

Distribution of Larger Benthic Foraminifera (LBF) in Selected Islands of Marine National Park, Port Blair, South Andaman, India

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Abstract

The present study enhances the knowledge on the diversity, abundance and depth distribution of larger benthic foraminifera (LBF) from six different islands in Mahatma Gandhi Marine National Park (MGMNP), where meagre anthropogenic impact existed. Very few works have been reported on the Larger Benthic Foraminifera (LBF) on this Island environment, as this region also falls under Marine Protected Area (MPA). Development of database on this study has a validity for pristine nature of LBF environment. Modern LBF hotspot diversity is often overlooked and no data are available to date on tropical regions. Out of 105 MPA's existed in this Island, MGMNP encompasses about 15 islands, out of which six islands were considered for the study. These six islands are Snob Island, Grub Island, Boat Island, Hobday Island, Belle Island and Jolly Buoy Island. The study revealed presence of 22 taxa of modern LBF and the most common families are the Amphisteginidae, Calcarinidae, Nummulitidae, Peneroplidae and Soritidae. The purpose of this study was to document the distribution of LBF species prevailing in this area, as well as develop the baseline environmental information of its existences to facilitate further continuous monitoring the changes occurring in this island environment. The environment suggested that the presence of major LBF species studied are *Calcarina calcarinoides*, *Calcarina defrancei*, *Calcarina hispida*, *Calcarina spengleri*, *Neorotalia calcar* and *Neorotalia gaimardi* exhibited the availability of good coral cover with commendable macro algal coverage or sparsely sea grasses, as they prefer such substratum for their epiphytic association.

Keywords

MPA, Wandoor, Andaman and Nicobar Islands, Amphisteginidae, Calcarinidae

1. Introduction

Andaman and Nicobar group of Islands are located about 1500 km from the mainland consisting of 672 Islands with latitude 6° - 17°N and longitude 93° - 94°E. From this archipelago, 105 islands have been listed under Marine Protected Areas (MPAs) for their unique marine biodiversity. Further, salt water crocodile proliferation (man and animal conflict) is also one of the major concerns on these areas. Mahatma Gandhi Marine National Park (MGMNP) is situated at Wandoor, which belongs to the South Andaman District Administration, which is part of the Indian Union Territory (UT). MGMNP was established on 24th may 1983 under the wildlife Protection Act of 1972 to protect marine life such as the corals and nesting sea turtles prevalent in the area. The open creeks running through the park is the special attraction. It is 16 kms towards south of Port Blair, covering about 281.5 km² area. It was placed under the protection of the Chief Conservator of Forest (Wildlife) of the forest department of the Andaman and Nicobar Islands. This Marine National Park comprises of 15 smaller group of islands with fringing type of coral reef and diverse form of associated flora and fauna. Type and composition of vegetation vary from island to island [1]. As these small group of islands fall under the MGMNP and not much study has conducted on the prevailing environmental condition of the coral reef, nor any monitoring study based on bio indicator organism. Globally, coastal zones are exposed to various anthropogenic activity likely, overfishing, pollution or tourism—recreational activity, that may pose threat to the prevailing environment [2]. So, a simplified monitoring mechanism essential to protect this environment is effected by the above factors.

Foraminifera constitute an inexpensive and easily abundant proxy for monitoring coastal environmental stressors, including elevated temperatures, acidification, and influx of pollutant. The symbiont-bearing benthic foraminifera are comparatively large, unicellular protist with test and lifestyle similar to that of corals, bearing zooxanthella [3] [4]. Experimental work carried out by Prazere *et al.*, [5] showed *Amphistegina lobifera* from inner shelf able to acclimatize to wide nutrient level and larger temperature variation, but from mid or outer shelf of reef showed sensitive to any elevation of temperature and variation in nitrate. Dinoflagellate bearing *Marginopora vertebralis* is regarded as indicative species for “blue-water” condition, thus sensitive to nutrients than diatom bearing *Calcarina* species or *Heterostegina* species [6] [7]. Increased in concentration of carbon-di-oxide (CO₂) up to 40% since pre-industrial period [8] likely result in decrease in pH (ocean acidification) affecting the calcifying organisms. Study by Vogel and Uthicke [9] found that decreased pH had no much effect on the growth rate of diatom bearing *Amphistegina radiata* and *Heterostegina depressa* and increased calcification was observed in dinoflagellate bearing *Marginopora vertebralis* and chlorophyta bearing *Amphisorus hemprichii* [10]. Later, study by Doo *et al.*, [11] stated that decrease in calcification rate in porcelaneous, dinoflagellate-bearing foraminifera was noted with decreasing pH, while the hya-

line diatom-bearing species showed no effect or increased calcification.

Further, study conducted by Talge and Hallock [12] and Schmidt *et al.*, [13] showed that sensitivity of genus *Amphistegina* towards bleaching showed light coloration with molting test without becoming completely white. Renema [7] generalized that diatom bearing hyaline LBF accommodate environmental changes than the dinoflagellate bearing porcelaneous LBFs. Hallock *et al.*, [14] reported that response of coral reef on environmental changes is just a part of response to gradual changing condition to which LBFs are much sensitive than the reefs. Any changes in their substrate may affect their assemblage and alteration in benthic habitat structure [6] [7] [15] [16] [17]. With substrate change, larger impact may be seen in individual LBF species in response to ocean warming, ocean acidification and nitrification [2].

Hallock [18] already remarked the extensive presence of calcarinids in reef communities from Indo-Pacific regions. According to Hallock *et al.*, [14], the distribution and abundance of the tests of symbiont-bearing benthic foraminifera can offer valuable clues to the health of a coral-reef ecosystem [19]. The well-known genus of symbiont-bearing foraminifera found worldwide on coral reefs and other shallow, tropical carbonate banks and its hardgrounds is *Amphistegina* [20] [21] [22]. Members of this genus are known to host diatom as their endosymbionts [4] [23] [24]. Any changes in local foraminiferal assemblages associated with coral reef environment may help in differentiating the deteriorating water quality from a temporary condition leading to an episodic mortality event [2] [25] in long term. Due to their abundance and species diversity, these microorganisms are reliable indicators of environmental disturbance and thus, reef foraminifera can be utilized as “bioindicators of coral-reef health” [26].

Therefore, the present study was carried out to enhance the knowledge on the diversity, abundance and depth distribution of larger benthic foraminifera (LBF) from six different islands in Mahatma Gandhi Marine National Park (MGMNP) and create a baseline data of the existing LBF in these prevailing environments.

2. Methodology

The study was undertaken to understand the LBF distribution and its environment from a protected area of Mahatma Gandhi Marine National Park (MGMNP), Wandoor, Port Blair, South Andaman (**Figure 1**), during the period of May-June, 2018, due to their very minimal anthropogenic impact on this region. Six islands with fringing coral reef environment were considered for the study. The fringing reef extended on the steep walls of submerged platform within 12 to 20 m depth ranges. The sediments were randomly collected by SCUBA divers on the sediments that extended up to 200 to 300 m width of the sea floor. Maximum two sediment samples were collected from each island, wherever thick sediment was deposited, otherwise only one sample was collected. This sediment was collected only one time during the study period. The collected sediments were brought to the laboratory and some amount of the sediment sample was spread in the tray

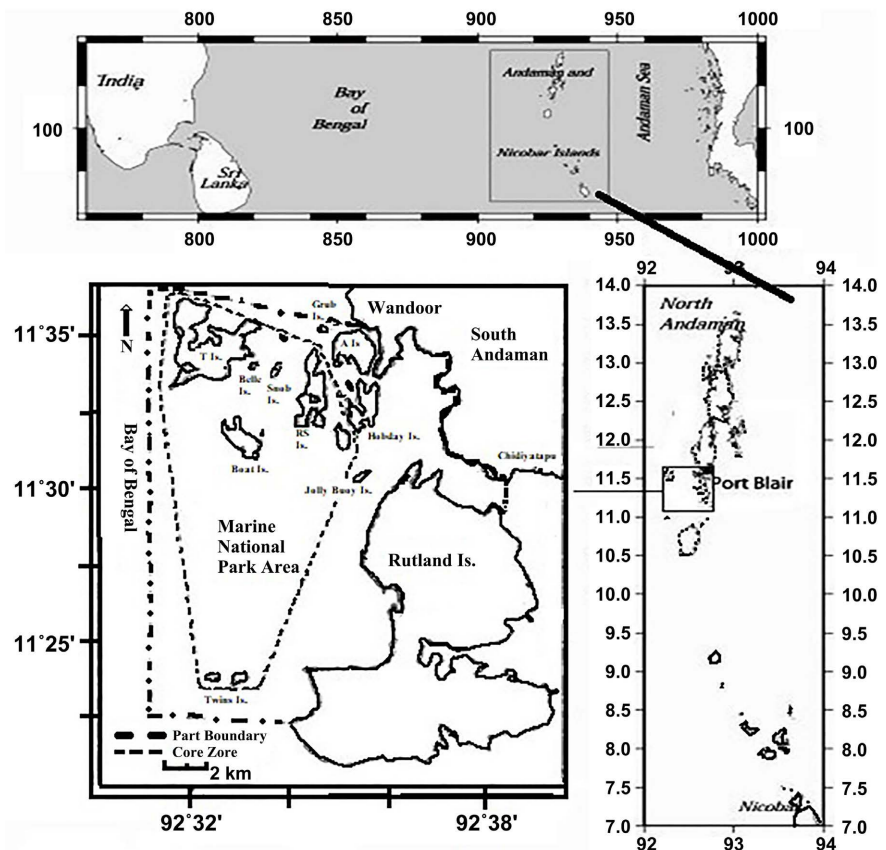


Figure 1. Study area.

