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Journal of Threatened Taxa

10.11609/jott.2023.15.4.22927-23138
www.threatenedtaxa.org

26 April 2023 (Online & Print)
15(4): 22927-23138
ISSN 0974-7907 (Online)
ISSN 0974-7893 (Print)

Open Access

ISSN 0974-7907 (Online); ISSN 0974-7893 (Print)

Publisher
Wildlife Information Liaison Development Society
www.wild.zooreach.org

Host
Zoo Outreach Organization
www.zooreach.org

43/2 Varadarajulu Nagar, 5th Street West, Ganapathy, Coimbatore, Tamil Nadu 641006, India
Registered Office: 3A2 Varadarajulu Nagar, FCI Road, Ganapathy, Coimbatore, Tamil Nadu 641006, India
Ph: +91 9385339863 | www.threatenedtaxa.org
Email: sanjay@threatenedtaxa.org

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Cover: Mauve Stinger *Pelagia noctiluca* by Swaathi Na. Medium used is soft pastels and gelly roll.

Journal of Threatened Taxa | www.threatenedtaxa.org | 26 April 2023 | 15(4): 23101–23113
ISSN 0974-7907 (Online) | ISSN 0974-7893 (Print)
https://doi.org/10.11609/jott.7813.15.4.23101-23113
#7813 | Received 31 December 2021 | Final received 24 March 2023 | Finally accepted 02 April 2023

COMMUNICATION

Recent Foraminifera from the coast of Mumbai, India: distribution and ecology

Ganapati Ramesh Naik [1], Manisha Nitin Kulkarni [2] & Madhavi Manohar Indap [3]

[1,3] Department of Zoology, Central Research Laboratory, D.G. Ruparel College of Arts, Science & Commerce, Senapati Bapat Marg, Mahim, Mumbai, Maharashtra 400016, India.
[2] Department of Zoology, The Institute of Science, 15, Madam Cama Road, Mumbai, Maharashtra 400032, India.
[1] gnsrnaik@gmail.com, [2] harmonium.mnk@gmail.com, [3] madhaviindap@yahoo.com (corresponding author)

Abstract: Foraminifera have been used in biostratigraphy and paleoenvironmental research. They are useful environmental indicators for monitoring the marine environment. Intertidal sediment samples were analysed for their diversity in relation to physicochemical parameters and sediment characteristics along the Mumbai coast of India. Thirty-five species were found, divided into five orders and 18 families. The orders Rotaliida and Miliolida were identified to be dominant. Foraminifera were observed to be inversely related to sand particle size in relation to sediment and physicochemical parameters of water. Canonical correlation analysis explained the relationship between species abundance and water physicochemical parameters.

Keywords: Abundance, anthropological activities, environmental indicators, foram, grain size, marine coastal area, physicochemical factors, Protista

Abbreviations: CCA—Canonical correlation analysis | DO—Dissolved oxygen | MON—Monsoon | MPCB—Maharashtra Pollution Control Board | OC—Organic carbon | OM—Organic matter | POM—Post-monsoon | PRM—Pre-monsoon | TFN—Total foraminifera number | WNT—Winter.

Editor: Rajashekhar K. Patil, Mangalore University, Mangalore, India.
Date of publication: 26 April 2023 (online & print)

Citation: Naik, G.R., M.N. Kulkarni & M.M. Indap (2023). Recent Foraminifera from the coast of Mumbai, India: distribution and ecology. *Journal of Threatened Taxa* 15(4): 23101–23113. https://doi.org/10.11609/jott.7813.15.4.23101-23113

Funding: There is no Government funding. Partially funded by Fine Envirotech Engineers, Mumbai.

Competing interests: The authors declare no competing interests.

Author details: Mr. Ganapati Ramesh Naik, PhD research scholar at D G Ruparel College's Department of Zoology, Central Research Laboratory. Has spent the last six years working in the subject of marine ecology. Dr. Manisha Nitin Kulkarni is currently a professor in the Department of Zoology at The Institute of Science in Mumbai. Her scientific interests include biodiversity and endocrinology. Dr. Madhavi Manohar Indap is an emeritus professor. Adjunct faculty at D G Ruparel College's Central Research Laboratory in Mumbai. Her areas of interest in study include biodiversity, ecology, and marine biotechnology.

Author contributions: Madhavi Indap (MI) had conceptualized the study, directed and finalized the manuscript. Ganapati Naik (GN) collated in the information, evaluated the data and wrote the manuscript. Manisha Kulkarni (MK) had supervised the manuscript.

Acknowledgements: We are thankful to National Centre for Nano-sciences and Nanotechnology, University of Mumbai (NCNNUM) for providing us the facility of scanning electron microscopy (SEM) for our work. We are grateful to Fine Envirotech Engineers, Mumbai for providing financial help to carry out this work.

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INTRODUCTION

Mumbai, the state capital of Maharashtra, has a population of about 22 million people. It is also the largest and busiest port on India's west coast. Intertidal zone of Mumbai represents the peak of adaptability by most types of marine life to harsh environmental circumstances such as wave action, desiccation and other associated aspects generated by the tides of the sea (Kameswara & Srinath 2002). Among marine microorganisms, foraminifera are exceptionally varied and widely spread (Cushman et al. 1928). They are distinguished as protists by having an external test and streaming granular ectoplasm. Their tests are composed of calcium carbonate or agglutinated sediments, which are well preserved after death (Vidya & Patil 2014). They are considered good ecological indicators for detection and monitoring of coastal pollution (Pravasini & Patra 2012). According to Fabrizio et al. (2013), *Ammonia tepida* has a high resistance to environmental stress while *Ammonia parkinsoniana* is sensitive to pollution. These are the most widely used fossil species for biostratigraphy, sediment correlation and palaeoenvironmental research (Murray 2006) and their usage as bio-indicators in offshore oil drilling operations is well documented (Mariéva et al. 2010). Abninath & Biswas (1954), Devi & Rajashekhar (2009), and Subhadra & Patil (2012) conducted intertidal studies of foraminifera from the Mumbai coast on diversity studies in the intertidal region. Coastal water is vulnerable to contamination since 38% of the world's population lives within 100 kilometres of the coast (Pravasini & Patra 2012). Coastal pollution is caused by point and non-point wastewater sources from cities, which include sewage water, waste from industry and harbours, beach tourism and fishing crafts activities. Pollution has a negative impact on organisations at all levels, from the organism to the community and the environment (Francisco et al. 2011).

