



Diversity of Foraminifera from the Indian Coast

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Foraminifera, members of the class *Granuloreticulosa*, are marine protozoans distributed across both pelagic and benthic zones of the ocean. After the death of these microscopic organisms, their shells are washed along the intertidal sandy shores along with sand granules. This organism's shell is called a test which is composed of calcium carbonate, silica, or agglutinated materials that characterize the genera of Foraminifera. In the present study, the sand samples were collected along the different sites of the Indian coastline viz. Juhu Beach (Mumbai), Alibaug Beach (Raigad), Palolem Beach (Goa), Kanyakumari Beach (Tamil Nadu), and Puri Beach (Odisha). In this study, samples from Juhu Beach showed the highest foraminiferan diversity (24%) followed by Alibaug (21%) > Kanyakumari = Puri (19%) > Goa (17%). Across all selected study sites, the prevalence of specimens from the *Globobulimina* class was notable, comprising 39% of the total foraminiferans. This was followed by *Monothalamae* (26%), *Fusulinata* (13%), *Tubothalamae* (11%), and *Nodosariata* (11%). 13 extinct genera were also documented in the study.

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1. INTRODUCTION

Foraminifera is a marine protozoan that belongs to the class *Granuloreticulosa*. These organisms when alive are found along the pelagic region. Foraminifera, according to Boltovskoy and Wright (1976), are mostly marine organisms that are extensively dispersed throughout seas bathymetrically (vertically) and geographically (horizontally), including marginal marine areas like estuaries, lagoons, and bays [1,2]. During the deceased state, the outer structure known as the test is deposited onto sandy coastlines. The Foraminifera test structure is made up of different materials. Certain tests are made up of chitinous substances, others are formed from aggregated particles bound together, and the predominant type consists of calcareous material. Although siliceous tests have been documented, they are infrequent, potentially originating as secondary formations [3]. These marine microscopic organisms are useful tools in understanding environmental health. According to Murray (2006), these are the most frequently utilized fossil species for age dating, sediment correlation, and paleoenvironmental interpretation in biostratigraphy. Understanding different ecological aspects is aided by the existence of species [4,5]. The World Foraminifera Database, from WORMS (World Register of Marine Species), is a comprehensive online repository for marine organisms globally. It documents a total of 49,054 species, encompassing 8,961 recent species and 40,996 fossil species of Foraminifera. In the present study, the Foraminifera were recorded from 5 sites along the Indian Coast which showed a diversity of foraminiferal species from the West to East Coast.

2. MATERIALS AND METHODS

Sand samples were collected from 5 selected sites along the Indian coastline viz. Juhu Beach (Mumbai), Alibaug Beach (Raigad), Palolem Beach (Goa), Kanyakumari Beach (Tamil Nadu), and Puri Beach (Odisha) (Fig. 1).

The identification of foraminiferal samples was observed under the light binocular research microscope in 10X and 40X magnification. For the identification of the Foraminifera, reference books and database repositories such as

WORMS (World Register of Marine Species) (<https://www.marinespecies.org/>) and The World Foraminifera Database (<https://www.marinespecies.org/foraminifera/>) were used [3,6].

3. RESULTS AND DISCUSSION

From the thorough analysis of the sand samples from the 5 selected sites of India viz. Juhu (Mumbai), Alibaug (Raigad), Palolem (Goa), Kanyakumari (Tamil Nadu), and Puri (Odisha), Juhu (24 %) showed a lot of diversity compared to Alibaug (21%), Kanyakumari (19 %), Puri (19%), and Goa (17%) (Fig. 2). Regarding the distribution of classes across all chosen study sites, specimens belonging to the class Globothalamea were prevalent accounting for 39% of the total, followed by Monothalamea (26%) > Tubothalamea (11%) > Fusulinata (13%) > Nodosariata (11%) (Fig. 3). In this present study, 13 extinct genera were also documented.

Webbinelloidea was the only genus present across all 5 samples collected from selected study sites. In total, 38 different genera were identified from sand samples obtained from all study-chosen sites along the Indian coastline.