and live LBF were hand-picked. About 300 individuals of LBF species were collected, and studied. The collected LBF was analyzed under stereo binocular microscope and taxonomical identification was done using Loeblich and Tappan [27], and Milker and Schmiel di [28] foraminiferal identification keys. For the investigation of species-environment relations, statistical method like Cluster analysis, Principal Component Analysis (PCA), and Multi-Dimensional Scaling (MDS) analysis were carried out and their results were interpreted. **Table 1** represented the individual stations locations, depth and sediment texture.

3. Result and Discussion

Over all this study identified 22 LBF species from this environment (**Table 2**). However, their distribution varies with represent to the individual island environment. They are classified more than 5% in total percentage are presented in **Table 3**, and similarly, less than 5%, which are also available in all the studied stations are grouped in **Table 4**, for discussion. **Table 5** represented by LBF and its symbionts available in varying depths. **Plate 1** (Fig A to N) represented hyaline LBF and **Plate 2** (A to H) represented the porcelaneous LBF.

Station 1—Snob Island (11°34.112'N; 92°34.631'E)

This island has a coastline cover of 2.18 km with an area coverage of about 17.65 Ha, having a length of 0.96 km and width of 0.26 km. It is one of the Island

Table 1. Study station with Latitude-Longitude, depth and sediment texture.

S. No.	Stations	Latitude	Longitude	Depth	Sediment texture
1.	Snob Island	11°34.112'	92°34.631'	15 m	Sandy with coral rubbles
2.	Grub Island	11°35.474'	92°35.712'	22 m	Carboneferous sand with coral rubbles
3.	Boat Island	11°30.679'	92°34.076'	20 m	Fine sand
4.	Hobday Island	11°33.982'	92°37.154'	15 m	Coral rubble with sand
5.	Belle Island	11°33.854'	92°33.906'	15 m	Fine carboneferous sand to coral rubbles
6.	Jolly Buoy Island	11°30.663'	92°37.022'	20 m	Fine carboneferous sand to coral rubbles

Table 2. Distribution of LBF species in the studied stations are represented by total percentage.

SPECIES NAME	Snob Island (SN)		Grub Island (GB)		Boat Island (BT)		Hobday Island (HY)	Belle Island (BE)	Jolly Buoy (JB)	
	SN1	SN2	GB1	GB2	BT1	BT2	HY1	BE1	JB1	JB2
<i>Alveolinella quoyi</i>	ND	ND	ND	ND	ND	ND	ND	5.0	ND	ND
<i>Borelis schlumbergeri</i>	1.63	0.69	ND	2.56	ND	ND	ND	5.0	ND	ND
<i>Amphistegina bicirculata</i>	0.54	0.69	1.00	ND	ND	3.77	ND	ND	0.37	ND
<i>Amphistegina lessonii</i>	0.54	ND	9.95	ND	3.09	3.77	3.7	5.0	2.24	5.71
<i>Amphistegina lobifera</i>	0.54	1.37	42.79	2.56	3.09	3.40	ND	ND	1.87	4.76
<i>Amphistegina papillosa</i>	ND	ND	ND	ND	ND	0.38	ND	ND	0.75	2.86
<i>Amphistegina radiata</i>	ND	ND	1.49	ND	1.39	1.89	ND	ND	0.75	ND
<i>Calcarina calcarinoides</i>	2.72	5.48	12.44	2.56	5.16	4.53	7.41	ND	2.24	ND
<i>Calcarina defrancei</i>	7.61	15.07	0.5	10.23	13.4	11.7	16.67	15	1.12	ND
<i>Calcarina hispida</i>	2.17	1.37	2.0	10.26	0.69	0.76	ND	5.0	2.99	4.81
<i>Calcarina spengleri</i>	19.57	21.92	7.46	15.39	15.46	14.34	16.67	20	2.99	1.91
<i>Neorotalia calcar</i>	7.07	5.68	13.93	10.26	11.34	6.8	9.24	10	13.06	2.86
<i>Neorotalia gaimardi</i>	14.13	13.7	3.48	ND	12.72	9.06	ND	5.0	27.24	12.38
<i>Nummulites venous</i>	1.09	ND	ND	ND	0.34	0.76	ND	5.0	ND	ND
<i>Operculina ammonoides</i>	ND	ND	ND	5.13	ND	ND	ND	ND	0.37	ND
<i>Heterostegina depressa</i>	1.09	0.69	0.5	ND	0.69	1.13	ND	ND	0.37	0.95
<i>Parasorites orbitolitoides</i>	0.54	ND	ND	10.26	ND	0.76	5.56	5.0	0.37	2.86
<i>Peneroplis pertusus</i>	5.43	2.74	3.0	12.82	9.28	13.96	ND	10	22.02	22.86
<i>Peneroplis planatus</i>	2.17	ND	ND	7.69	11.34	9.43	1.85	ND	8.96	17.14
<i>Amphisorus hemprichii</i>	11.41	9.59	0.5	2.56	3.44	5.66	ND	ND	0.75	1.91
<i>Marginopora vertebralis</i>	8.15	6.16	0.5	ND	0.69	1.51	9.26	5.0	5.22	6.67
<i>Sorites orbiculus</i>	13.59	15.07	0.5	7.67	7.56	6.42	29.63	5.0	6.36	13.33
Total count of LBF	368	292	201	190	291	265	270	100	268	315
Number of LBF species	18	14	15	13	15	18	9	13	15	14

ND—Not Detected.

Table 3. LBF species observed more than 5% in all the stations.

SPECIES NAME	Snob Island (SN)		Grub Island (GB)		Boat Island (BT)		Hobday Island (HY)	Belle Island (BE)	Jolly Buoy (JB)	
	SN1	SN2	GB1	GB2	BT1	BT2	HY1	SN1	SN2	GB1
<i>Calcarina calcarinoides</i>	2.72	5.48	12.44	2.56	5.16	4.53	7.41	ND	2.24	ND
<i>Calcarina defrancei</i>	7.61	15.07	0.5	10.23	13.4	11.7	16.67	15.0	1.12	ND
<i>Calcarina spengleri</i>	19.57	21.92	7.46	15.39	15.46	14.34	16.67	20.0	2.99	1.91
<i>Neorotalia calcar</i>	7.07	5.68	13.93	10.26	11.34	6.8	9.24	10.0	13.06	2.86
<i>Neorotalia gaimardi</i>	14.13	13.7	3.48	ND	12.72	9.06	ND	5.0	27.24	12.38
<i>Peneroplis pertusus</i>	5.43	2.74	3.00	12.82	9.28	13.96	ND	10.0	22.02	22.86
<i>Marginopora vertebralis</i>	8.15	6.16	0.5	ND	0.69	1.51	9.26	5.0	5.22	6.67
<i>Sorites orbiculus</i>	13.59	15.07	0.5	7.67	7.56	6.42	29.63	5.0	6.36	13.33
Total 5% Species present In the station	7	7	3	5	7	6	6	7	5	4

ND—Not Detected.

Table 4. LBF species observed less than 5% in all the stations.

SPECIES NAME	Snob Island (SN)		Grub Island (GB)		Boat Island (BT)		Hobday Island (HY)	Belle Island (BE)	Jolly Buoy (JB)	
	SN1	SN2	GB1	GB2	BT1	BT2	HY1	SN1	SN2	GB1
<i>Amphistegina radiata</i>	ND	ND	1.49	ND	1.39	1.89	ND	ND	0.75	ND
<i>Amphistegina papillosa</i>	ND	ND	ND	ND	ND	0.38	ND	ND	0.75	2.86
<i>Amphistegina bicirculata</i>	0.54	0.69	1.0	ND	ND	3.77	ND	ND	0.37	ND
<i>Heterostegina depressa</i>	1.09	0.69	0.5	ND	0.69	1.13	ND	ND	0.37	0.95

ND—Not Detected.

Table 5. LBF species and its associated endosymbiont from varying depth.