The current study was undertaken to document the Foraminifera at several sites along the Mumbai coast. The objective was to determine the relationship between foram abundance and various physicochemical factors, as well as anthropological activities. This information will aid in the creation of a database of foraminifera along Mumbai's coastline and contribute to understanding the effects of natural and anthropogenic events on Foraminifera.

Study Area

Mumbai is located at 19.0760° N & 72.8777° E, with an overall coast length of 149 km. Four coastal locations with distinct ecology were chosen for sampling. These sites range from north to south along the Mumbai shoreline (Figure 1). Gorai beach (M1) is located in Mumbai's northwestern outskirts. It is regarded as one of Mumbai's cleanest beaches. Juhu beach (M2) has a five-kilometre coastline. Dadar beach (M3) is situated on the south-west side of Mahim Island. Girgaon beach (M4) is located on Mumbai Island's south-west coast. M2, M3, and M4 are well-known tourist attractions. Mumbai's water quality is deteriorating as a result of pollutants from wastewater treatment facilities, sewage discharges, and discharges from point and non-point sources in the creek and along the shore (Ritesh et al. 2015).

MATERIAL AND METHODS

Sediment samples were collected in two phases: September 2013–August 2014 and December 2016–November 2017, from four stations: M1, M2, M3, and M4. The sampling was divided into four seasons: pre-monsoon (March–May), monsoon (June–August), post-monsoon (September–November), and winter (December–February).

Using a scientific spatula, the upper one cm layer of sand sediment was collected in duplicates between the intertidal zone during low tide. Forams were stained using Rose Bengal solution and stored in 70% isopropyl alcohol (Walton et al. 1952). The materials were washed through a 63 µm sieve and oven-dried at 60°C for analysis. A stereo microscope was used to examine one gram of sand from each station. The total number of specimens (live + dead) was used to calculate abundance. Foram tests were hand-picked and put on micro-paleontological slides using a foram sorting brush. 'JEOL JSM - 5800VS' scanning electron microscope (SEM) was used to image selected specimens. The Loeblich & Tappan (1988) classification system and the e-site "World Foraminifera Database" (Hayward et al. 2022) were used for taxonomic analysis.

Temperature, pH, salinity, dissolved oxygen (DO), phosphates and nitrates were chosen as water physicochemical parameters. A digital thermometer was used to record the temperature of the water at sample sites. pH, salinity and DO were measured with a "Thermo Scientific Eutech PCD-650 multi-parameter metre." Nutrients nitrate and phosphate were estimated

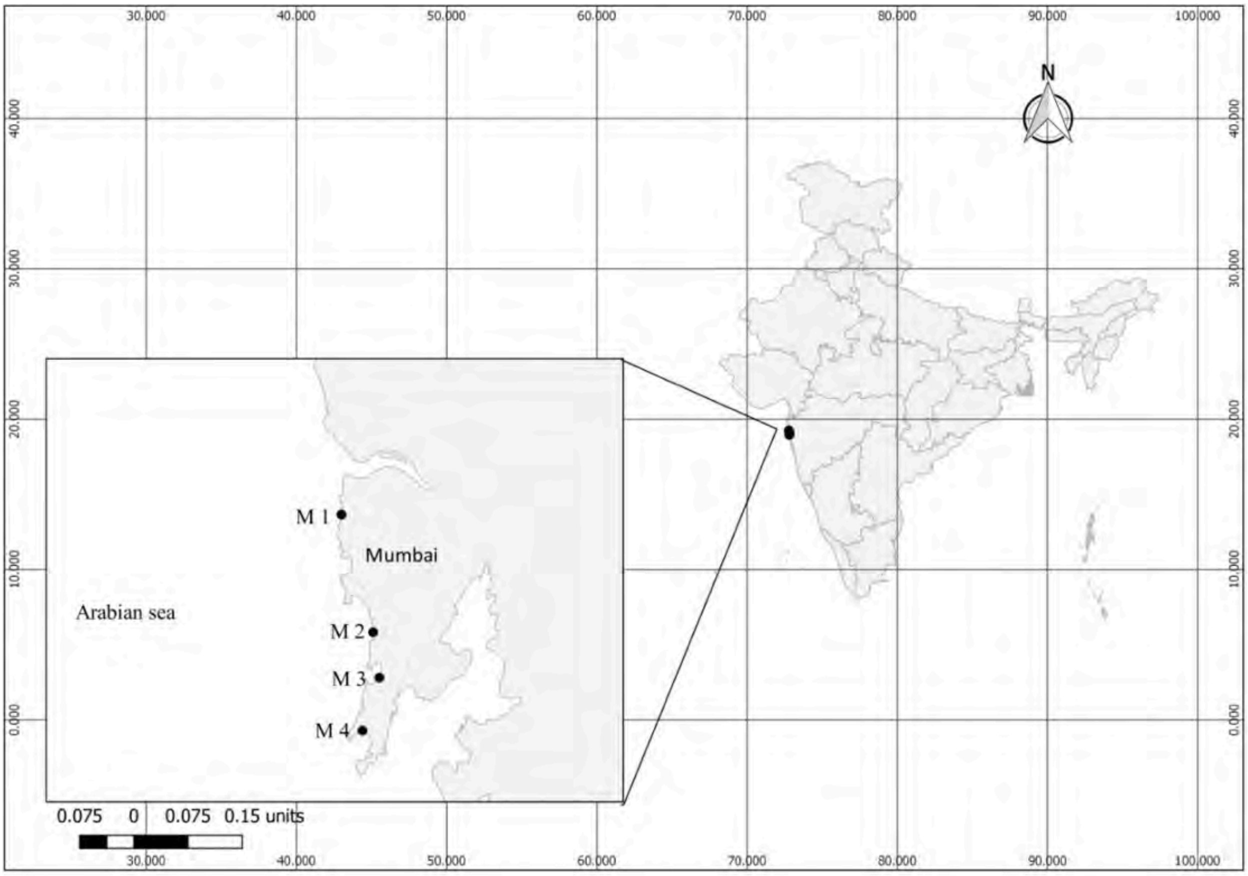

Figure 1. Map depicting the study area with sampling sites.

using standard methods given in the APHA manual (Lenore et al. 1999).

