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FoRAM Index in Manado Bay coral reef areas, Northern Sulawesi, Indonesia

Exel V. Sumale[1], Jane M. Mamuaja[1]*, Markus T. Lasut[2], Hermanto W.K. Manengkey[1], Royke M. Rampengan[1], Jans D. Lalita[3]

[1]*Marine Science Study Program, Faculty of Fisheries and Marine Science, Sam Ratulangi University, Jl. Kampus UNSRAT Bahu, Manado.*
[2]*Aquatic Science Study Program, Faculty of Fisheries and Marine Sciences, Sam Ratulangi University, Manado.*
[3]*Aquatic Resources Management Study Program, Faculty of Fisheries and Marine Science, Sam Ratulangi University, Manado.*
*Corresponding author: janemamuaja@unsrat.ac.id

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Abstract: Benthic foraminifera are protozoans that are readily preserved in marine sediments. The relative proportion of benthic foraminifera that harbor symbionts compared to the proportion that are opportunistic or small/heterotrophic can be used to indicate the quality of the aquatic environment for coral reefs via the FoRAM Index (Foraminifera in Reef Assessment and Monitoring). This study assesses the functional composition of benthic foraminifera in the waters of Manado Bay using the FoRAM Index. Sampling was carried out at 4 stations with 3 replicates each using *SCUBA* equipment at a depth of 3-6 meters. The 4,124 benthic foraminifera specimens collected were distributed over 37 genera and the FoRAM Index ranged from 1.90 to 9.12. The water conditions at three of the stations (Meras, Molas, and Malalayang) are very conducive to the growth of coral reefs, with FoRAM Index values ranging from 5.64 to 9.12, while at the Sario station the FoRAM Index value was only 1.90 to 2.04, indicating that this aquatic environment is unsuitable for the growth and development of coral reefs.

Keywords: benthic foraminifera; FoRAM Index; Manado Bay; coral reef health; coastal pollution

INTRODUCTION

Among the wide range of global marine ecosystem (Nybakken, 1988), coral reefs have especially high economic, ecological and social values (Toruan, 2011), and thus their health is of upmost importance. Among the many taxa that live in coral reef areas are benthic foraminifera. These microscopic protozoans preserve well in marine sediments, and they have been widely used as an environmental indicator because of their sensitivity to changes in the surrounding environment (Widianingsih *et al*. 2013). Moreover, small benthic foraminifera are among the main contributors of sediment in shallow water, and they can also attach to coral fragments (Boersma, 1998).

Benthic foraminifera, through the application of the FoRAM (Foraminifera in Reef Assessment and Monitoring) Index, have been used as part of monitoring the marine environments in areas with coral reefs, in a wide range of areas around the globe. In Indonesia, this index has been applied by several researchers (Natsir, 2010; Dewi and Darlan, 2008; Toruan *et al*., 2013; Aulia *et al*., 2012; Gustiani and Ilahude, 2012; Paringgi *et al*., 2018; Kalalo *et al*., 2020), and here we apply it to Manado Bay.

MATERIALS AND METHODS

Sampling and sample processing

The area of study was Manado Bay, and sampling was done at four stations that also have living coral reefs (Figure 1). Sediment samples were collected by divers by filling a plastic bag with the upper 2 cm of surface sediments. Three replicates were done at each station. The water depth at the sampling stations varied from three to six meters.

Preparation of the samples followed the method of Kennedy and Ziedler (as stated in Natsir, 2010). The samples were first washed with freshwater through a 63 µm sieve and dried under the sun. The foraminifera tests were then separated from the sediment on a picking tray under a microscope and then mounted on micropaleontology slides for identification and documentation. At least 300 tests