Sl. No.	LBF Species	Depth ranges	Substrate	Symbiont	Reference
1.	<i>Alveolinella quoyi</i>	3 - 4 m depth or 20 - 30 m depth [29]; 15 - 40 m [30]; reaching upto 100 m depth depending upon the transparency of the water [31]	Found in 3 - 5 m if algal covered over Coral rubble or at 20 - 30 m depth in stable sediment covered with organic detritus [29]	Diatom-symbionts	[4] [31] [32] [33] [34] [35]
2.	<i>Borelis schlumbergeri</i>	Found in fringing reef within 40 m depth [36]; 15 - 40 m [30]	Coral sand and plant substrate [37]	Diatom-symbiont	[4] [31] [32] [33] [34] [35] [38] [39] [40] [41]
3.	<i>Amphistegina bicirculata</i>	40 - 130 m [16]; 40 - 100 m [42]; Firm substrates [44] or coarse 53 - 129 m [43]; 15 - 40 m [30]	sand [43]	Diatom-symbiont	[4] [31] [32] [33] [34] [35] [38]
4.	<i>Amphistegina lessonii</i>	15 - 40 m [30]; ~60 m [16] [45] [46]	Sandy and coral rubble or hard substratum [6] [7] [16]	Diatom-symbiont	[4] [31] [32] [33] [34] [35] [38]
5.	<i>Amphistegina lobifera</i>	Shallowest > 10 m [6] [16] [47] 15 - 40 m [30]	Coral rubble but rare in reef rock and macro algal or algal turf substrate [6] [16] [17]	Diatom-symbiont	[4] [31] [32] [33] [34] [35] [38]

Continued

6.	<i>Amphistegina papillosa</i>	Abundant within 20 - 30 m [45]; 15 - 40 m [30]; 95 m depth [44]	Carbonate rich sandy substrate [42]	Diatom-symbiont	[4] [31] [32] [33] [34] [35] [38]
7.	<i>Amphistegina radiata</i>	10 - 90 m but abundant shallower about 15 cms deep [6] to 20 m [48]; 15 - 40 m [30]	Firm substrates or found attached on coral rubbles [15] [16] [44] [45]	Diatom-symbiont	[4] [31] [32] [33] [34] [35] [38]
8.	<i>Calcarina calcarinoides</i>	<5 m down to 30 m depth [49]	epiphytically attached on algal turf [50]	Diatom-symbiont	[4] [31] [32] [33] [34] [35] [38]
9.	<i>Calcarina defrancei</i>	3 - 25 m [6] [16] [48]	Coral rubble [6] [16] [48]	Diatom-symbiont	[4] [31] [32] [33] [34] [35] [38]
10.	<i>Calcarina hispida</i>	>5 m depth [6] [50] [51] 10 - 20 m depth [52]	Filamentous algal mat [6] [50] [51]	Diatom-symbiont	[4] [31] [32] [33] [34] [35] [38]
11.	<i>Calcarina spengleri</i>	Available within 1 - 45 m depth but abundant in 15 - 25 m [6]	Coral rubble covered by coralline algae; algal turf and Halimeda substrate [6] [7] [45]	Diatom-symbiont	[4] [31] [32] [33] [34] [35] [38]
12.	<i>Neorotalia calcar</i>	10 - 20 m [7] [15] [45]	Epiphytic attached to macro algae or sea grass (Halophilas) in coral cay reef [7] [15] [45]	Diatom-symbiont	[4] [31] [32] [33] [34] [35] [38]
13.	<i>Neorotalia gaimardi</i>	35 m [17]	Algal turf, macro algae (Turbinaria and Sargassum) [7] [17]	Diatom-symbiont	[4] [31] [32] [33] [34] [35] [38]
14.	<i>Nummulites venosus</i>	10 m [48]; depth ranges from 15 - 85 m to maximum 35 - 60 m depth [53] [54]	Coarse sand and less tolerant to clastic sediment input [42] [45]	Diatom-symbiont	[4] [31] [32] [33] [34] [35] [38]
15.	<i>Operculina ammonoides</i>	Wider depth distribution	Soft substratum [7] [30] [45] [48] [55]	Diatom-bearing	[4] [31] [32] [33] [34] [35] [38]
16.	<i>Heterostegina depressa</i>	10 m to 90 m [48] or wider depth range [56]	Solid substrate with coralline algae [6] [7] [16] [45]	Diatom-symbiont	[4] [31] [32] [33] [34] [35] [38]
17.	<i>Parasorites orbitolitoideis</i>	35 m depth [44]; 15 - 40 m [30] or wider depth range	Algal mat coral rubble [44]	Chlorophyta	[39] [69] [78] [79]
18.	<i>Peneroplis pertusus</i>	3.5 - 30 m [57]; 10 - 15 m [58]	Found attached to short filamentous algae on coral rubble [57]	Red algae-Rhodophyte-bearing	[4] [31] [34] [35] [59] [60] [61] [62] [74]
19.	<i>Peneroplis planatus</i>	3.5 - 30 m [57]; 10 - 15 m [58]	Found attached to short filamentous algae on coral rubble [57]	Rhodophyte-bearing	[59] [62] [74]
20.	<i>Amphisorus hemprichii</i>	8 - 18 m depth [57]	Mostly rocky substrate, found epiphytically clinging on Posidonia oceanica and Halophila stipulacea [57]	Chlorophytes and Dinoflagellate Endosymbiont	[62]-[67] [74]
21.	<i>Marginopora vertebralis</i>	25 m depth [51]; 15 - 40 m [7]	Coral rubbles	Red Cyanobacteria endosymbiont	[4] [31] [38] [65]
22.	<i>Sorites orbiculus</i>	2 - 36 m [51]	Found living epiphytically on thalli of algae rarely on coral rubbles [51]	Dinoflagellate, Cyanobacteria and haptophytes endosymbiont	[31] [39] [59] [62] [67] [75] [76] [77] [80]