Another batch of sand sediment was collected for measurement of organic carbon by titration with ammonium ferrous sulphate using the Walkley-Black technique with suitable modification (Syed et al. 2011). To determine the texture of sand sediment, samples were sieved through multiple mesh sizes. The soil textural triangle approach (Derek et al. 2015) was used to determine their type. Past 3 v4.03 software was used to calculate diversity indices including the Shannon index, Simpson index, Evenness, Margalef index, canonical correlation, and Q-mode cluster.

RESULTS AND DISCUSSION

Foraminifera Assemblage & Physicochemical Parameters

The current study revealed the existence of 35 species from four orders, 18 families and 21 genera (Table 1). These 35 species were divided into 33 benthic and two planktonic species. M1, M2, M3, and M4 stations revealed the presence of 34, 32, 33, and 22 species, respectively. Order Rotaliida was dominant with 19 species, followed by order Miliolida, which had 11 species. The dominant species identified along Mumbai's shore were *Nonion scaphum* (17.8%), *Ammonia beccarii* (15.7%), *A. dentata* (12%), *Elphidium hispidulum* (8.9%), and *Bolivina striatula* (5.7%). Table 2 has a Foraminifera checklist. Images 1 (1–20) and 2 (1–19) displays SEM images that illustrate the morphological trait of species.

The total Foraminifera number (TFN) is the total number of individuals found in one gram of sediment. TFN values in samples ranged from 590 at M2 to 178 at M4 per gram. Northern Mumbai stations (M1, M2) showed greater values, whereas southern Mumbai stations recorded lesser values (M3, M4).

Shannon index (H) represented both species abundance and evenness in areas ranging from 2.06 (M4) to 2.77 (M2). Simpson index of dominance (D) revealed the dominance of cosmopolitan species with values 0.08 (M2) to 0.21 (M4). Equitability index revealed species evenness (e^H/S) with values ranging from 0.41 (M3) to 0.67 (M4). The Margalef index of species richness ranged from 2.09 (M4) to 5.04 (M1), and is directly related to taxonomic numbers 12 (M4) and 32 (M1). Table 3 presents the diversity indices.

The water parameters including pH, temperature, salinity, dissolved oxygen, phosphate, and nitrate were considered for study of various seasons including, pre-monsoon, monsoon, post-monsoon, and winter, which are represented in Table 4.

The pH ranged from 6.54 at M2 during post-monsoon to 7.89 at M4 during monsoon. Water temperatures in the intertidal zone ranged from 25°C reflecting monsoon at M4 to 29°C representing pre-monsoon at M1. Salinity at all sites varied with the seasons, ranging from 17 during the monsoon at M1 to 41 during the pre-monsoon at M2.

Dissolved oxygen, phosphate and nitrate showed variations in its concentrations. DO levels were highest during the pre-monsoon (7.4 mg/l) and lowest during the winter (3.1 mg/l) at M1. Similarly, in monsoon, M4 station had the lowest phosphate and nitrate levels, viz., 0.14 mg/l and 0.1 mg/l and M3 in winter revealed the greatest phosphate and nitrate ranges 0.56mg/l to 1.5mg/l, respectively.

The sediment type study revealed that silt type occurred at the M1 and M2, loamy sand at the M3 and sandy loam at the M4. The organic carbon percentage of sediment varied between stations, ranging from 0.28% to 0.37% (Table 4).

Pearson Correlation & Canonical Correlation Analysis (CCA)

For the water parameters and diversity indices, a Pearson correlation matrix was calculated (Table 5). The pH and dissolved oxygen correlated positively with species evenness but negatively with the other indices. Temperature correlated positively with the number of taxa, the H index and the Margalef index. Salinity only correlated positively with species dominance. Phosphate and nitrate had a significant negative correlation with species evenness.

CCA defined a relationship between species, stations and environmental parameters (Figure 2). For this analysis, species having a total population more than 1% was chosen, which included population of 18 species. Phosphate and dissolved oxygen defined axis one, whereas nitrate, pH, salinity, and temperature defined axis two. According to CCA analysis nitrate, pH and salinity correlated positively, but temperature correlated negatively with all other physicochemical parameters. All of the water parameters were found to have a significant correlation with 12 species.

Ammonia beccarii, *E. repandus*, *A. dentata*, and *S. raphana* were abundant at three sample stations displayed in the top-right quadrant of the graph. *T. oblonga*, *A. intricata*, *T. tricarinata*, and *E. hispidulum* peaked at five stations in the bottom right quadrant of the graph. *Q. vulgaris*, *U. senticosa*, *N. scaphum*, and *B. pseudoplicata* showed the highest abundance at five stations represented at top-left quadrant of graph and species *B. marginata*, *R. globularis*, *B. striatula*, *C. lobatulus*, *Q. tropicalis*, and *E. advenum* were most abundant at three stations represented at bottom-left quadrant of graph.

A. beccarii and *A. dentata* are mainly found in waters with high nitrate levels. *N. scaphum* was well associated with ambient temperature and phosphate concentration. *B. striatula*, *C. lobatulus* and *Q. tropicalis* held the average positions for all parameters. *E. hispidulum* and *T. tricarinata* were significantly correlating with DO, pH, and salinity.

Species-ecological Relationship

This research attempted to investigate the relation of foraminifera to intertidal benthic ecology at different stations. Data from physicochemical parameters were correlated with dominant species using specific indices.

At M1 TFN ranged from 533 to 450 individuals per gram, it was represented by 34 species. *N. scaphum* (28.33%), *A. dentata* (12.3%), *E. hispidulum* (8%) and *A. beccarii* (7.64%) were dominant species representing the area. According to Kumar & Manivannan (2001) *N. scaphum* has shown positive correlation to an increase in temperature and DO, our data support this statement. During the winter, the Simpson's index 0.14 is correlating with nitrate value. There is cumulative impact of nitrate and temperature with bleaching response on foraminifera (Martina et al. 2017), allowing only tolerant species to thrive. Thirty-one species have been identified at M2, with a maximum foraminifera test count of 590 in pre-monsoon. Here major taxa were again *N. scaphum* (21%), *A. dentata* (10.82%), and *A. beccarii* (10.59%). Phosphate has long been recognized as a calcite formation inhibitor, adsorbing onto the calcite surface and inhibiting active crystal growth sites (Aldridge et al. 2011), which might account for lower test numbers than M1. After *A. beccarii*, the dominant species was *B. striatula* (8.12%). *Lagena*, *Fissurina*, *Bolivina*, *Bulimina*, and *Uvigerina* species are found in finer sediments and exist in the shelf to slope area, according to Rajiv et al. (1986); however their prevalence in the study area

Table 1. Foraminiferal taxa composition along with the stations of Mumbai coast.