Regarding species abundance, Juhu showed a prevalence of *Cibicides* and *Endothyra* in the present study. Naik et. al (2023) collected sediment samples from different sites of Mumbai shoreline viz. Gorai Beach, Juhu Beach, Dadar Beach, and Girgaon Beach. Sample collection occurred in two parts: 1) from September 2013 to August 2014, and 2) from December 2016 to November 2017. Identification was analyzed with the assistance of SEM (Scanning Electron Microscopy). From this analysis, thirty-five foraminiferal species were obtained which were divided into five orders and eighteen families [7].

From the present study, the Alibaug sample showed *Discorbis* and *Planularia* as predominant. A study was conducted on the foraminiferal diversity of Alibaug Beach and its nearby sites along the Alibaug Coast in 2018. In this study, genera such as *Bathysiphon*, *Elphidium*, *Cyclammina*, *Textularia*, *Saccorhiza*, *Saccammina*, and *Spiroloculina* were found to be dominant [8].

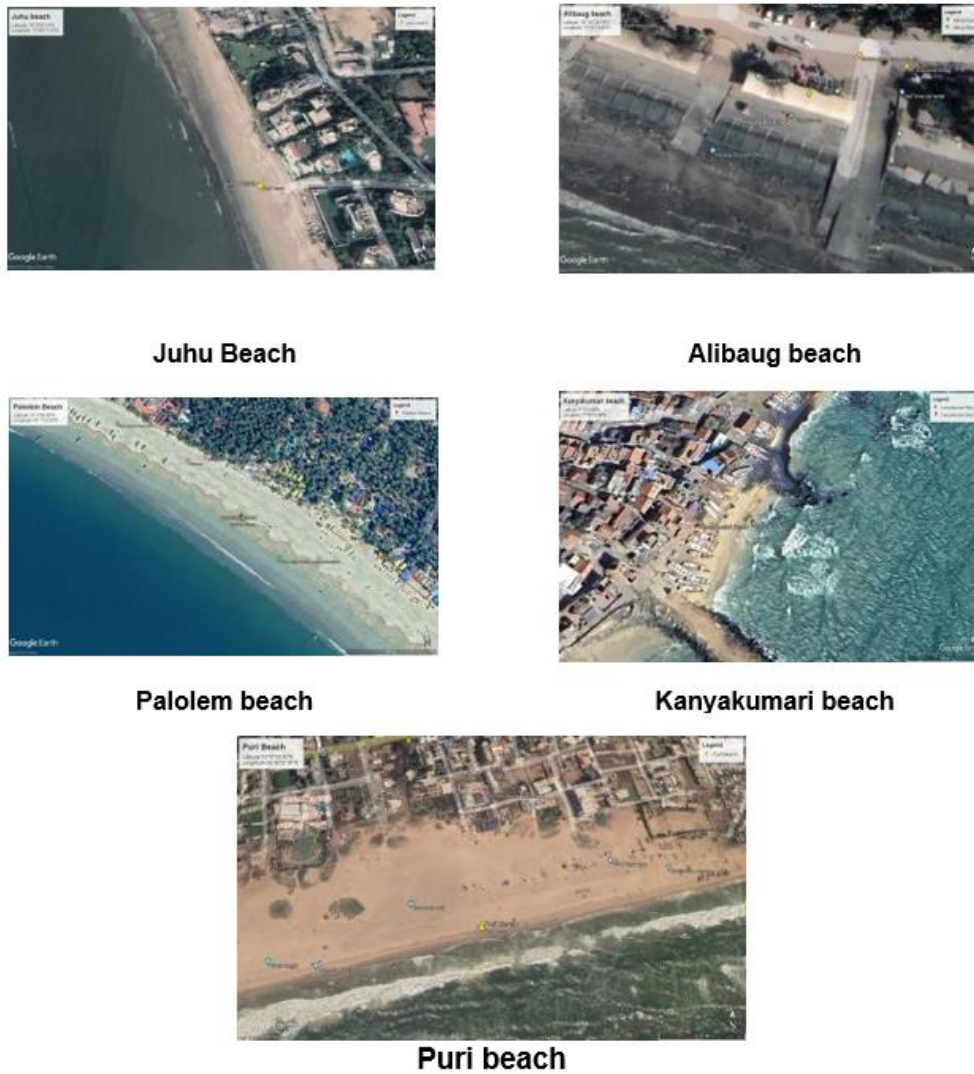


Fig. 1. Geolocation of selected study sites along the Indian Coast
(Source: Google Earth Pro)