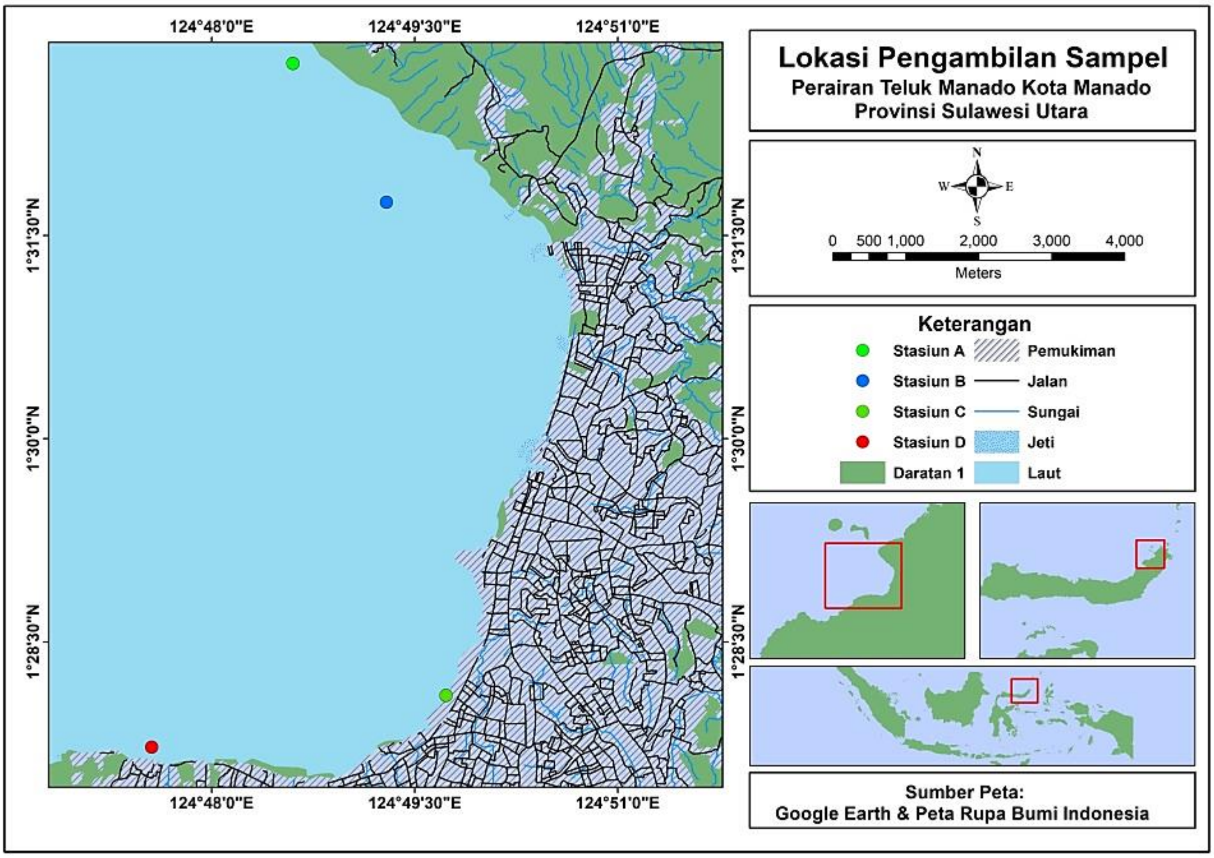

Figure 1. Sampling locations (A: Meras; B: Molas; C: Sario; D: Malalayang)

were picked from each sample, the standard sample size used by foraminiferal researchers for community analyses (Hallock *et al*., 2003). Identifications were made to the genus level using Nobes and Uthicke (2008), Toruan (2011), and Forderer and Langer (2018), followed by rechecking against the online WORMS database (World Register of Marine Species, http://www.marine species.org/index.php).

Data analysis

The FoRAM Index is a simple summary statistic based on the foraminiferal assemblages on the sediment surface which is indicative of whether the water quality in the environment can support reef growth and/or recovery (Hallock *et al.*, 2003). The value of the FoRAM Index is computed the following formula: $FI = (10 \times Ps) + (Po) + (2 \times Ph)$, where FI is the FoRAM Index, Ps represents the proportion of specimen of symbiont-bearing foraminifera, Po is the proportion of specimen of opportunistic taxa, and Ph is the proportion of small/heterotrophic foraminifera. The values of Ps, Po and Ph are the number of specimens of each functional group divided by the total number of specimens counted (T). The values of FI are presented in Table 1. For more information about the index, please see Hallock *et al.,* (2003).