	Order	Family	Genus	Species
1	Rotaliida	Nonionidae	*Nonion*	*Nonion scaphum*
2		Ammoniidae	*Ammonia*	*Ammonia beccarii*
3				*Ammonia dentata*
4		Bolivinitidae	*Bolivina*	*Bolivina striatula*
5				*Bolivina pseudoplicata*
6		Siphogenerinoididae	*Spiroloxostoma*	*Spiroloxostoma glabra*
7			*Siphogenerina*	*Siphogenerina raphana*
8				*Siphogenerina* sp.
9		Elphidiidae	*Elphidium*	*Elphidium hispidulum*
10				*Elphidium advenum*
11				*Elphidium* sp.
12		Rosalinidae	*Rosalina*	*Rosalina globularis*
13		Eponididae	*Eponides*	*Eponides repandus*
14		Cibicididae	*Cibicides*	*Cibicides lobatulus*
15		Discorbinellidae	*Discorbinella*	*Discorbinella* sp.
16		Buliminidae	*Bulimina*	*Bulimina marginata*
17		Uvigerinidae	*Uvigerina*	*Uvigerina senticosa*
18		Globigerinidae	*Globigerina*	*Globigerina bulloides*
19			*Globigerinoides*	*Globigerinoides* sp.
20	Miliolida	Hauerinidae	*Quinqueloculina*	*Quinqueloculina tropicalis*
21				*Quinqueloculina porterensis*
22				*Quinqueloculina vulgaris*
23				*Quinqueloculina polygona*
24				*Quinqueloculina agglutinans*
25			*Triloculina*	*Triloculina tricarinata*
26				*Triloculina oblonga*
27		Spiroloculinidae	*Spiroloculina*	*Spiroloculina antillarum*
28				*Spiroloculina communis*
29		Cribrolinoididae	*Adelosina*	*Adelosina intricata*
30		Cornuspiridae	*Cornuspira*	*Cornuspira involvens*
31	Nodosariida	Lagenidae	*Lagena*	*Lagena vulgaris*
32				*Lagena sulcata*
33				*Lagena laevis*
34	Polymorphinida	Ellipsolagenidae	*Fissurina*	*Fissurina cucullata*
35				*Fissurina* sp.

may be due to wave action. M3 receives water runoff from the Mithi River and had low salinity during the monsoon due to monsoon water, in addition to large amount of sewage and industrial garbage from the Mithi (Jayasiri et al. 2014). At the M3, 33 distinct taxa were present. *A. beccarii* (24.18%), *A. dentata* (15.2%), and *E. hispidulum* (12.21%) dominated the station. M4 had taxa count 20 with a maximum of 198 individuals. The dominant species representing the area were *A. beccarii* (32.67%), *T. tricarinata* (15.02%), and *E. hispidulum* (11.55%).

The distribution of benthic Foraminifera is influenced by organic carbon (OC) and sediment type (Elakkiya & Manivannan 2013). Benthic foram have been shown to be closely associated with variations in percent gravel, organic carbon flux, temperature and salinity (Alexandra

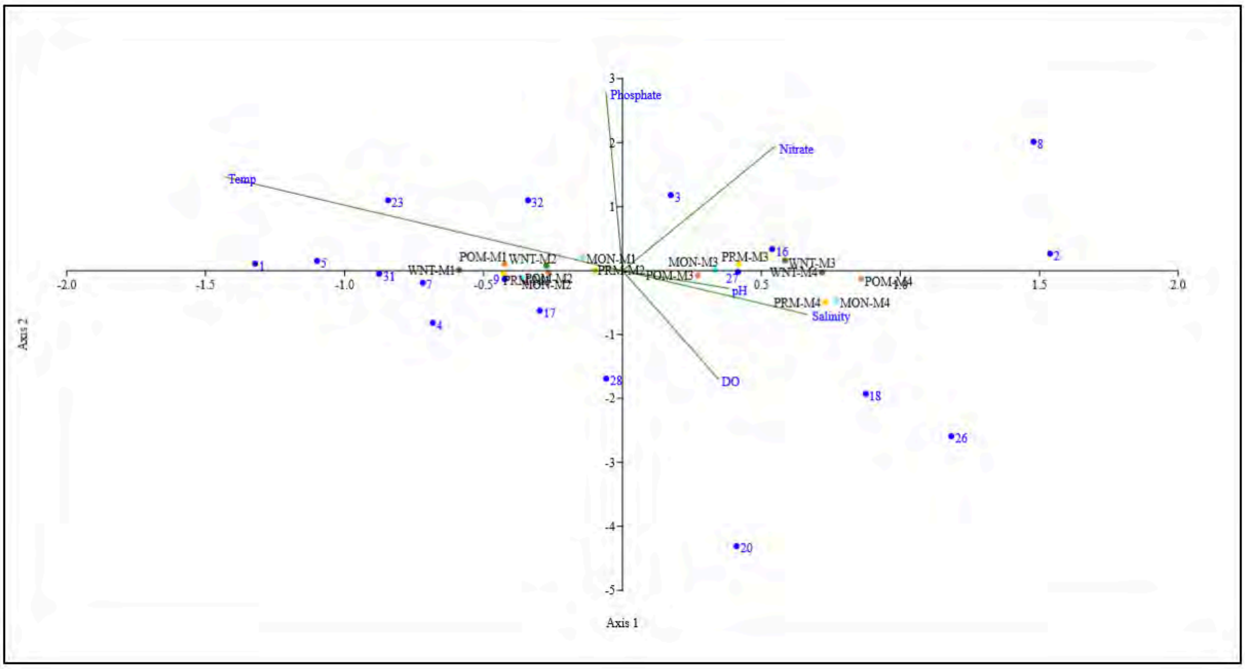

Figure 2. Canonical correlation analysis (CCA) of abundant species with relation to physico-chemical parameters of water and station distribution.