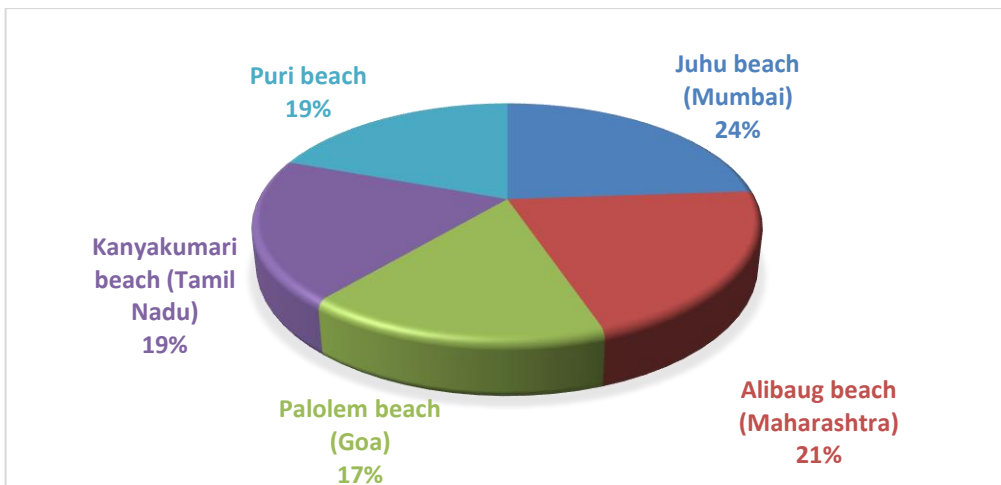


Fig. 2. Foraminiferan distribution of selected sites along the Indian coastline

Table 1. Foraminifera genera list from selected sites along the Indian Coast

Sr no.	Species	J	A	P	K	O
1	<i>Ceratobulimina</i> Toula, 1915	✓	✓	✓		
2	<i>Colonammima</i> Moreman, 1930†	✓			✓	
3	<i>Tholosina</i> Rhumber, 1895	✓		✓	✓	✓
4	<i>Globotrucana</i> Cushman, 1927†	✓				
5	<i>Cibicides</i> Montfort, 1808	✓	✓		✓	
6	<i>Marssonella</i> Cushman, 1933†	✓				
7	<i>Psammophax</i> Rhumbler, 1931	✓				✓
8	<i>Hyperammima</i> Brady, 1878	✓				
9	<i>Thurammima</i> Brady, 1879	✓		✓		✓
10	<i>Mooreinella</i> Cushman & Waters, 1928†	✓				
11	<i>Webbinoidea</i> Stewart & Lampe 1947†	✓	✓	✓	✓	✓
12	<i>Siphogenerinoides</i> Cushman, 1927†	✓				
13	<i>Praerhapydionina</i> van Wesseem, 1943†	✓		✓		
14	<i>Endothyra</i> Phillips, 1846 †	✓	✓	✓	✓	
15	<i>Siphonina</i> Reuss, 1850	✓	✓			✓
16	<i>Triticites</i> Girty, 1904†	✓				
17	<i>Gyroidina</i> d'Orbigny, 1826		✓			
18	<i>Bathysiphon</i> Sars, 1872		✓			
19	<i>Semitextularia</i> Miller & Carmer, 1933†		✓			✓
20	<i>Discorbis</i> Lamarck, 1804		✓			✓
21	<i>Sorosphaera</i> Brady, 1879		✓		✓	
22	<i>Amphistegina</i> d'Orbigny, 1826		✓			
23	<i>Textularia</i> DeFrance, 1824		✓			
24	<i>Planularia</i> DeFrance, 1826		✓	✓		
25	<i>Bolivina</i> d'Orbigny, 1839		✓			
26	<i>Stensioeina</i> Brotzen, 1936†			✓		
27	<i>Saccammima</i> Sars in Carpenter, 1869			✓	✓	
28	<i>Nodosarella</i> Rzehak, 1895 †			✓		
29	<i>Peneroplis</i> Montfort, 1808			✓		
30	<i>Glyphostomella</i> Cushman & Waters, 1928 †				✓	✓
31	<i>Valvulineria</i> Cushman, 1926				✓	✓
32	<i>Globivalvulina</i> Schubert, 1921				✓	✓
33	<i>Orthovertella</i> Cushman & Waters, 1928†				✓	
34	<i>Triloculina</i> d' Orbigny, 1826				✓	
35	<i>Lenticulina</i> Lamarck, 1804				✓	
36	<i>Stegnammina</i> Moreman, 1930†					✓
37	<i>Marginulina</i> d'Orbigny, 1826					✓
38	<i>Arenobulimina</i> Cushman, 1927†					✓