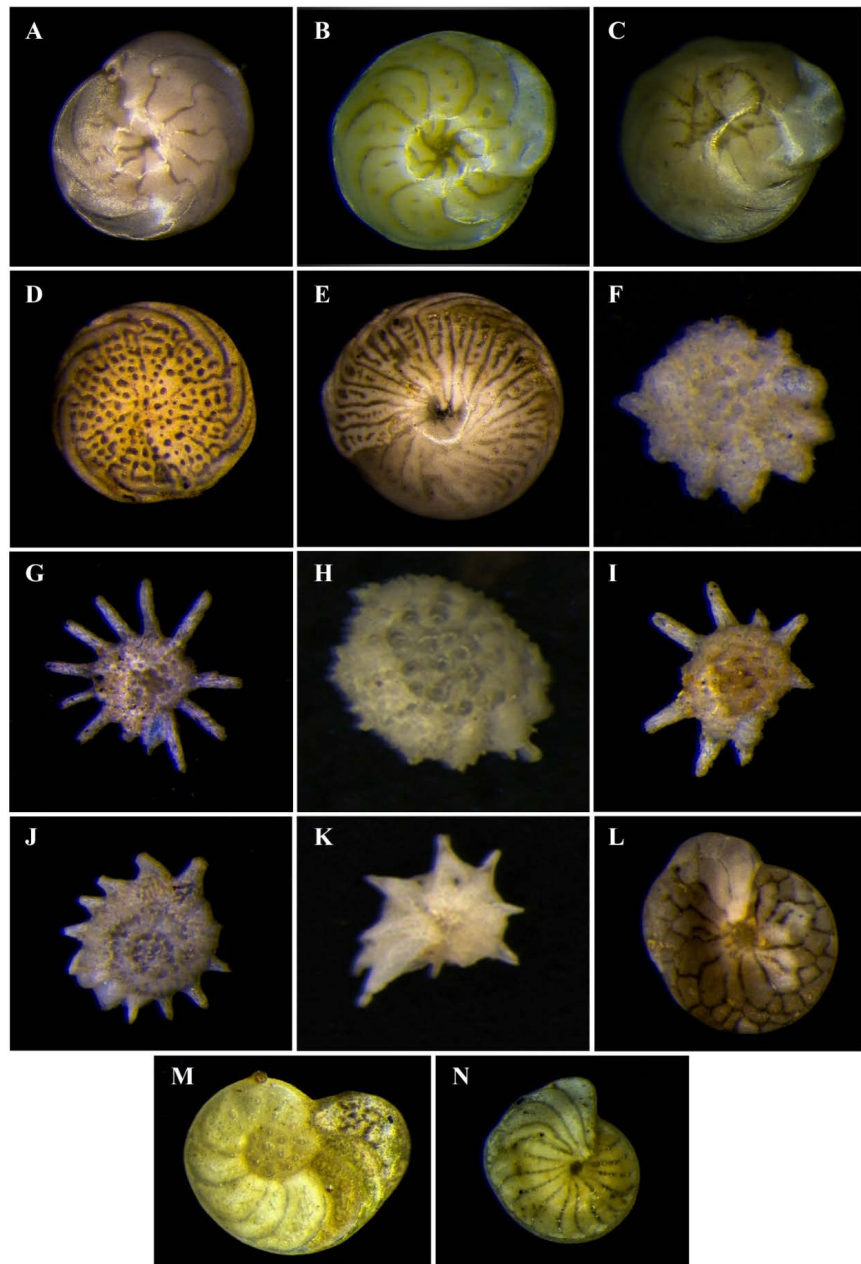


Plate 1. Hyaline LBF. Images of hyaline LBF from the study. (A) *Amphistegina bicirculata* Larsen, 1976 (B) *Amphistegina lessonii* d'Orbigny in Guerin-Meneville, 1832 (C) *Amphistegina lobifera* Larsen, 1976 (D) *Amphistegina papillosa* Said, 1949 (E) *Amphistegina radiata* (Fichtel & Moll, 1798) (F) *Calcarina calcarinoides* (Cheng & Zheng, 1978) (G) *Calcarina defrancei* d'Orbigny, 1826 (H) *Calcarina hispida* Brady, 1876 (I) *Calcarina spengleri* (Gmelin, 1791) (J) *Neorotalia calcar* (d'Orbigny in Deshayes, 1830) (K) *Neorotalia gaimardi* (d'Orbigny in Fornasini, 1908) (L) *Heterostegina depressa* d'Orbigny, 1826 (M) *Operculina ammonoides* (Gronovius, 1781) (N) *Nummulites venosus*, Fichtel & Moll, 1798.

included as part of Mahatma Gandhi National Park and known to have a good coral cover and biodiversity. Two samples were collected from this station, where both the samples showed seven dominant LBF species, respectively (**Table 3**). The LBF species are as follows: *Calcarina defrancei*, *C. spengleri*, *Neorotalia*

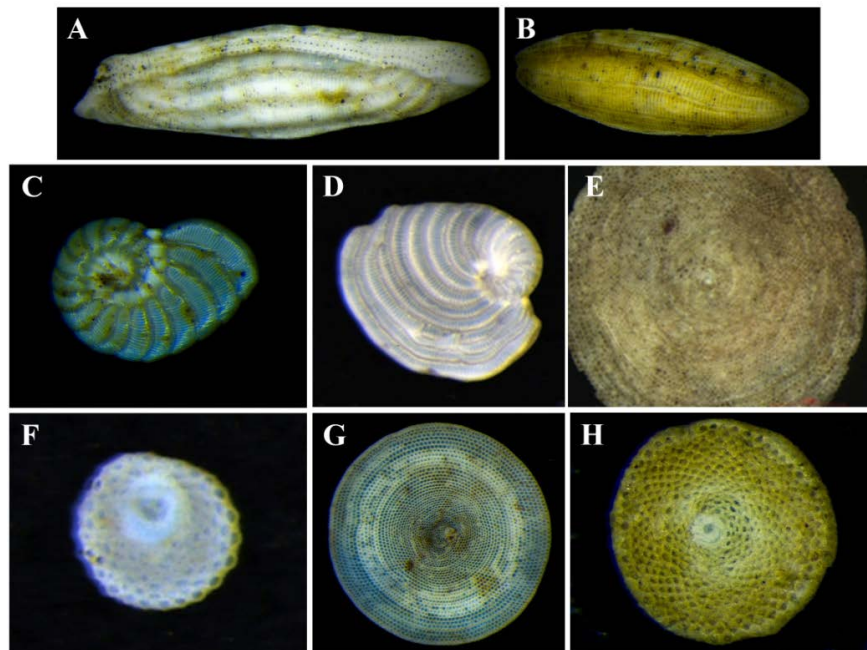


Plate 2. Hyaline LBF. Images of porcelaneous walled LBF from the study. (A) *Alveolinella quoyi* (d'Orbigny, 1826) (B) *Borelis schlumbergeri* (Reichel, 1937) (C) *Peneroplis pertusus* (Forsskal in Niebuhr, 1775) (D) *Peneroplis planatus* (Fichtel & Moll, 1798) (E) *Amphisorus hemprichii* Ehrenberg, 1839 (F) *Marginopora vertebralis* Quoy & Gaimard, 1830 (G) *Parasorites orbitolitoides* (Hofker, 1930) (H) *Sorites orbiculus* (Forsskal in Niebuhr, 1775).

calcar, *Neorotalia gaimardi*, *Marginopora vertebralis* and *Sorites orbiculus*. They found to be common in both the samples. Out of the dominant LBF species, *Peneroplis pertusus* was observed exclusively only in the first sample, while *Calcarina calcarinoides* has seen only in the second sample.

Station 2—Grub Island (11°35.474'N; 92°35.712'E)

This island is also a part of Mahatma Gandhi Marine National Park with total area of about 2.3 Ha and coastline cover of 0.7 km. It has a length of about 0.13 km and width of 0.25 km. It is home for spectacular coral reef environment. From the two samples, six dominant LBF species (**Table 3**), i.e., *Calcarina calcarinoides*, *Calcarina defrancei*, *Calcarina spengleri*, *Neorotalia calcar*, *Peneroplis pertusus* and *Sorites orbiculus* are present.

Station 3—Boat Island (11°30.679'N; 92°34.076'E)

This island comprises of 247.6 Ha landmass with a coastline cover of 7.71 km, length of 2.7 km and width of 1.3 km. Two samplings were carried out from this station, where the number of dominant LBF species was documented to be seven (**Table 3**). They are *Calcarina calcarinoides*, *Calcarina defrancei*, *C. spengleri*, *Neorotalia calcar*, *N. gaimardi*, *Peneroplis pertusus* and *Sorites orbiculus*, whereas it has present only in the first sample.

Station 4—Hobday Island (11°33.982'N; 92°37.154'E)

This station has an area cover of 367.80 Ha with a coastline 10.50 km, length of 3.23 km width of 1.91 km. It has only one sample available with total of six

dominant LBF species (Table 3). They are *Calcarina calcarinoides*, *C. defrancei*, *C. spengleri*, *Neorotalia calcar*, *Marginopora vertebralis* and *Sorites orbiculus*.

Station 5—Belle Island (11°33.854'N; 92°33.906'E)

This island has a land area of about 6.7 Ha along with coastline cover of 1 km and length 0.38 km and width 0.21 km. Even this station had only one sample which showed dominance of seven LBF species, *Calcarina calcarinoides*, *C. defrancei*, *C. spengleri*, *Neorotalia calcar*, *Peneroplis pertusus*, *Marginopora vertebralis* and *Sorites orbiculus* (Table 3).

Station 6—Jolly Buoy (11°30.663'N; 92°37.022'E)

This island has an area of 18.80 Ha and a coastline cover of 2.50 km with a length 1.10 km and width 0.20 km, well known for its ecotourism. Two samples were collected and showed dominance of five LBF species (Table 3). The LBF species *Neorotalia calcar*, *Neorotalia gaimardi*, *Peneroplis pertusus*, *Marginopora vertebralis* and *Sorites orbiculus* are dominant in this environment.

Over all, compared all the study area, there are 22 species of LBF identified from these studied environments. Among these, the species *Calcarina calcarinoides*, *Calcarina defrancei*, *Calcarina spengleri*, *Neorotalia calcar*, *Peneroplis pertusus*, *Marginopora vertebralis* and *Sorites orbiculus* are present in considerable amount in all the study locations or except one location. These seven species extended almost same level of concentration in all these six studied island environments.

According to Renema [17], *Calcarina* species are found in abundance in coral covered environment with adequate algal cover or algal turf, showing distinct habitat with reference to water quality, substrate type and bathymetry. Even, Hohenegger, [16] and Renema and Troelstra, [45] observed a characteristic feature where reef slopes were dominated by *Calcarina mayori*, *C. spengleri*, *Heterostegina depressa*, *Amphistegina lessonii* and *Amphistegina radiata*, where, *Amphisorus hemprichii* was said to be most available in less algal growth zone in the reef slopes. *Neorotalia calcar* and *Neorotalia gaimardi* also occur in reef slopes with limited amount of interstitial space in between the coral rubbles which may be due to transport of carbonate sediments from the overlying reef flats.

Amphisorus hemprichii are best represented in sediments associated with seagrass. This has observed in the samples of Snob Island and Boat Island, where patches of seagrass observed. In addition, Renema *et al.*, [43], recognized that the near shore is often dominated by *Neorotalia gaimardi*, and *Marginopora vertebralis* for high energy condition, support the present environment condition of the studied environment of these islands. Further, the genus *Heterostegina*, *Amphistegina*, *Calcarina* and *Amphisorus* also support the higher energy settings of these locations. The less presence of eurytopic taxa such as *Heterostegina depressa* and *Amphistegina lessonii* suggested that these locations are sandy and rock crevices are less in number [6]. In terrestrial influenced reefs, the reef flat is either dominated by *Amphistegina lobifera* or various *Calcarina* species. Further, the above inferences are supported by the Renema's [17], observation

that the genus *Amphistegina* dominated regions are often associated with low algal abundance and moderate coral reef cover, whereas the calcarinids proliferate in algal dominated environments. *Neorotalia gaimardi* has also reported from algal environment from Kepulam Seribu, near Java [7]. Thus, Hottinger [68], Reiss and Hottinger [15], Hallock [52], and Renema and Troelstra [45] were suggested that, location of a reef (reef flat, reef slope, reef base and inter-reef) have an important role to play as parameters determining the LBF assemblage composition. However, this may not support this study, as the Andaman and Nicobar Island has a fringing reef only, *i.e.* terrace model coral reef, pertaining to limitations in studying with the above stated areas and distribution in the coral reef region.