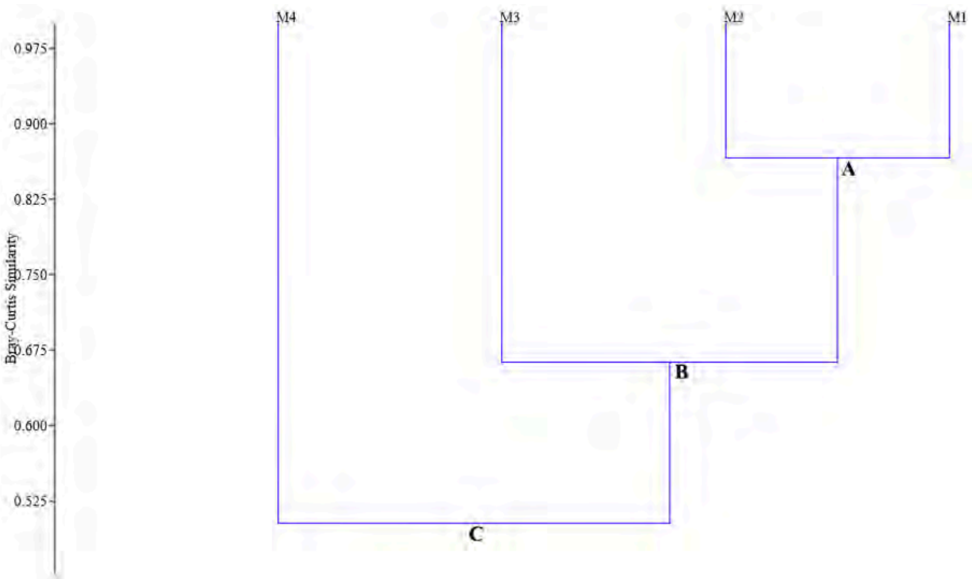

Figure 3. Bray-Curtis hierarchical cluster analysis for sampling stations.

et al. 2007). The sediment at stations M1 and M2 was silt type, with 0.34% and 0.28% organic carbon, respectively. At M1 Margalef index of 5.04 and at M2 Shannon value of 2.77 were both positively correlated with sediment type, as sand mixed with shelly fragments and silt or clay support the richest standing crop of foraminifera (Chaturvedi et al. 2000). Station M3 had loamy sand with the highest organic carbon content of 0.37% of all stations. Water discharge from Mahim Creek has the highest percentage of organic carbon, as the creek is the largest sink for the most of waste created by residential complexes and small-scale industry (Singare et al. 2015). Station M4 is associated with 0.31% organic carbon with sediment particle size larger than other stations. According to Elena et al. (2019) stations exposed to the open sea and intensified currents were

Table 2. Distribution of Foraminifera species along four stations of Mumbai coast.

	Species	M1	M2	M3	M4
1	*Nonion scaphum*	+	+	+	+
2	*Ammonia beccarii*	+	+	+	+
3	*Ammonia dentata*	+	+	+	+
4	*Bolivina striatula*	+	+	+	+
5	*Bolivina pseudoplicata*	+	+	+	+
6	*Spiroloxostoma glabra*	+	+	+	-
7	*Siphogenerina raphana*	+	+	+	+
8	*Siphogenerina* sp.	+	+	+	-
9	*Elphidium hispidulum*	+	+	+	+
10	*Elphidium advenum*	+	+	+	+
11	*Elphidium* sp.	+	-	+	+
12	*Rosalina globularis*	+	+	+	+
13	*Eponides repandus*	+	+	+	+
14	*Cibicides lobatulus*	+	+	+	+
15	*Discorbinella* sp.	-	-	+	-
16	*Bulimina marginata*	+	+	+	+
17	*Uvigerina senticosa*	+	+	+	+
18	*Globigerina bulloides*	+	+	+	-
19	*Globigerinoides* sp.	+	+	+	-
20	*Quinqueloculina tropicalis*	+	+	+	+
21	*Quinqueloculina porterensis*	+	+	+	-
22	*Quinqueloculina vulgaris*	+	+	+	+
23	*Quinqueloculina polygona*	+	+	+	+
24	*Quinqueloculina agglutinans*	+	-	-	-
25	*Triloculina tricarinata*	+	+	+	+
26	*Triloculina oblonga*	+	+	+	+
27	*Spiroloculina antillarum*	+	+	+	+
28	*Spiroloculina communis*	+	+	+	+
29	*Adelosina intricata*	+	+	+	+
30	*Cornuspira involvens*	+	+	+	-
31	*Lagena vulgaris*	+	+	+	-
32	*Lagena sulcata*	+	+	+	-
33	*Lagena laevis*	+	+	-	-
34	*Fissurina cucullata*	+	+	+	-
35	*Fissurina* sp.	+	+	+	-

defined by coarser sediments. As M4 had sandy loam type of sediment suggesting good wave action due to its association with open sea. The moderate value of OC at this station is associated with sediment type, since in coarse-grained sand, interstitial water may travel easily through pore spaces, resulting in less organic particle settling (Hiroshi 1994).

A. beccarii and *A. dentata* correlated negatively with DO values from all stations, making them adaptable to anoxic conditions (Fatin et al. 2012; Sundara et al. 2016). *B. striatula* which thrived well in low oxygen stations (Abhijit & Nigam 2014) and was positively associated to salinity since it is an opportunistic species that can thrive in both high and low salinity conditions (Patricia et al. 2019). The dominance of *Ammonia* sp. and *Elphidium* sp. in study area indicated that they are resistant to decreased salinity, pH or a combination of the two factors (Laurie et al. 2018).

N. scaphum adapted to environments characterized by high organic matter (OM) quality and it indicates affinity for OM-rich sediments (Pierre et al. 2016), so its distribution is well associated with M1 and M2 as compared to M4 which had more coarse type of sediment. *A. dentata* and *E. hispidulum* was abundant at M1, M2 and M3 as silt sand is preferred by the species over coarse sandy sediment (Elakkiya & Manivannan 2013), with affinity for larger amount of organic carbon values (Maria et al. 2012). However, based on our understanding of above work on foraminifera, we may conclude that the cosmopolitan species *A. beccarii*, *A. dentata*, *B. striatula*, *N. scaphum*, and *E. hispidulum* thrive well in Mumbai waters.

Hierarchical Cluster Analysis

Foraminifera species were tested to a Bray-Curtis cluster analysis in relationship to stations (Figure 3). It divided stations into three groups: Cluster A (M1 + M2), Cluster B (Cluster A + M3), and Cluster C (Cluster B + M4).

