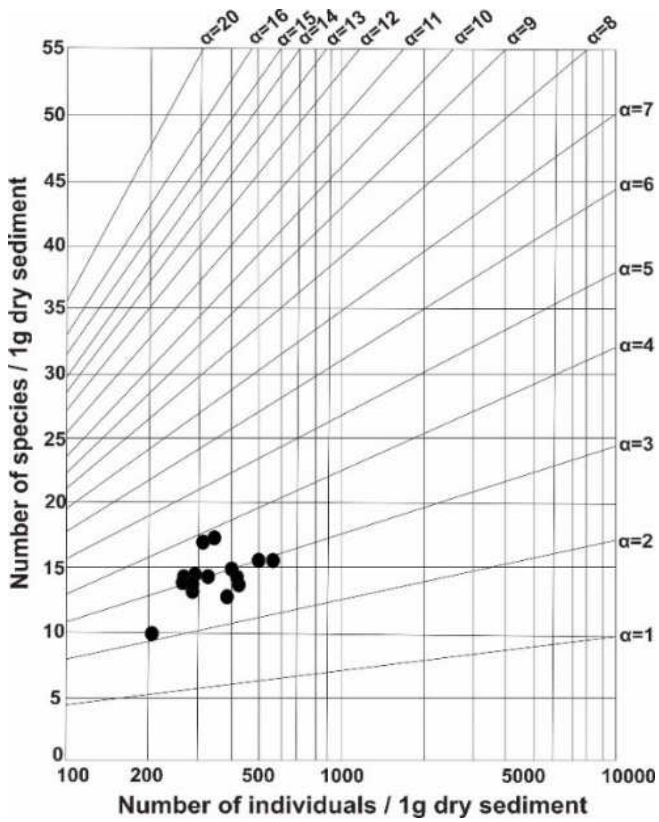


Figure-4.20: Fisher's α diversity index plot for core sample of the Harshad region

4.4.3 Biofacies zone

We have studied the distribution pattern of individual taxa constituting the biofacies zone along the west coast. Two biofacies zones were identified (Figure-4.21). *Rotalidium annectens* and *Elphidium crispum* are present in all the sampling stations.

Biofacies zone I includes *Rotalidium annectens*, *Elphidium crispum*, *Pararotalia nipponica* and *Quinqueloculina seminulum.*

Biofacies zone II consists of *Rotalidium annectens*, *Elphidium crispum* and *Eponides repandus.* The Biofacies map of the west coast is shown below-