From their study, Narayan and Pandolfi [69], stated that, substrate difference and depth preference among species [6] [7] [16] influenced their assemblage of individual taxa. Along with depth variation, the light availability, tolerance to terrestrial sediments even the occurrence of certain LBF species differed drastically. Renema [30], observed that species like *Marginopora vertebralis*, *Parasorites orbitolitoideis* and *Alveolinella quoyi* are mostly found in inter reef region, *i.e.*, between 15 m - 40 m depth was evinced by Jolly Buoy, Snob, Hobday and Grub Islands sites, where the depth goes around 20 m than the remaining islands environmental depth (15 m). *Marginopora vertebralis* also accompanied by other species of LBF assemblages belonging to genus *Operculina* and *Amphistegina*. *Amphistegina lobifera* that is basically shallow living LBF species around 10 m [5] [6] [16] [47], but at deeper depth it is replaced by *Amphistegina lessonii* [45]. Basically, both *Amphistegina* species prefer hard, coral rubble or may be a loose coarse sandy substratum but over time, if algal growth takes place on the rocky substratum, then Calcarinid species are found in abundance [6] [16] [17] [42]. Even *Amphistegina bicirculata* is well documented as deep dweller along with *A. lessonii* with depth range of about 40 m - 140 m [16] [42] [43] preferring firm substratum [44] or coarse sand [42] [43]. However, the present environment has less depth and algal mat has present, the above two species are very much less in this environment. As documented by Renema, [6], *Amphistegina radiata* is found living in abundance from 10 m - 90 m depth. Highest abundance was recorded from 20 m depth from Okinawa, Japan by Hohenegger *et al.*, [48]. They prefer carbonate rich sandy substrate with more tolerance to terrestrial influence or coral rubble as firm substrate to cling on the sides and inhabit in between the interstitial space [6] [15] [16] [44] [45]. However, the present study proved that the less abundance of this species due to the shallow water environment with less coral rubble. *Calcarina spengleri* is well documented from a coral rubble with coralline algal growth or algal turf and *Halimeda* as substrate [6] [7] [45] with assemblage within 15 - 25 m depth. While *Calcarina defrancei* exist within 3 - 25 m [6] [16] [42] [48], living in between interstitial gap of coral rubble covered with sand. *Calcarina hispida* are abundant at the base of filamentous algal mat [6] [50] [51] and may be found within >5 m depth, however, Hallock [23] [52] described its depth range to be from 10 m - 20 m from a strong currents region.

Calcarina calcarinoides were reported from firm substrate [50], epiphytically attached on algal turf from South China Sea [49]. Though its abundance is reported from <5 m, but it is mostly found down to 30 m water depth on the reef [48]. *Neorotalia calcar* are epiphytically present on macro algae or sea grass (*Halophila*) on sand cay occurring within 10 m - 20 m in most places [7] [15] [45] [51]. *Neorotalia gaimardi* prefers depth within 30 m with algal turf surrounding or macro algae like *Turbinaria* and *Sargassum* [7] [17]. The above inferences clearly supported the present study environment has coral rubble with algal turf and current laden environment.

Diversity of larger benthic foraminifera (LBF) is said to decline to the east in the Pacific ocean and west of Indian Ocean and reef slopes are less differentiated by depth [16] [70]. Renema [30] studied and reported that terrestrial influence is one of the key driving factor for LBF assemblage composition that was not predicted before. According to Renema [30], Hottinger [19], and Hohenegger *et al.*, [48], it has been suggested that depth distribution of LBF taxa is determined by the intensity of light and wavelength required by their algal symbiont.

Heterostegina depressa need broad range of light intensity (2% to 70% surface illumination), and its thick tests protects them from against irradiation, a cryptic life mode near the surface. Test construction enables life under strong hydrodynamic regimes. This species lives firmly attached to hard substrates, which help them to counteract against transportation by water movement. *Nummulites venosus* differs from *Heterostegina depressa*, having undivided chambers and its exclusive preference for coarse sand. It avoids high sediment movement with distribution range of 10 - 85 m depth [48] [53] [54]. *N. venosus* morphology shows distinct habitat preference with upper light intensity requirement limiting to that of *Operculina ammonoides* (80%) and lower limit of 2.5% surface illumination. *H. depressa* has wider depth distribution, 15 m - 40 m depth range [30] with larger tolerance to light and found in coral rubbles along with coralline algae [6] [7] [16] [45]. *Heterostegina depressa* and *Nummulites venosus* have less in abundance suggested that the present environment has very less rocky out crop as well comparatively less hydrodynamic conditions in these study areas.

LBF species like *Sorites orbiculus*, *Amphisorus hemprichii* and *Marginopora vertebralis* share similar morphology but differ in their external features like thickness of their test, number of chamberlets and their forms and distribution of aperture on their peripheral region and the endosymbiont they have [66] [71]. Peneroplidae family is observed to host rhodophyte along with chlorophyte [62] [74] [75]. *Parasorites orbitolitoides* and *Amphisorus hemprichii* hosts dinoflagellates as well as chlorophytes [34] [40] and *Sorites orbiculus* is known to host dinoflagellate as their endosymbiont [71] while *Marginopora vertebralis* has red cyanobacteria along with dinoflagellate [76]. These are all porcelaneous wall structure which is said to be sensitive to much depth ranges or any changes in their surrounding environment. According to Lee [59], Bourne *et al.*, [72] and Lee and Anderson, [4], it is observed that milioliida order mostly host chlorophyta, rhodophyta and dinoflagellates either at one point of time or may be one

at a time depending upon the changes and adaptation they go through. Lee and Anderson [4] suggested that flexibility in the acceptance of the potential foraminiferal endosymbionts has considered favorable in chances of adaptation to broader range of environmental parameters. Several other experimental studies also demonstrate that algal symbiosis enhances calcification that contributes to the excellent growth of the foraminiferal test [38].

High specificity in their association with diatom or dinoflagellate is probably driven by selective recognition mechanisms of symbiont and biogeographical isolations [73]. Photosynthetic activity of endosymbionts is well known to provide foraminiferal host with the needed energy for survival and growth in any environment [24]. Symbiotic association proves to be necessary for the successful adaptation of Soritids to oligotrophic environment. In addition, Soritids are particularly abundant in the Indo-Pacific as they play very important role in biogeochemical mineral cycle.

The statistical plot for cluster analysis and multidimensional scaling (MDS) suggested that (Figure 2 and Figure 3) among these island environments, exhibited

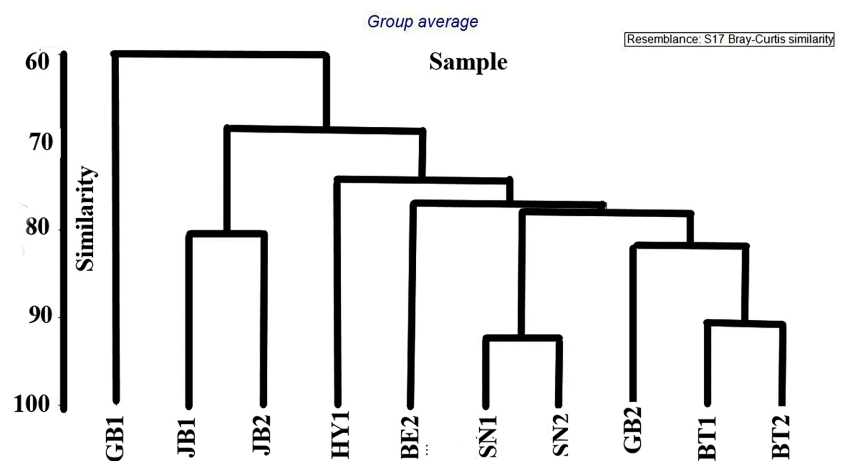


Figure 2. Cluster diagram.