Cluster A consists of two stations (M1 + M2) that share 32 species. It had a similar type of sediment, silt with physicochemical properties. CCA analysis showed these stations near to one other on the middle and left sides of Axis one. The main representatives of this cluster were *N. scaphum* (21–28.3%), *A. beccarii* (7.6–10.5%), *A. dentata* (10.8–12.3%), *B. striatula* (6.6–8.1%), *B. pseudoplicata* (5.5–5.6%), *C. lobatulus* (4.7–5.5%), *Q. tropicalis* (3.5–6.4%), *E. hispidulum* (6.5–8%), *U. senticosa* (2.9–3.7%), *T. tricarinata* (1.8–3.5%) and *B. marginata* (2.8–3.1%). Species like *N. scaphum*, *A. dentata*, and *B. striatula* have more affinity for fine sediment like silt than coarse type of sediment.

Cluster B comprised of three stations (Cluster A + M3) with 31 species in common. In this cluster M3 is having more similarity with M2 than M1. The cluster had silt and loamy sand sediment which showed a little correlation with one another. The main species represented by the cluster were *N. scaphum* (8.2–28.3%), *A. beccarii* (7.6–24.1%), *A. dentata* (10.8–15.2%), *E. hispidulum*

Table 3. Biodiversity indices of Foraminifera for Mumbai coast.

Station	Season	Taxa	Individuals	Dominance	Shannon	Evenness	Margalef
M1	Pre-monsoon	32	467	0.1249	2.646	0.4407	5.044
	Monsoon	28	533	0.1224	2.529	0.4479	4.3
	Post-monsoon	29	476	0.1203	2.585	0.4575	4.541
	Winter	28	450	0.1474	2.525	0.446	4.42
M2	Pre-monsoon	29	590	0.1039	2.671	0.4983	4.389
	Monsoon	27	431	0.087	2.776	0.5945	4.286
	Post-monsoon	28	414	0.08698	2.757	0.5625	4.481
	Winter	27	486	0.1057	2.625	0.5113	4.203
M3	Pre-monsoon	27	363	0.1259	2.528	0.4638	4.411
	Monsoon	29	385	0.1069	2.681	0.5035	4.703
	Post-monsoon	26	328	0.09856	2.644	0.5411	4.316
	Winter	29	389	0.1413	2.484	0.4132	4.695
M4	Pre-monsoon	19	193	0.1416	2.317	0.5339	3.42
	Monsoon	12	192	0.1593	2.086	0.6711	2.092
	Post-monsoon	17	178	0.2122	2.064	0.4632	3.088
	Winter	20	198	0.1662	2.297	0.4971	3.593

(6–12.2%), *T. tricarinata* (1.8–6.2%), *E. repandus* (0.9–3.3%), *C. lobatulus* (3.2–5.5%), *B. striatula* (3.1–8.1%), and *Q. tropicalis* (3.2–6.4%).

Cluster C comprised of all four stations (Cluster B + M4) that share 22 species in common. In this cluster M4 had more similarity with M3 as compared with Cluster A. As M3 and M4 had loamy sand and sandy loam sediment, which had more similarity with each other. Having a more coarse type of sediment was responsible for more resistant taxa to sediment particle movements by wave action. The main species represented by the cluster were *A. beccarii* (1.9–28.3%*)*, *T. tricarinata* (1.8–15%), *E. hispidulum* (6.5–11.5%), *A. dentata* (8.5–15.2%), *E. repandus* (0.9–5.2%), *E. advenum* (1.6–4.1%), *T. oblonga* (0.8–3.1%), and *R. globularis* (1.1–2.3%).

Test Deformity

Environmental stress induced by large fluctuations in environmental factors such as salinity, DO, temperature, pH, sedimentation, pollution and hydrodynamics has been connected to a significant percentage of abnormal tests in foraminiferal assemblages (Rehab et al. 2011). Mumbai is India's economic hub, and increased urbanization and industrialization have resulted in an increase in marine discharges to coastal areas (Jayasiri et al. 2014). According to Maharashtra Pollution Control Board (MPCB) data on Maharashtra's water quality condition, water at stations Juhu (M2), Dadar (M3), and Girgaon (M4) had a bad water quality index (MPCB 2013–14, 2016–17). In the present study *Quinqueloculina* sp. (M3)*, Triloculina* sp. (M3), *Siphogenerina raphana* (M2, M3*)* and an Undetermined taxa showed the abnormal formation of shells. These deformed tests have been shown in Image 2 (15–19).

Quinqueloculina sp. (M3) showed reduced chambers, *Triloculina* sp. (M3) had twisted chambers, *Siphogenerina raphana* (M2, M3) represented by enlarged chambers and uneven costae lines, and the undetermined taxa had unusually extended chambers. These abnormalities imply that environmental conditions and industrialization have had a negative impact on foraminiferal diversity. All of these abnormalities were associated predominantly with M3 station. According to studies conducted by Shamrao & Kadam (2003), Jayasiri et al. (2014), and Ritesh et al. (2015), Dadar beach is extremely contaminated owing to effluents carried in by the Mithi River, with low-energy hydrodynamics generated by the lagoon region. According to MPCB publications (MPCB 2013–14, 2016–17), the water quality index for M3 is also rated as bad to very-bad. According to Suresh & Sonia (2012) morphological abnormalities are induced by pollution, strongly in shallow waters than deep seas. According to Jayaraju et al. (2008), heavy metal contamination has a greater negative impact on

Table 4. Physico-chemical parameters of water, organic carbon, and sediment type from sampling stations.

Station	Season	pH	Temperature (°C)	Salinity (‰)	Dissolved oxygen (mg/L)	Phosphate (mg/L)	Nitrate (mg/L)	Organic carbon %	Sediment type
M1	Pre-monsoon	7.52	29	30	7.4	0.2181	0.2	0.34	Silt
	Monsoon	7.61	28	17	7.2	0.327	0.5		
	Post-monsoon	7.33	28	35	6.2	0.349	0.44		
	Winter	7.11	27	38	3.1	0.315	0.648		
M2	Pre-monsoon	7.65	27	41	6.04	0.1455	0.95	0.28	Silt
	Monsoon	7.6	27	32	7.1	0.269	0.513		
	Post-monsoon	6.54	28	37	6.4	0.328	0.465		
	Winter	7.42	28	38	3.45	0.413	0.782		
M3	Pre-monsoon	7.43	28	38	5.8	0.264	0.65	0.37	loamy sand
	Monsoon	7.06	27	25	6.7	0.261	0.38		
	Post-monsoon	7.81	27	36	6.1	0.352	0.425		
	Winter	7.39	28	38	3.42	0.563	1.5		
M4	Pre-monsoon	7.09	29	39	6.1	0.214	0.687	0.31	Sandy loam
	Monsoon	7.89	25	29	7.4	0.1454	0.1		
	Post-monsoon	7.05	27	37	6.7	0.361	0.456		
	Winter	7.45	27	39	4.6	0.289	0.663		