RESULTS AND DISCUSSIONS

Benthic foraminifera

A total of 4,124 specimens of benthic foraminifera were identified consisting of 37 genera (Table 2). The genera identified included the

Table 1. Interpretation of FoRAM Index (Hallock *et al*., 2003)

Index	Interpretation
FI > 4	The environment is conducive to reef growth
FI between 3 and 5	The environment is changing
2 < FI < 4	The environment is marginal for reef growth and unsuitable for recovery
FI < 2	Stressed condition unsuitable for reef growth

Table 2. Composition of benthic foraminifera at each station

No.	Genera	Station												Total (Indiv.)
		Meras			Molas			Sario			Malalayang			
		A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3	
1.	*Ammonia*	0	0	0	1	0	0	4	0	19	91	50	42	207
2.	*Amphistegina*	75	50	53	15	23	14	3	2	1	15	13	8	272
3.	*Baculogypsina*	1	0	1	0	0	0	0	0	0	0	2	0	4
4.	*Bolivina*	1	1	1	0	0	0	0	0	1	0	0	0	4
5.	*Buliminella*	0	0	0	0	0	0	1	0	0	0	0	0	1
6.	*Calcarina*	129	86	101	294	245	208	3	0	2	114	71	135	1388
7.	*Cibicides*	0	5	1	0	2	0	0	0	2	0	0	0	10
8.	*Cornuspira*	1	0	0	0	0	1	8	9	4	0	0	0	23
9.	*Cymbaloporetta*	0	0	2	0	0	1	0	1	0	1	3	1	9
10.	*Discorbinella*	0	0	0	0	0	0	4	0	0	0	9	0	13
11.	*Elphidium*	27	26	19	8	7	9	20	24	17	11	8	5	181
12.	*Epistomaroides*	0	0	0	0	0	0	0	1	1	0	1	0	3
13.	*Eponides*	1	2	0	0	1	0	1	0	0	0	1	0	6
14.	*Flintina*	0	0	0	0	0	0	0	0	0	0	1	0	1
15.	*Heterostegina*	0	1	2	2	1	2	0	0	0	0	1	0	9
16.	*Lachlanella*	0	0	0	0	0	0	0	0	0	0	1	0	1
17.	*Laevipeneroplis*	1	0	1	0	0	0	0	0	0	0	0	0	2
18.	*Miliolinella*	1	0	1	0	0	0	3	5	3	0	0	0	13
19.	*Neoconorbina*	0	0	0	0	0	0	0	0	0	0	1	0	1
20.	*Neorotalia*	101	88	56	53	52	54	0	0	0	99	53	71	627
21.	*Nonionoides*	0	0	0	0	0	0	0	0	0	0	3	0	3
22.	*Operculina*	0	0	0	1	1	0	0	0	0	0	0	0	2
23.	*Parasorites*	0	0	0	0	0	0	1	0	0	1	0	0	2
24.	*Peneroplis*	16	4	11	1	0	0	0	1	0	1	0	0	34
25.	*Planorbulina*	2	1	5	1	2	1	0	0	1	2	1	3	19
26.	*Pyrgo*	0	0	2	0	2	0	0	0	0	0	0	0	4
27.	*Pseudopyrgo*	0	0	0	0	0	0	0	0	0	11	7	1	19
28.	*Quinqueloculina*	14	21	24	10	15	16	78	65	41	23	22	7	336
29.	*Reussela*	0	0	1	0	0	0	0	0	0	0	5	0	6
30.	*Rosalina*	0	1	1	1	0	1	0	5	1	0	0	0	10
31.	*Rotorbis*	1	1	0	0	0	0	1	0	0	0	0	0	3
32.	*Sahulia*	7	0	0	0	0	0	0	0	0	0	0	0	7
33.	*Septotextularia*	0	0	1	0	0	0	0	1	0	1	0	3	6
34.	*Sorites*	7	6	5	0	0	2	0	0	0	0	1	1	22
35.	*Spiroloculina*	2	0	1	0	0	0	2	6	3	3	2	1	20
36.	*Textularia*	23	29	30	9	12	15	2	14	16	5	1	17	173
37.	*Triloculina*	9	0	5	0	1	2	171	169	191	57	64	14	683
	Total	419	322	324	396	364	326	302	303	303	435	321	309	4124