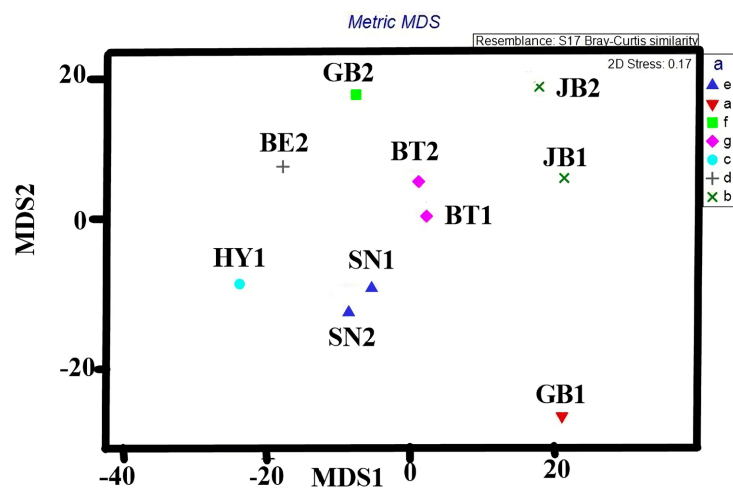


Figure 3. Multi dimensional scaling (MDS).

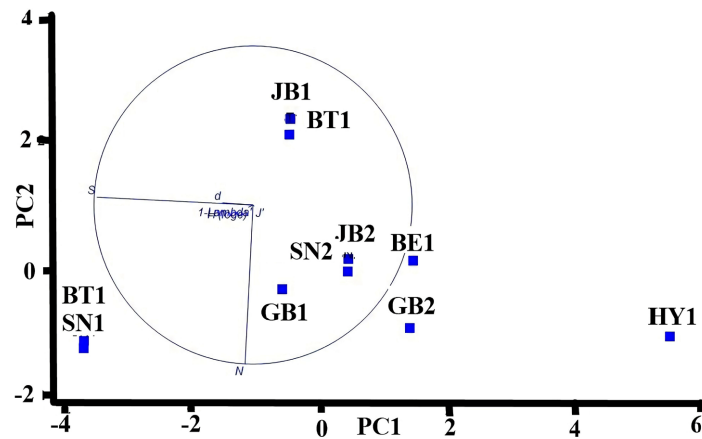


Figure 4. Principal component analysis (PCA).

a maximum similar in their conditions. However, it may vary in the environment such as Grab Island as well as Jolly Buoy Islands, where the change of depth and its slope has an influence of their distribution was evinced from these figures (A & B). The principal component analysis (**Figure 4**) suggested that among the differences of environment in the inter islands will match with the intra islands environment, which again suggested that all these study area have almost similarity in their environmental conditions.

4. Conclusion

This present study from Mahatma Gandhi Marine National Park, Wandoor, Port Blair suggested that the stations selected for this study has a challenging environment with varying factors involved. The presence of few dominant LBF species, *Calcarina calcarinoides*, *C. spengleri*, *C. defrancei*, *Neorotalia calcar*, *N. gaimardi*, *Peneroplis pertusus*, *Marginopora vertebralis* and *Sorites orbiculus* suggested the availability of good fringing coral cover with commendable macro algae along with sea grass coverage, as they prefer such substratum for their epiphytic association. Even other LBF species *Alveolinella quoyi*, *Borelis schlumbergeri*, *Amphistegina lessonii*, *A. lobifera* and *Calcarina hispida*, *Nummulites venosus* and *Operculina ammonoides* showed significant presence, indicating presence of sandy—carboniferous substrate with exposure to greater hydrodynamic energy. Their robustness is evidence to their adaptation to such rough environment. Nevertheless, presence of few more LBF species was observed, *i.e.*, *Amphistegina radiata*, *A. papillosa*, *A. bicirculata* and *Heterostegina depressa* that were in much negligible number and their indication suggested that the present studied environment need for still larger amount of coral rubble, high hydrodynamic and high sea grass presence, than what it has present now.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

- [1] Balakrishnan, M., Srivastava, R.C. and Pokhriyal, M. (2008) Biodiversity of Andaman and Nicobar Islands. *Biobytes*, **3**, 9-12.
- [2] Hughes, T.P., Kerry, J.T., Álvarez-Noriega, M., Álvarez-Romero, J.G., Anderson, K.D., Baird, A.H., *et al.* (2017) Global Warming and Recurrent Mass Bleaching of Corals. *Nature*, **543**, 373-377. <https://doi.org/10.1038/nature21707>
- [3] Rottger, R. (1976) Ecological Observations of *Heterostegina Depressa* (Foraminifera, Nummulitidae). *The Laboratory and in Its Natural Habitat. International Symposium of Benthic Foraminifera of Continental Margins*, Vol. 1, Mar Sed Spec Publ, Springer Tokyo, 75-79.
- [4] Lee, J.J. and Anderson, O.R. (1991) Symbiosis in Foraminifera. In: *Biology of Foraminifera*, Vol. 1, Academic Press, London, 157-220.
- [5] Prazeres, M., Uthicke, S. and Pandolfi, J.M. (2016) Influence of Local Habitat on the Physiological Responses of Large Benthic Foraminifera to Temperature and Nutrient Stress. *Scientific Reports*, **6**, Article No. 21936. <https://doi.org/10.1038/srep21936>
- [6] Renema, W. (2006) Habitat Variables Determining the Occurrence of Large Benthic Foraminifera in the Berau Area (East Kalimantan, Indonesia). *Coral Reefs*, **25**, 351-359. <https://doi.org/10.1007/s00338-006-0119-4>
- [7] Renema, W. (2008) Habitat Selective Factors Influencing the Distribution of Larger Benthic Foraminiferal Assemblages over the Kepulauan Seribu. *Marine Micropaleontology*, **68**, 286-298. <https://doi.org/10.1016/j.marmicro.2008.06.002>
- [8] Intergovernmental Panel on Climate Change (2014) International Proceedings on Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge. <https://doi.org/10.1017/CBO9781107415324>
- [9] Vogel, N. and Uthicke, S. (2012) Calcification and Photobiology in Symbiont-Bearing Benthic Foraminifera and Responses to a High CO₂ Environment. *Journal of Experimental Marine Biology and Ecology*, **424-425**, 15-24. <https://doi.org/10.1016/j.jembe.2012.05.008>
- [10] Fujita, K., Hikami, M., Suzuki, A., Kuroyanagi, A. and Kawahata, H. (2011) Effects of Ocean Acidification on Calcification of Symbiont-Bearing Reef Foraminifera. *Biogeosciences Discussions*, **8**, 1809-1829. <https://doi.org/10.5194/bgd-8-1809-2011>
- [11] Doo, S.S., Fujita, K., Byrne, M. and Uthicke, S. (2014) Fate of Calcifying Tropical Symbiont-Bearing Larger Benthic Foraminifera: Living Sands in a Changing Ocean. *The Biological Bulletin*, **226**, 169-186. <https://doi.org/10.1086/BBLv226n3p169>
- [12] Talge, H.K. and Hallock, P. (2003) Ultrastructural Responses in Field-Bleached and Experimentally Stressed *Amphistegina gibbosa* (Class Foraminifera). *Journal of*