Table 5. Pearson correlation analysis for diversity indices and physico-chemical parameters of water.

	pH	Temperature	Salinity	Dissolved oxygen	Phosphate	Nitrate	Taxa	Individuals	Dominance	Shannon	Evenness	Margalef
pH												
Temperature	-0.3695											
Salinity	-0.2218	0.092786										
Dissolved oxygen	0.16147	-0.10486	-0.559									
Phosphate	-0.2266	0.27571	0.1359	-0.58298								
Nitrate	-0.0683	0.26441	0.4791	-0.70243	0.57205							
Taxa	-0.127	0.53909	-0.093	-0.17265	0.27933	0.2728						
Individuals	0.08318	0.29869	-0.193	-0.093673	0.083084	0.2117	0.85011					
Dominance	-0.0449	-0.22792	0.1315	-0.10616	0.057666	-0.012	-0.6639	-0.663				
Shannon	-0.0992	0.3675	-0.073	-0.028479	0.090162	0.1115	0.87788	0.78129	-0.9176			
Evenness	0.20239	-0.58162	-0.059	0.39673	-0.49099	-0.458	-0.5564	-0.3568	-0.2039	-0.1202		
Margalef	-0.1953	0.59841	-0.038	-0.19832	0.3278	0.2943	0.98356	0.74471	-0.614	0.85002	-0.6019	

foraminiferal test morphology than agricultural and aquacultural wastes. From these damaged shells it may be concluded that they act as a sensitive taxon to environmental and anthropogenic conditions.

CONCLUSION

The present study revealed diversity and distribution of Foraminifera along Mumbai coast with presence of 35 species belonging to four orders, 18 families, and 21 genera. The orders Rotaliida and Miliolida dominated the taxa. *A. beccarii*, *N. scaphum*, *A. dentata*, and *E. hispidulum* were the most opportunistic species present at all stations. Due to similarities in sediment and species distribution, CCA and Bray-Curtis similarity analysis revealed that M1-M2 and M3-M4 were more associated with each other. *N. scaphum* served as sensitive taxa by showing affinity for oxygen and finer sediment type. *A. beccarii* and *E. hispidulum* acted

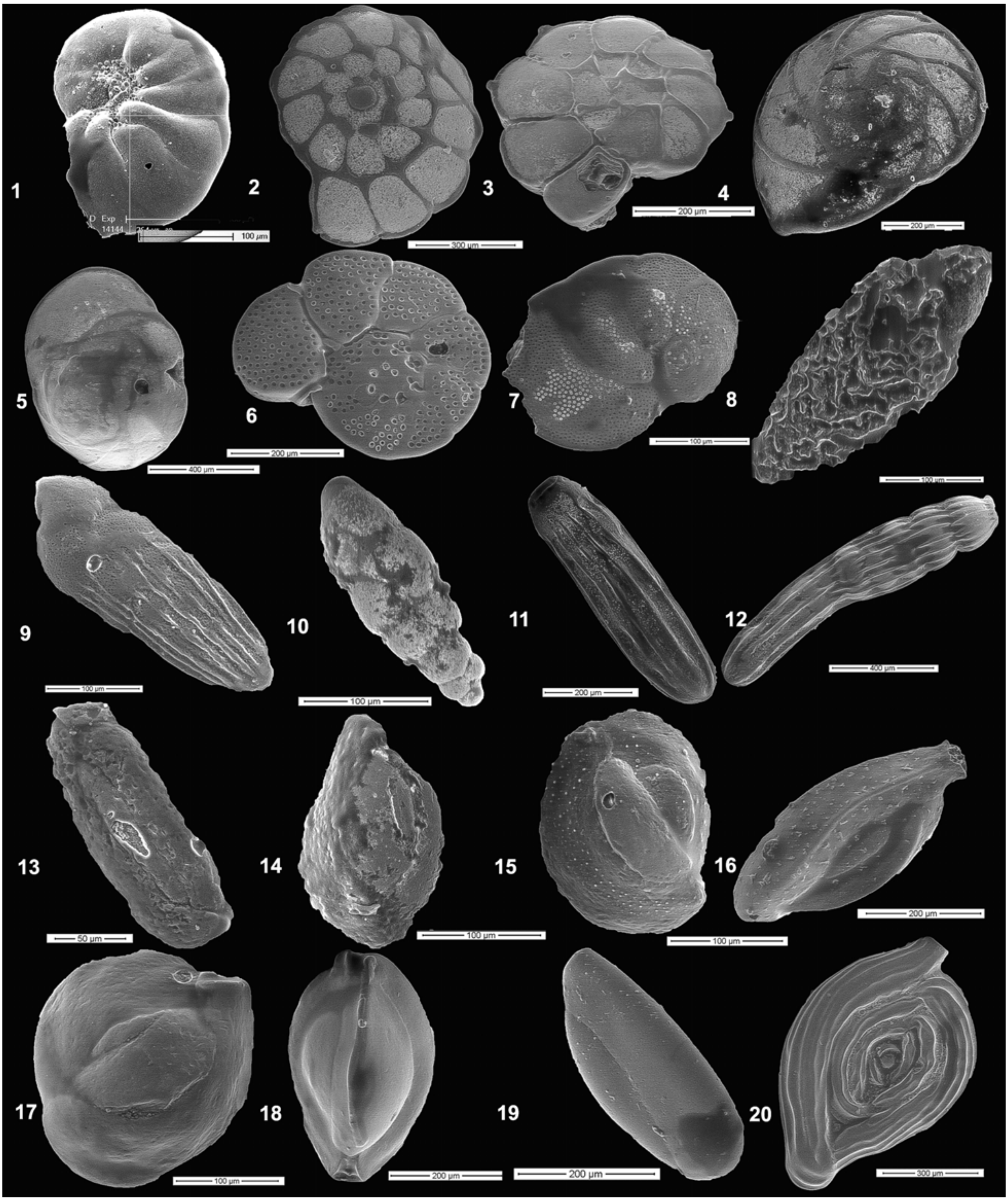

Image 1. 1 —*Nonion scaphum* | 2—*Ammonia beccarii* | 3—*Ammonia dentata* | 4—*Eponides repandus* | 5—*Rosalina globularis* | 6—*Cibicides lobatulus* | 7—*Discorbinella* sp. | 8—*Bolivina pseudoplicata* | 9—*Bolivina striatula* | 10—*Spiroloxostoma glabra* | 11—*Siphogenerina raphana* | 12—*Siphogenerina* sp. | 13—*Quinqueloculina tropicalis* | 14—*Quinqueloculina agglutinans* | 15—*Quinqueloculina vulgaris* | 16—*Quinqueloculina polygona* | 17—*Quinqueloculina porterensis* | 18—*Triloculina tricarinata* | 19—*Triloculina oblonga* | 20—*Spiroloculina antillarum*. © SEM image is created and edited by Ganapati Naik.