[J- Juhu Beach (Mumbai); A- Alibaug (Maharashtra); P- Palolem Beach (Goa); K- Kanyakumari Beach (Tamil Nadu; O- Puri (Odisha)] †- extinct species

In the Goa sand sample, *Endothyra* and *Ceratobulimina*. In Goa, twenty-one samples were collected from Colva Beach in December 1983 near the tourist entrance of the beach approximately covering 1 km. In this study, 29 foraminiferal species were observed. The specimens were comprised of calcareous as well as agglutinated types. Species such as *Textularia conica*, *T. foliacea*, *Globorotaloides hexagona*, *Spiroloculina inflata*, *Glabratella* sp., and *Brizalina* sp. were reported for the first time in the Goa region [9]. In another study on intertidal foraminiferan diversity along the

Miramar-Caranzalem Shoreline, Goa, a total of forty-four species were found, out of which 29 species belong to the subclass Rotallina, 11 species composed of subclass Miliolina, and 5 species comprised of subclass Textulariina [10].

From the sand samples of Kanyakumari, *Tholosina* and *Cibicides* were prevalent. A foraminiferan diversity study was carried out on nine stations between Thirayshapuram to Vanthivu from the Gulf of Mannar, Tuticorin. In this study, benthic Foraminifera belonging to four suborders, five superfamilies, ten families, eleven