- Eukaryotic Microbiology*, **50**, 324-333.
<https://doi.org/10.1111/j.1550-7408.2003.tb00143.x>
- [13] Schmidt, C., Heinz, P., Kucera, M. and Uthicke, S. (2011) Temperature-Induced Stress Leads to Bleaching in Larger Benthic Foraminifera Hosting Endosymbiotic Diatoms. *Limnology and Oceanography*, **56**, 1587-1602.
<https://doi.org/10.4319/lo.2011.56.5.1587>
- [14] Hallock, P., Lidz, B.H., Cockey-Burkhard, E.M. and Donnelly, K.B. (2003) Foraminifera as Bioindicators in Coral Reef Assessment and Monitoring: The FORAM Index. In: Melzian, B.D., Engle, V., McAlister, M., Sandhu, S. and Eads, L.K., Eds., *Coastal Monitoring through Partnerships*, Springer, Dordrecht, 221-238.
https://doi.org/10.1007/978-94-017-0299-7_20
- [15] Reiss, Z. and Hottinger, L. (1984) The Gulf of Aqaba: Ecological Micropaleontology. *Ecological Studies*, Vol. 50, Springer, Berlin, Heidelberg, 1-354.
https://doi.org/10.1007/978-3-642-69787-6_1
- [16] Hohenegger, J. (1994) Distribution of Living Larger Foraminifera NW of Sesoko-Jima, Okinawa, Japan. *Marine Ecology*, **15**, 291-334.
<https://doi.org/10.1111/j.1439-0485.1994.tb00059.x>
- [17] Renema, W. (2010) Is Increased Calcarinid (Foraminifera) Abundance Indicating a Larger Role for Macro-Algae in Indonesian Plio-Pleistocene Coral Reefs? *Coral Reefs*, **29**, 165-173. <https://doi.org/10.1007/s00338-009-0568-7>
- [18] Hallock, P. (2012) The FoRAM Index Revisited: Uses, Challenges, and Limitations. *Proceedings of the 12th International Coral Reef Symposium*, Cairns, 9-13 July 2012, Article No. 1218.
- [19] Hottinger, L. (1983) Processes Determining the Distribution of Larger Foraminifera in Space and Time. *Utrecht Micropaleontological Bulletins*, **30**, 239-253.
- [20] Hallock, P. (1981) Production of Carbonate Sediments by Selected Large Benthic Foraminifera on Two Pacific Coral Reefs. *Journal of Sedimentary Petrology*, **51**, 467-474. <https://doi.org/10.1306/212F7CB1-2B24-11D7-8648000102C1865D>
- [21] Hallock, P. (1981) Algal Symbiosis: A Mathematical Analysis. *Marine Biology*, **62**, 249-255. <https://doi.org/10.1007/BF00397691>
- [22] Hallock, P. (1981) Light Dependence in Amphistegina. *Journal Foraminiferal Research*, **11**, 40-46. <https://doi.org/10.2113/gsjfr.11.1.40>
- [23] Hallock, P. (1985) Why Are Larger Foraminifera Large? *Paleobiology*, **11**, 195-208. <https://doi.org/10.1017/S0094837300011507>
- [24] Hallock, P. (1999) Symbiont-Bearing Foraminifera. In: Sen Gupta, B., Ed., *Modern Foraminifera*, Springer, Dordrecht, 123-139.
https://doi.org/10.1007/0-306-48104-9_8
- [25] Cockey, E., Hallock, P. and Lidz, B.H. (1996) Decadal-Scale Changes in Benthic Foraminiferal Assemblages off Key Largo, Florida. *Coral Reefs*, **15**, 237-248.
<https://doi.org/10.1007/BF01787458>
- [26] Schueth, J.D. and Frank, T.D. (2008) Reef Foraminifera as Bioindicators of Coral Reef Health: Low Isles Reef, Northern Great Barrier Reef, Australia. *Journal of Foraminiferal Research*, **38**, 11-22. <https://doi.org/10.2113/gsjfr.38.1.11>
- [27] Loeblich Jr., A.R. and Tappan, H. (1987) *Foraminiferal Genera and Their Classification*. Springer, New York, 2. <https://doi.org/10.1007/978-1-4899-5760-3>
- [28] Milker, Y. and Schmiedl, G. (2012) A Taxonomic Guide to Modern Benthic Shelf Foraminifera of the Western Mediterranean Sea. *Palaeontologia Electronica*, **15**, Article No. 16A. <https://doi.org/10.26879/271>

- [29] Severin, K.P. and Lipps, J.H. (2007) The Weight-Volume Relationship of the Test of *Alveolinella quoyi*: Implications for the Taphonomy of Large Fusiform Foraminifera. *Lethaia*, **22**, 1-12. <https://doi.org/10.1111/j.1502-3931.1989.tb01163.x>
- [30] Renema, W. (2018) Terrestrial Influence as a Key Driver of Spatial Variability in Large Benthic Foraminiferal Assemblage Composition in the Central Indo-Pacific. *Earth-Science Reviews*, **177**, 514-544. <https://doi.org/10.1016/j.earscirev.2017.12.013>
- [31] Lee, J.J. (1994) Diatoms, or Their Chloroplasts, as Endosymbiotic Partners for Foraminifera: Proceedings of the 11th International Diatom Symposium. *Memoirs of the California Academy of Science*, **17**, 21-36.
- [32] Lee, J.J., Mcenery, M.E., Ter Kuile, B., Erez, J., Rottger, R., Rockwell, R.F., Faber Jr., W.W. and Lagziel, A. (1989) Identification and Distribution of Endosymbiotic Diatoms in Larger Foraminifera. *Micropaleontology*, **35**, 353-366. <https://doi.org/10.2307/1485677>
- [33] Saraswati, P.K. (2007) Symbiont Bearing Benthic Foraminifera of Lakshadweep. *Indian Journal of Marine Sciences*, **36**, 351-354.
- [34] Prazeres, M. and Renema, W. (2019) Evolutionary Significance of the Microbial Assemblages of Large Benthic Foraminifera. *Biological Review*, **94**, 828-848. <https://doi.org/10.1111/brv.12482>
- [35] Prazeres, M., Roberts, T.E., Ramadhani, S.F., Doo, S.S., Schmidt, C., Stuhr, M. and Renema, W. (2021) Diversity and Flexibility of Algal Symbiont Community in Globally Distributed Larger Benthic Foraminifera of the Genus *Amphistegina*. *BMC Microbiology*, **21**, Article No. 243. <https://doi.org/10.1186/s12866-021-02299-8>
- [36] Hottinger, L. (1977) Foraminifères Operculiniformes. *Memoires Musée Naturelle D'Histoire Naturelle, Paris*, 1-159.
- [37] Langer, M.R. and Hottinger, L. (2000) Biogeography of Selected Larger Foraminifera. *Micropaleontology*, **46**, 105-126.
- [38] Lee, J.J., Lanners, E. and TerKuile, B. (1988) The Retention of Chloroplasts by the Foraminifer *Elphidium Crispum*. *Symbiosis*, **5**, 45-59.
- [39] Pawlowski, J. (2000) Introduction to the Molecular Systematics of Foraminifera. *Micropalaentology*, **46**, 1-12.
- [40] Pawlowski, J., Holzmann, M., Fahrni, J.F. and Hallock, P. (2001) Molecular Identification of Algal Endosymbionts in Large Miliolid Foraminifera: 1. Chlorophytes. *Journal of Eukaryotic Microbiology*, **48**, 362-367. <https://doi.org/10.1111/j.1550-7408.2001.tb00325.x>
- [41] Pawlowski, J., Holzmann, M., Fahrni, J.F., Pochon, X. and Lee, J.J. (2001) Molecular Identification of Algal Endosymbionts in Large Miliolid Foraminifera: 2. Dinoflagellates. *Journal of Eukaryotic Microbiology*, **48**, 368-373. <https://doi.org/10.1111/j.1550-7408.2001.tb00326.x>
- [42] Renema, W. (2006) Large Benthic Foraminifera from the Deep Photic Zone of a Mixed Siliciclastic-Carbonate Shelf off East Kalimantan, Indonesia. *Marine Micropaleontology*, **58**, 73-82. <https://doi.org/10.1016/j.marmicro.2005.10.004>
- [43] Renema, W., Beaman, R.J. and Webster, J.M. (2013) Mixing of Relict and Modern Tests of Larger Benthic Foraminifera on the Great Barrier Reef Shelf Margin. *Marine Micropaleontology*, **101**, 68-75. <https://doi.org/10.1016/j.marmicro.2013.03.002>
- [44] Hohenegger, J. (2004) Depth Coenoclines and Environmental Considerations of Western Pacific Larger Foraminifera. *Journal of Foraminiferal Research*, **34**, 9-33. <https://doi.org/10.2113/0340009>
- [45] Renema, W. and Troelestra, S.R. (2001) Larger Foraminifera Distribution on a Me-