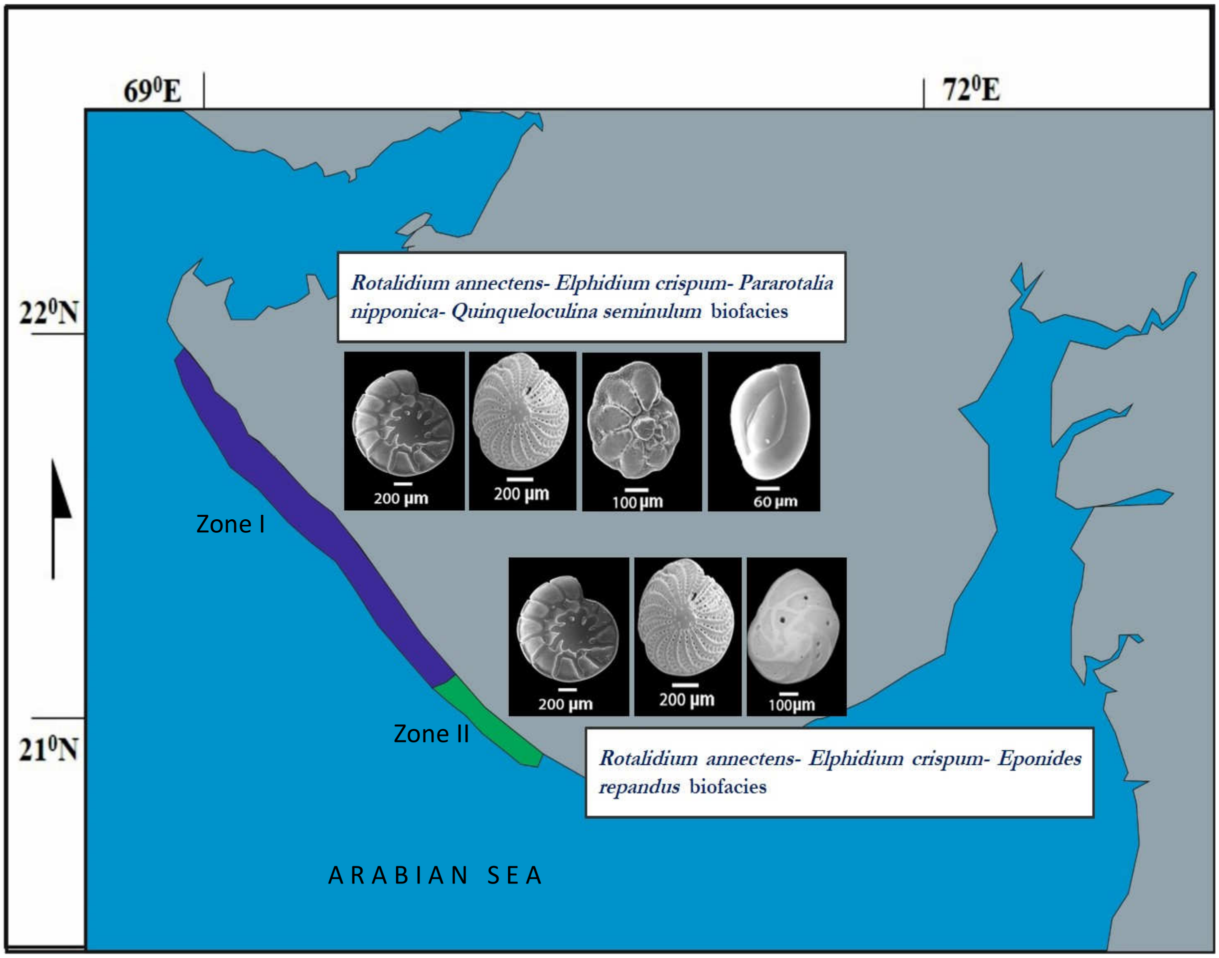


Figure-4.21: Biofacies zones of foraminiferal assemblages along the west coast

Chapter-5

Discussion and Conclusions

5.1 Discussion

The study of benthic foraminiferal assemblages has a broad perspective nowadays. Benthic foraminifera vary latitudinally, which is evident in the comparison of both the coasts of India. The factors such as temperature, pH, salinity, substrate, nutrients and sedimentation rate are the controlling factors. It provides a basic understanding about the components of biodiversity and its interrelation with abiotic factors. Comparative chart for the east and west coast of India has been shown in Table-5.1.

Parameters	**East coast**	**West coast**
Foraminiferal size	>63µm and >125µm	>125µm and >500µm
Abundance (TFN/gram)	5- 193	15-732
Species richness	18	35
Agglutinated Test structure	Agglutinated present	Agglutinated absent
Diversity	α=1-3	α=1-5
Average Salinity (‰)	29	35
Average temperature (^{0}C)	25.4	26.3
Larger benthic foraminifera	Absent	Present
Dominant species	*Cribroelphidium excavatum,* *Cribroelphidium poeyanum,* *Haynesina germanica,* *Asterorotalia trispinosa,* *Ammonia tepida* and *Quinqueloculina seminulum*	*Rotalidium annectens,* *Pararotalia nipponica,* *Elphidium crispum,* *Eponides repandus* and *Quinqueloculina seminulum*

Table-5.1: Comparative chart for the east and west coast of India

The species richness in the west coast is high as compared to the east coast. The study of surface samples on 15 sampling stations and 2 core samples from both the coasts of India reveals the presence of 35 foraminiferal species along the west coast sampling stations and

18 species from the east coast. If we look at size variation for both the coasts, we can see that the west coast has larger foraminiferal size as compared to the east coast. The east coast is having major river systems such as Rajmahal, Bhagirathi-Hoogly, Mahanadi, Damodar, Sunderban etc. But there is no significant river system along the west coast of India except the Bhadar and Shetrunji along the Saurashtra coast. Due to the presence of big river systems, the total suspended sediment (TSS) to the Bay of Bengal is higher as compared to the Arabian sea. This TSS disrupts the natural food chain by destroying the habitat where the smallest organisms live and causing massive declines in their populations. Also, it prevents the proper sunlight to the organisms, which causes the growth of the organisms. So, the size of the east coast foraminiferal assemblages is smaller than the west coast.