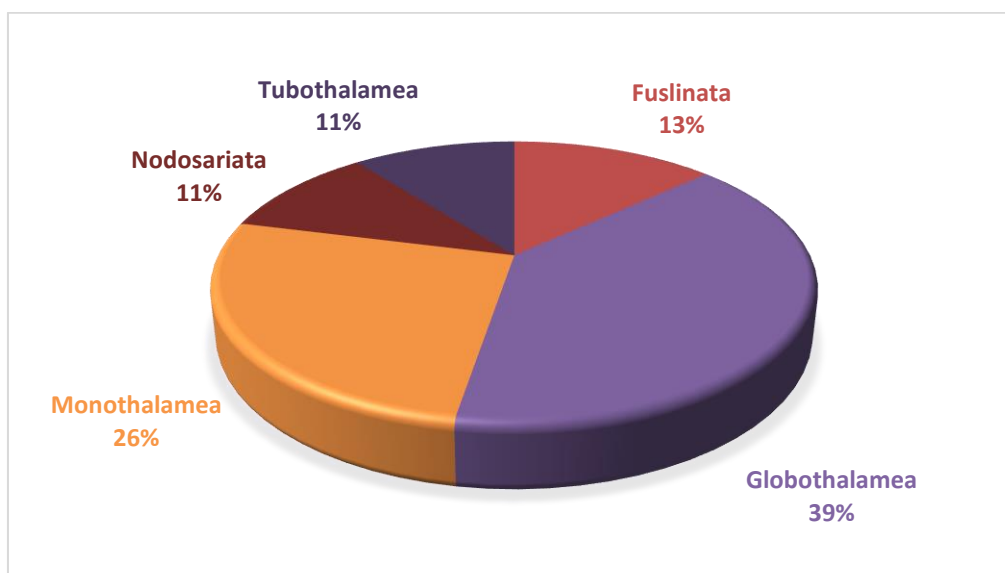


Fig. 3. Class-wise distribution of foraminifera genera of all selected site

subfamilies, fourteen genera, and twenty-nine species were recorded. In terms of species abundance, five species viz. *Ammonia beccarii*, *A. dentate*, *Spiroloculina communis*, *Quinqueloculina seminulam*, and *Pararotalina nipponica* were considered to be abundant [11].

Thurammina and *Discorbis* genera were highly abundant in the Puri sand samples. A comparative analysis of foraminiferal diversity between the west and east coasts of India was carried out within two years span i.e. from October 2004 to September 2006. On both Coasts of India, thirty-three species were common. In terms of the number of Foraminifera species, the West Coast was significantly higher (seventy-four) compared to the East Coast (fifty-five species). In terms of the uniqueness of Foraminifera species, the West Coast of India showed forty-one unique species and the East Coast showed twenty-four species unique to their coast [5].

A photomicrographic catalog was created through a Scanning Electron microscope by Devi & Rajashekhar, (2009). In their study, the samples were obtained from twelve West Coast sites and ten from East Coast sites. A total of 151 species of foraminifera were observed by them. This recorded species belonged to 65 genera, 41 families, and 7 suborders. In suborders, Rotalina and Miliolina were dominant [12,13].

Below is the morphological description of the foraminiferan specimens observed during the present investigation.

Following are the diagnostic characteristics of thirty-eight identified foraminiferan genera:

1. *Ceratobulimina*:

- The test is ovate in outline, and robust in structure.
- Chambers are enrolled trochospirally and slightly convex; dextrally coiled.
- Periphery broadly rounded [6].

2. *Colonamina*:

- The test is a single hemispherical attached chamber.
- Agglutinated wall; A single, slightly raised aperture in the upper surface's center [6].

3. *Tholosina*:

- Test structure is attached and globular and much inflated.
- The wall is agglutinated with a smoothly finished surface [6].

4. *Globotrucana*

- Test with high to low trochospiral chambers.
- Umbilicus, which occupies between one-fourth and half of the flat, concave umbilical side's diameter [6].

5. *Cibicides*

- Test is commonly attached to a substrate
- Planoconvex and trochospiral chambers; spiral side flat to concave [6].

6. *Marssonella*

- The test is conical and circular in cross-section, starting with a small trochospiral shape consisting of four to five chambers per whorl.
- The wall is formed by agglutinated calcareous particles adhering to an organic lining, often featuring canals; the aperture is a shallow basal arch with a narrow bordering flap [6].

7. *Psammophax*

- The test is free i.e. it is not attached to any substratum.
- The genera have few chambers that are globular in shape and the arrangement of the chambers is in rectilinear or curved series.
- The wall is agglutinated with a roughly finished surface [6].

8. *Hyperammia*

- The proloculus is sizable, succeeded by a continuous tubular chamber with a consistent diameter throughout, narrowing slightly towards the rounded aperture at the end.
- The wall is composed of medium-sized quartz particles that are agglutinated and may be either firmly or loosely cemented together [6].

9. *Thurammia*

- The test is globular to sub-globular in shape and with many short conical protuberances.
- Wall is agglutinated, and very thin with a single layer of fine quartz grains [6].

10. *Mooreinella*

- Elongated test.
- The organism experiences a short triserial phase, succeeded by a longer biserial phase [6].

11. *Webbinelloidea*

- Attached test with a few spreading or linearly arranged sub-globular, sub-angular, to hemispherical chambers.