- sotrophic Carbonate Shelf in South West Sulawesi Indonesia. *Paleogeography Paleoclimatology Paleocology*, **175**, 125-146.
[https://doi.org/10.1016/S0031-0182\(01\)00389-3](https://doi.org/10.1016/S0031-0182(01)00389-3)
- [46] Kuile, B.H. and Erez, J. (1991) Carbon Budgets for Two Species of Benthonic Symbiont-Bearing Foraminifera. *The Biological Bulletin*, **180**, 489-495.
<https://doi.org/10.2307/1542350>
- [47] Prazeres, M., Roberts, T.E. and Pandolfi, J.M. (2016) Shifts in Species Abundance of Large Benthic Foraminifera Amphistegina: The Possible Effects of Tropical Cyclone Ita. *Coral Reefs*, **36**, 305-309. <https://doi.org/10.1007/s00338-016-1497-x>
- [48] Hohenegger, J., Yordanova, E., Nakano, Y. and Tatzreiter, F. (1999) Habitats of Larger Foraminifera on the Upper Reef Slope of Sesoko Island, Okinawa, Japan. *Marine Micropaleontology*, **36**, 109-168.
[https://doi.org/10.1016/S0377-8398\(98\)00030-9](https://doi.org/10.1016/S0377-8398(98)00030-9)
- [49] Li, Q. and Wang, P. (1985) Distribution of Larger Foraminifera in the Northwestern Part of the South China Sea. In: Wang, P., Ed., *Marine Micropaleontology of China*, China Ocean Press, Beijing, 176-195.
- [50] Sugihara, K., Masunaga, N. and Fujita, K. (2006) Latitudinal Changes in Larger Benthic Foraminiferal Assemblages in Shallow-Water Reef Sediments along the Ryukyu Islands, Japan. *Island Arc*, **15**, 437-454.
<https://doi.org/10.1111/j.1440-1738.2006.00540.x>
- [51] Renema, W. (2002) Larger Foraminifera as Marine Environmental Indicators. *Scripta Geologica*, **124**, 1-230.
- [52] Hallock, P. (1984) Distribution of Selected Species of Living Algal Symbiont-Bearing Foraminifera on Two Pacific Coral Reefs. *Journal of Foraminiferal Research*, **14**, 250-261. <https://doi.org/10.2113/gsjfr.14.4.250>
- [53] Hohenegger, J., Yordanova, E. and Hatta, A. (2000) Remarks on West Pacific Nummulitidae (Foraminifera). *Journal of Foraminiferal Research*, **30**, 3-28.
<https://doi.org/10.2113/0300003>
- [54] Beavington-Penney, S. and Racey, A. (2004) Ecology of Extant Nummulitids and Other Larger Benthic Foraminifera: Applications in Palaeoenvironmental Analysis. *Earth-Science Reviews*, **67**, 219-265. <https://doi.org/10.1016/j.earscirev.2004.02.005>
- [55] Pecheux, M.J.F. (1995) Ecomorphology of a Recent Large Foraminifer, *Operculina ammonoides*. *Geobios*, **28**, 529-566. [https://doi.org/10.1016/S0016-6995\(95\)80209-6](https://doi.org/10.1016/S0016-6995(95)80209-6)
- [56] Hohenegger, J. (2006) The Importance of Symbiont-Bearing Benthic Foraminifera for West Pacific Carbonate Beach Environments. *Marine Micropaleontology*, **61**, 4-39. <https://doi.org/10.1016/j.marmicro.2006.05.007>
- [57] Yokes, M.B., Meriç, E. and Avsar, N. (2007) On the Presence of Alien Foraminifera *Amphistegina lobifera* Larsen on the Coasts of Maltese Islands. *Aquatic Invasions*, **2**, 439-441. <https://doi.org/10.3391/ai.2007.2.4.15>
- [58] Yuvaraja, M.P. and Ramanujam, N. (2013) Abnormal Growth of Benthic Foraminifera of Inter Generic Individuals and Microboring Indicating Environmental Stress in Port Blair, India. *International Journal of Current Research*, **5**, 332-335.
- [59] Lee, J.J. (2006) Algal Symbiosis in Larger Foraminifera. *Symbiosis*, **42**, 63-75.
- [60] Prazeres, M., Roberts, T.E., Pandolfi, J.M., Schmaljohann, R. and Hoegh-Guldberg, O. (2017) Variation in Sensitivity of Large Benthic Foraminifera to the Combined Effects of Ocean Warming and Local Impacts. *Scientific Report*, **7**, Article No. 45227. <https://doi.org/10.1038/srep45227>
- [61] Oron, S., Evans, D., Abramovich, S., Almogi-Labin, A. and Erez, J. (2020) Differen-

- tial Sensitivity of a Symbiont-Bearing Foraminifer to Seawater Carbonate Chemistry in a Decoupled DIC-PH Experiment. *JGR Biogeoscience*, **125**, e2020JG005726. <https://doi.org/10.1029/2020JG005726>
- [62] Richardson, S.L. (2001) Endosymbiont Change as a Key Innovation in the Adaptive Radiation of Soritida (Foraminifera). *Paleobiology*, **27**, 262-289. [https://doi.org/10.1666/0094-8373\(2001\)027<0262:ECAAki>2.0.CO;2](https://doi.org/10.1666/0094-8373(2001)027<0262:ECAAki>2.0.CO;2)
- [63] Lopez, E. (1979) Algal Chloroplasts in the Protoplasm of Three Species of Benthic Foraminifera: Taxonomic Affinity, Viability and Persistence. *Marine Biology*, **53**, 201-211. <https://doi.org/10.1007/BF00952427>
- [64] Lee, J.J., McEnery, M.E. and Garrison, J.R. (1980) Experimental Studies of Larger Foraminifera and Their Symbionts from the Gulf of Elat on the Red Sea. *Journal of Foraminiferal Research*, **10**, 31-47. <https://doi.org/10.2113/gsjfr.10.1.31>
- [65] Lee, J.J., Soldo, A.T., Reisser, W., Lee, M.J., Jeon, K.W. and Görtz, H.D. (1985) The Extent of Algal and Bacterial Endosymbioses in Protozoa. *Journal of Protozoology*, **32**, 391-403. <https://doi.org/10.1111/j.1550-7408.1985.tb04034.x>
- [66] Lee, J.J., Burnham, B. and Cevasco, M.E. (2004) A New Modern Soritid Foraminifer, *Amphisorus saurensis* n. sp., from the Lizard Island Group (Great Barrier Reef, Australia). *Micropaleontology*, **50**, 357-368. <https://doi.org/10.2113/50.4.357>
- [67] Pochon, X., Pawlowski, J., Zaninetti, L. and Rowan, R. (2001) High Genetic Diversity and Relative Specificity among Symbiodinium-Like Endosymbioticdinoflagellates in Soritid Foraminiferans. *Marine Biology*, **139**, 1069-1078. <https://doi.org/10.1007/s002270100674>
- [68] Hottinger, L. (1977) Distribution of Larger Peneroplidae, Borelis and Nummulitidae in the Gulf of Elat, Red Sea. *Utrecht Micropaleontological Bulletins*, **15**, 35-109.
- [69] Narayan, Y.R., Lybolt, M., Zhao, J.-X., Feng, Y. and Pandolfi, J.M. (2015) Holocene Benthicforaminiferal Assemblages Indicate Long-Term Marginality of Reef Habitats FromMoreton Bay, Australia. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **420**, 49-64. <https://doi.org/10.1016/j.palaeo.2014.12.010>
- [70] Reymond, C.E., Roff, G., Chivas, A.R., Zhao, J.X. and Pandolfi, J.M. (2013) Millenium-Scale Records of Benthic Foraminiferal Communities from the Central Great Barrier Reef Reveal Spatial Differences and Temporal Consistency. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **374**, 52-61. <https://doi.org/10.1016/j.palaeo.2013.01.001>
- [71] Gudmundsson, G. (1994) Phylogeny, Ontogeny and Systematics of Recent Soritacea Ehrenberg 1839 (Foraminiferida). *Micropaleontology*, **40**, 101-155. <https://doi.org/10.2307/1485772>
- [72] Bourne, D.G., Dennis, P.G., Uthicke, S., Soo, R.M., Tyson, G.W. and Webster, N. (2013) Coral Reef Invertebrate Microbiomes Correlate with the Presence of Photosymbionts. *The ISME Journal*, **7**, 1452-1458. <https://doi.org/10.1038/ismej.2012.172>
- [73] Garcia-Cuetos, L., Pochon, X. and Pawlowski, J. (2005) Molecular Evidence for Host-Symbiont Specificity in Soritid Foraminifera. *Protist*, **156**, 399-412. <https://doi.org/10.1016/j.protis.2005.08.003>
- [74] Lee, J.J. (1990) Phylum Granuloreticulosa (Foraminifera). In: Margulis, L., Corliss, J.O., Melkonian, M. and Chapman, D.J. Eds., *Handbook of Protoctista*, Jones and Bartlett Publishers, Boston, 524-548.
- [75] Hawkins, E.K. and Lee, J.J. (2001) Architecture of the Golgi Apparatus of a Scale-Forming Alga: Biogenesis and Transport of Scales. *Protoplasma*, **216**, Article No. 227. <https://doi.org/10.1007/BF02673874>
- [76] Lee, J.J., Morales, J., Bacus, S., Diamont, A., Hallock, P., Pawlowski, J. and Thorpe, J.

- (1997) Progress in Characterizing the Endosymbiotic Dinoflagellates of Soritid Foraminifera and Related Studies on Some Stages in the Life Cycle of *Marginopora Vertebralis*. *Journal of Foraminiferal Research*, **27**, 254-263.
<https://doi.org/10.2113/gsjfr.27.4.254>
- [77] Leutenegger, S. (1984) Symbiosis in Benthic Foraminifera: Specificity and Host Adaptations. *Journal of Foraminiferal Research*, **14**, 16-35.
<https://doi.org/10.2113/gsjfr.14.1.16>
- [78] Renema, W. (2003) Larger Foraminifera on Reefs around Bali (Indonesia). *Zoologische Verhandelingen Leiden*, **345**, 337-366.
- [79] Ranju, R., Menon, N.N. and Menon, N.R. (2019) Observations on Some Symbiont Bearing Foraminifera from the Shelf and Slope Sediments of Eastern Arabian Sea. *Journal of the Marine Biological Association of India*, **60**, 53-58.
<https://doi.org/10.6024/jmbai.2018.60.2.2054-08>
- [80] Pochon, X., LaJeunesse, T.C. and Pawlowski, J. (2004) Biogeographic Partitioning and Host Specialization among Foraminiferan Dinoflagellate Symbionts (Symbiodinium; Dinophyta). *Marine Biology*, **146**, 17-27.
<https://doi.org/10.1007/s00227-004-1427-2>