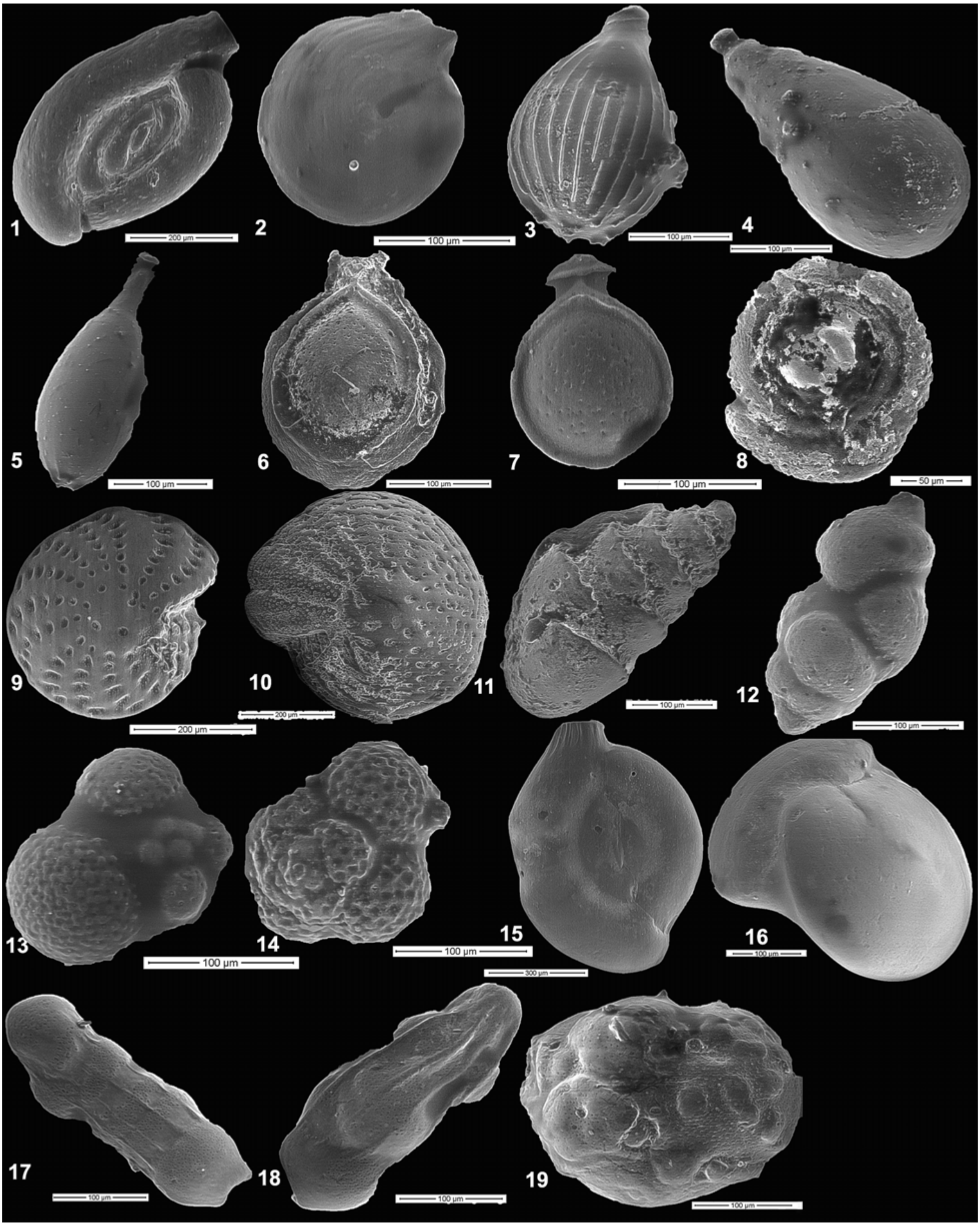

Image 2. 1—*Spiroloculina communis* | 2—*Adelosina intricata* | 3—*Lagena sulcata* | 4—*Lagena vulgaris* | 5—*Lagena laevis* | 6—*Fissurina cucullata* | 7—*Fissurina* sp. | 8—*Cornuspira involvens* | 9—*Elphidium advenum* | 10—*Elphidium hispidulum* | 11—*Bulimina marginata* | 12—*Uvigerina senticosa* | 13—*Globigerina bulloides* | 14—*Globigerinoides* sp. | 15—*Quinqueloculina* sp. | 16—*Triloculina* sp. | 17—*Siphogenerina raphana* | 18—*Siphogenerina raphana* | 19—Undetermined taxa. © SEM image is created and edited by Ganapati Naik.

as stress tolerant taxa flourishing well in fine as well as coarse sediment type. The presence of *B. striatula* indicated the hypoxic condition of water and sediment during winter season. The study found that finer to medium grain sand was associated with more species than coarse sand. Organic carbon concentrations correlated directly with fine sediment type and stations with low-energy hydrodynamic circumstances (M1, M3), allowing more organic carbon to trap between sand particles. The presence of deformed tests suggested that Mumbai's coastal water had physicochemical parameter fluctuations and received contaminated water from industrial areas. It symbolized the potential use of foraminifera in understanding the effects of urbanization and industrialization on coastal water. This creates a great need to construct foraminifera study models to comprehend long-term consequences of changing environmental and anthropogenic activities along urban coasts, since we cannot halt industrialization, but such research will assist to limit the impact of pollution on the marine environment.

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NAAS rating (India) 5.64

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OPEN ACCESS

ISSN 0974-7907 (Online) | ISSN 0974-7893 (Print)

April 2023 | Vol. 15 | No. 4 | Pages: 22927–23138
Date of Publication: 26 April 2023 (Online & Print)
DOI: 10.11609/jott.2023.15.4.22927-23138

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