- Wall agglutinated; rough surface; aperture not visible [6].

12. *Siphogenerinoides*

- Test small, elongate, slender, both microspheric and megalospheric generations,
- With a biserial early stage and uniserial and rectilinear later stage, chambers broad and low, closely compressed, sutures straight and horizontal in the adult [6].

13. *Praerhapydionina*

- Test elongate, subconical, up to 1 mm long, circular in section, planispirally enrolled in the early stage, later uncoiled and rectilinear, chambers low and arched centrally, interior subdivided by a few inward projecting radial septula.
- Wall is made of calcareous and porcelaneous material [6].

14. *Endothyra*

- The test is fully enrolled, partially involute, and has a broadly rounded outer edge.
- The chambers are inflated in few per whorl and with few whorls.
- Wall is calcareous and microgranular with two or three layers [6].

15. *Siphonina*

- The test is lenticular to unequally biconvex and is circular in outline.
- Trochospiral in nature with a few broad, low, and crescentic chambers per whorl.
- Wall is calcareous [6].

16. *Triticites*

- Sizes found are in small to medium.
- Inflated fusiform to subcylindrical.
- Whorls expanding slowly and evenly [6].

17. *Gyroidina*

- Test is trochospiral, evolute in the spiral side.
- The wall is made of calcium, has granular particles in it, and is coarsely perforated. There is a low interio-marginal slit that extends almost to the edge and halfway to the umbilicus [6].

18. *Bathysiphon*

- The test is a straight unbranched elongated tube with open ends on both sides.
- The wall is thick and agglutinated with sponge spicules, sand grains and many other foreign particles [6].

19. *Semitextularia*

- A compressed, test-free section characterized by a flattened, palmate structure, displaying a brief early biserial portion with two to four pairs of wide, low chambers arranged in a biserial fashion.
- The chamber interior is divided into multiple sections by numerous vertical interseptal partitions [6].

20. *Discorbis*

- Test is trochospiral.
- Structure is planoconvex to unequally biconvex with a flattened umbilical side [6].

21. *Sorosphaera*

- Test is free consisting of a series of sub-globular chambers lacking a specific arrangement.
- The wall is made up of loosely cemented coarse particles that have been agglutinated together [6].

22. *Amphistegina*

- The test is characterized by a low trochospiral shape, being lenticular and unequally biconvex
- It exhibits a bi-involute or partially evolute structure on the spiral side [6].

23. *Textularia*

- The test is consistently biserial, or it may occasionally feature an additional third chamber positioned next to the initial pair of chambers in the microspheric stage.
- The wall is composed of agglutinated material and contains canaliculi that might appear as perforations or be sealed externally by a thin layer of agglutinated material. Internally, these canaliculi are typically closed off by the organic lining of the test [6].

24. *Planularia*

- The test is large, broadly oval-shaped, strongly flattened.
- Chambers widen quickly in breadth, with a slightly greater increase in height along the dorsal margin compared to the ventral side, causing the test to flare [6].

25. *Bolivina*

- Test is elongated, ovoid to triangular in outline, slightly compressed, with broad, low, biserial chambers throughout.
- Rarely, the final chamber may be nearly central in position.
- Wall calcareous, hyaline, perforate, optically radial, surface decorated with irregularly anastomosing imperforate costae, or occasionally exhibiting pore formation in the costae [6].

26. *Stensioeina*

- The test is coiled in a flat trochospiral shape and has a form that is either planoconvex or unequally biconvex.
- The wall is composed of calcareous material, characterized by a granular appearance when viewed optically and coarse perforations. On the spiral side, the surface exhibits prominent irregular ridges along the sutures [6].

27. *Saccamina*

- The test is unattached and consists of a solitary spherical chamber that can reach up to 3.5 mm in diameter.
- The wall has a proteinaceous inner layer and is coated with small agglutinated quartz particles bound together by organic cement [6].

28. *Nodosarella*

- The test is elongated and composed of a series of slightly tapering chambers with straight sutures, without any depressions.
- The chambers overlap significantly [13].