Moreover, the presence of two larger benthic foraminifera *Nummulites venosus* and *Amphistegina radiata* in the west coast sampling stations indicates the presence of coral reefs in the study area. In contrast, we have not found larger benthic foraminiferal species in the east coast, which indicates that the east of India within the same latitude does not contain coral reefs in the seawater. The presence of larger benthic forms indicates the clear marine water with no significant suspended sediments. Kunte (2008) showed a quantitative estimation of suspended sediment along the Saurashtra coast and found it to be low.

The Total Foraminiferal Number is high during the pre-monsoon season compared to the post-monsoon season for both the coasts. This might be due to the reproductive seasons of foraminifera occurs during the pre-monsoon months. Ghosh *et al*., (2014) reported a similar high abundance of foraminifera along the Cambay coast in the pre-monsoon season. The abundance of foraminifera in the northern and the southern part of the east coast sampling stations is higher than that of middle part of the sampling stations. Sampling stations such as Mandarmani, Digha and Dagara are popular tourist spot and extensive construction activities and pollution affecting the benthic communities. This may be the reason of getting low abundance of foraminiferal species along these sampling stations. The low foraminiferal abundance observed in Kuranga and Sutrapada is because of the unfavourable habitat of this protists group. There is no such trend of abundance from the north (N) to south (S) of the studied location in west coast.

If we compare the Total foraminiferal number of the east and the west coast, the abundance of the west coast is higher than the east coast. Also, the diversity of the foraminifera along the east coast (α=1-3) is lower than the west coast (α=1-5). The foraminiferal assemblages depend on various abiotic factors. Salinity and temperature control the diversity and abundance of the foraminifera. Johns *et. al*. 1993 stated that, the Bay of Bengal circulation is very much influenced by freshwater outflow due to the freshwater discharge from the various major river systems along the east coasts joining the Bay. The higher rate of freshwater discharge lowers the salinity of the east coast (22‰$_0$-30‰$_0$) which controls the abundance and diversity of the foraminiferal populations, whereas, the salinity is higher (35.99 ‰ to 36.64 ‰) in the west coast due to the less freshwater influx. Again, the freshwater outflow of the river varies seasonally with its maximum during monsoon (June to August). This freshwater outflow from the river system adjoining the sea lowers the salinity during this time (Rao *et al*., 2009) for both the coasts. Thus, relatively higher salinity during pre-monsoon may be another factor for a higher abundance of the protist. Also, the temperature of west coast water is higher than that of the east coast, which favours the growth of foraminifera.

Murray’s Ternary diagram shows the dominance of the calcareous hyaline test in both seasons at all the stations. The calcareous porcelaneous forms were slightly higher in count in the pre-monsoon period than in the post-monsoon period. Few sampling stations of the east coast consist of agglutinated forms which indicate the low energy condition and can be explained by the fact that it is not directly connected to the open ocean. On the other hand, we did not observe any agglutinated forms along the west coast sampling stations, which indicates the high energy condition along the west coast.

An assessment of the foraminiferal populations and their sensitivity to nutrient supply is carried out. *Elphidium crispum* is considered to be sensitive to organic enrichment and mainly occurs in natural, oligotrophic and unpolluted ecosystems (Jorissen *et al.*, 2018). In our west coast study area, *Elphidium crispum* is found in good counts (>10%) along the northern stations (Madhavpur to Dwarka stretch) during pre-monsoon. This is the indicative of low organic enrichment in these areas. But in post-monsoon season *Elphidium crispum* decreases in abundance which indicates that the supply of nutrients is higher. Setty and Nigam (1982) reported that populations of *Elphidium* are inversely proportional to the fluctuations of organic matter in the sediment. Similarly, Yun *et al.*, (2015) also found that the Total Organic Carbon (TOC) content in the marine surface sediments during post-monsoon was higher than the pre-monsoon. Such organic carbon enrichment during post-monsoon may be due to the higher river discharge, which supplies the organic matter into the coastal seas. This is more evident by the abundance of shallow larger benthic forms *Nummulites venosus* and *Amphistegina radiata* along the stretch during April (pre-monsoon). These forms are generally found in low suspended sediment areas (Hallock, 1988). *Asterorotalia trispinosa* is the kind of species, present only in the east coast of India indicates the preference of muddy substrate and high suspended load within the water column.