29. *Peneroplis*

- The test is compressed and initially planispirally coiled and involute during the early stages of development.

Subsequently, later chambers rapidly widen and strongly arch, maintaining nearly constant height, leading to a flaring test shape. The interior of the chambers remains undivided, and sutures are slightly depressed.

- The wall is composed of calcareous and porcelaneous material, featuring perforations during the juvenile stage that later become imperforate [6].

30. *Glyphostomella*

- The test is coiled, planispiral, and involute, typically containing three chambers per whorl that increase in size quickly.
- Triangular septal chamberlets are present, created by septal lamellae or partitions.
- The nature of the wall is granular or calcareous, with the internal being alveolar to keriothecal and an external tectum [6].

31. *Valvulineria*

- The test is rounded in shape, sturdy, and coiled in a trochospiral manner, comprising approximately two and a half whorls.
- Periphery region is broadly rounded, with a flattened or moderately convex spiral side.
- The wall is composed of calcareous material, optically displaying radial patterns, finely perforated, and exhibiting a smooth surface [6].

32. *Globivalvulina*

- The test is unattached, ranging from subglobular to flattened perpendicular to the wide apertural face.
- Chambers are arranged in two rows, and the axis of biserial arrangement is coiled in a planispiral to slightly trochoid manner.
- The wall is made of microgranular, calcareous material. An inner fibrous or radial layer may be present, with the septa being the most prominent location for it [6].

33. *Orthovertella*

- The test is elongated, beginning with a proloculus and progressing to a tubular, undivided second chamber that is spirally coiled in a streptospiral pattern with a relatively constant diameter. In its final phase, it becomes uncoiled and rectilinear.

- The wall is made of calcareous and porcelaneous material, presenting a smooth surface. The aperture is located at the open end of the tube [6].

34. *Triloculina*

- The test is ovate, with an equilateral triangular or nearly triangular cross-section.
- Chambers extend for half of a coil's length.
- The test possesses a calcareous wall that is imperforate and exhibits a porcelaneous texture [6].

35. *Lenticulina*

- The test is coiled, typically planispiral, although occasional atypical specimens may display asymmetry or even a trochoid, lenticular, or biumbonate shape.
- The specimen structure commonly features an umbonal boss.
- The periphery is angled or carinate, with relatively wide and shallow chambers that gradually increase in size.
- The final one or two chambers may tend to flare out or uncoil [6].

36. *Stegnammina*

- The test is unattached, taking on a subcylindrical to prismatic form.
- Its wall is composed of agglutinated material, made up of fine to medium-sized grains that are tightly cemented together, resulting in a rough surface texture.
- The aperture is indistinct [6].

37. *Marginulina*

- The structure is elongated and exhibits a circular cross-section.
- Composed of calcareous material, the wall is transparent and radially perforated, featuring prominent longitudinal ridges on its surface.
- It may possess a pointed base. The aperture is radial, positioned terminally at the dorsal angle, and occasionally extends from a neck [6].

38. *Arenobulimina*

- The structure is coiled in a trochospiral manner, with four or more chambers in each whorl.

- The interior is uncomplicated and lacks division.
- The wall is composed of agglutinated material [6].

4. CONCLUSION

The present study showed a high abundance of foraminiferan diversity in Juhu Beach (Mumbai) and the lowest in Palolem Beach (Goa). Specimens belonging to the class Globothalamea were prevalent accounting for 39% of the total, followed by Monothalamea (26%) > Tubothalamea (11%) > Fusulinata (13%) > Nodosariata (11%). In this present study, 13 extinct genera were also documented. The occurrence of 13 extinct genera opines with the literature review and documented by other researchers.

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Some part of this manuscript was previously presented and published in the conference: An International Conference on Coastal and Marine Conservation CMC-2024 dated from 1st and 2nd March, 2024 in Mumbai, India. Web Link of the proceeding: <https://mithibai.ac.in/wp-content/uploads/2024/02/CMC-2024-CONFERENCE-brochure..pdf>.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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