In case of core sample also, the abundance of the foraminifera in each depth in the Chandipur area is lower than Harshad region. In Harshad, the abundance reaches up to 557/gram, whereas in Chandipur it is only 67/gram. This is because of the dynamic environment of Chandipur. The high sediment load brought by the river Budhabalanga and the action of waves and currents causes migration of the bar – inter bar system in this intertidal setting. Hence, the species variation is low in this area (Das *et al*., 2019). Ghosh *et al*., 2014 also observed a similar low variation of species in the mangrove ecosystem of the Indian Sunderbans. Dutta *et al.,* 2021 described that, the higher abundance of the foraminiferal assemblages and the dominance of the calcareous hyaline forms in the Harshad region as a result of high salinity condition.

Vertical distribution of the taxa is a reflection of the tolerance and/or preference level of taxa with respect to one or more controlling parameters (Sengupta, 2003). In the Chandipur core sample, the abundance increases towards the middle part. It may be due to the bioturbation effect of this dynamite intertidal setting. Bioturbation can actively transport living foraminifera into deeper sediments (Das *et al*., 2019). In the Harshad core sample also, we have observed that the abundance increases consistently towards the lower part of the core. It may be due to the favourable conditions such as salinity temperature and nutrients were available and led to a high foraminiferal population. Also, for type-C and Type-D profiles, bottom water oxygenation may play an important role (Sengupta, 2003).

The presence of agglutinated species in the Chandipur core sample indicates the low energy condition in the area. Although the core collected from Harshad is of marsh environment, but no agglutinated foraminifera has been reported. It is typically characterized by rotaliid and miliolid groups.

The biofacies map of the east coast shows that *Ammonia tepida* and *Asterorotalia trispinosa* are the most dominant species, whereas in the west coast biofacies map, *Rotalidium annectens* and *Elphidium crispum* are the dominant foraminifera. This can be explained by the variation of abiotic factors responsible for the growth, diversity and abundance of the characteristic benthic foraminiferal assemblages along both the east and west coast of India.

5.2 Conclusions

1. Eighteen species were identified along the east coast and thirty five species along the west coast where only seven species are common in both the coastal regions.

2. The size of the foraminiferal species of the east coast is smaller than the west coast. Mostly, all the foraminifera we have identified are <125 µm in the east coast, whereas in the west coast, all the foraminifera we have identified are >125 µm.

3. The foraminiferal assemblages are more diverse in pre-monsoon months and are indicative of marginal to normal marine environment. The abundance and diversity of foraminifera are lower in the east coast as compared to the west coast.

4. The characteristic assemblages of the east coast are *Haynesina germanica*, *Cribroelphidium* spp., *Asterorotalia trispinosa*, *Haynesina depressula*, and *Ammonia tepida.* and the agglutinated species such as *Trochammina inflata, Haplophragmoides* sp. and *Miliammina fusca.* The characteristic calcareous

assemblages of the west coast are *Rotalidium annectens*, *Elphidium crispum*, *Pararotalia nipponica*, *Eponides repandus*, *Quinqueloculina seminulum*, *Cibicides refulgens*, *Nonion* cf. *commune* and *Ammonia tepida*.

5. Salinity is lower in the east coast ($22\%_{0}$-$30\%_{0}$) as compared to the west coast (35.99 ‰ to 36.64 ‰).

6. R-Mode cluster analysis of east coast shows three different clustered groups. Group A - *Quinqueloculina seminulum, Ammonia tepida* and *Asterorotalia trispinosa*, Group B - *Rotalidium annectens* and Group C - *Cribroelphidium excavatum, Cribroelphidium poeyanum, Haynesina germanica* and *Haynesina depressula.* R-Mode cluster analysis of west coast shows three different clustered groups. Group A - *Nummulites venosus*, Group B - *Rotalidium annectens*, *Elphidium crispum*, *Pararotalia nipponica*, *Eponides repandus* and *Cibicides refulgens* and Group C - *Quinqueloculina seminulum*, *Ammonia tepida* and *Nonion* cf. *commune.*

7. Two biofacies zones were identified from the east coast. Biofacies zone 1 includes *Ammonia tepida, Asterortalia trispinosa* and *Quinqueloculina seminulum.* Biofacies zone 2 consists of *Ammonia tepida, Asterortalia trispinosa, Haynesina germanica* and *Cribroelphidium* spp.

8. Two biofacies zones were identified from the west coast. Biofacies zone I includes *Rotalidium annectens, Elphidium crispum, Pararotalia nipponica* and *Quinqueloculina seminulum.* Biofacies zone II consists of *Rotalidium annectens, Elphidium crispum* and *Eponides repandus.*

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