symbiont bearing taxa (*Amphistegina, Baculogypsina, Calcarina, Heterostegina, Laevipeneroplis, Neorotalia, Operculina, Parasorites, Peneroplis,* and *Sorites*), the opportunistic taxa (*Ammonia* and *Elphidium*), and the small/heterotrophic taxa (*Bolivina, Buliminella, Cibicides,Cornuspira, Cymbaloporetta, Discorbinella, Epistomariodes, Eponides, Flintina, Lachlanella, Millionella, Neoconorbina, Nonionoides, Planorbulinella, Pyrgo, Pseudopyrgo, Quinqueloculina, Reussella, Rosalina, Rotorbis, Sahulia, Septotextularia, Spiroloculina, Textularia,* and *Triloculina*).

Calcarina was the most common genus at three stations (Meras, Molas, and Malalayang), with a total of 1388 (33.66%) specimens found across the four stations. The second most dominant genus was *Triloculina*, with 683 specimens (15.56%) across the four stations. This genus was the most dominant only at Station Sario. In total, 57.25% of the benthic foraminifera collected belonged to the symbiont-bearing functional group, largely consisting of *Amphistegina, Calcarina,* and *Neorotalia.* The opportunistic functional group only had 9.40% of the specimens, while those from small and heterotrophic group had 33.35%. The comparison of the number of specimens from each genus is shown in Figure 2.

FoRAM Index

The FoRAM Index in the study area in Manado Bay varied from 1.90 to 9.12 (Figure 3). At

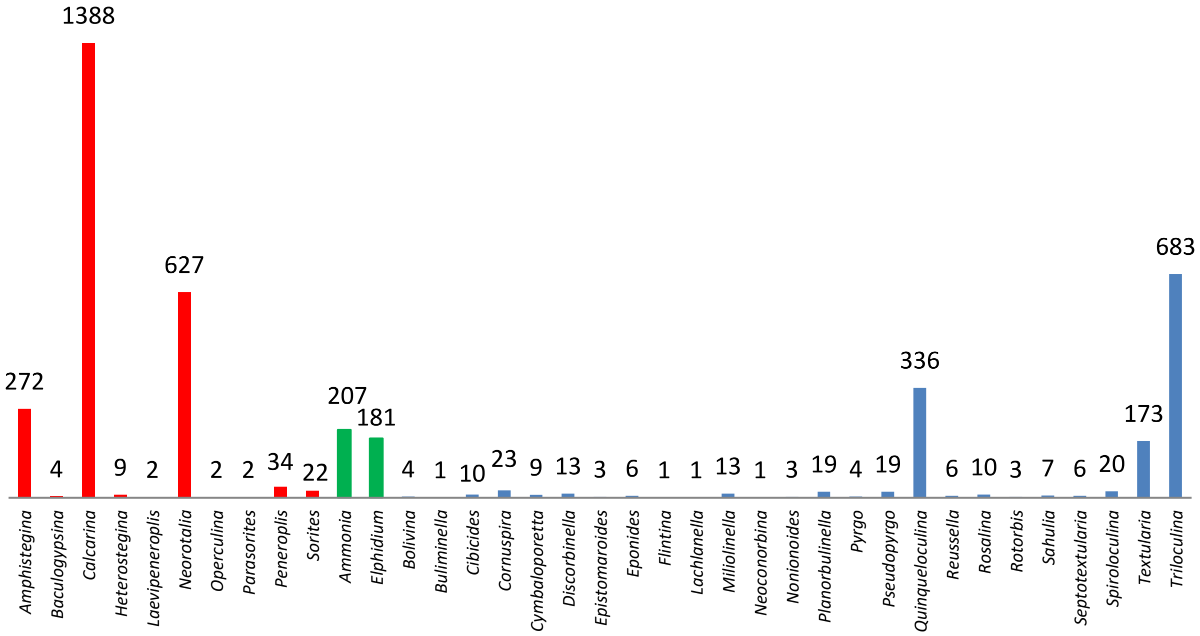

Figure 2. Number of benthic foraminifera in each genus.

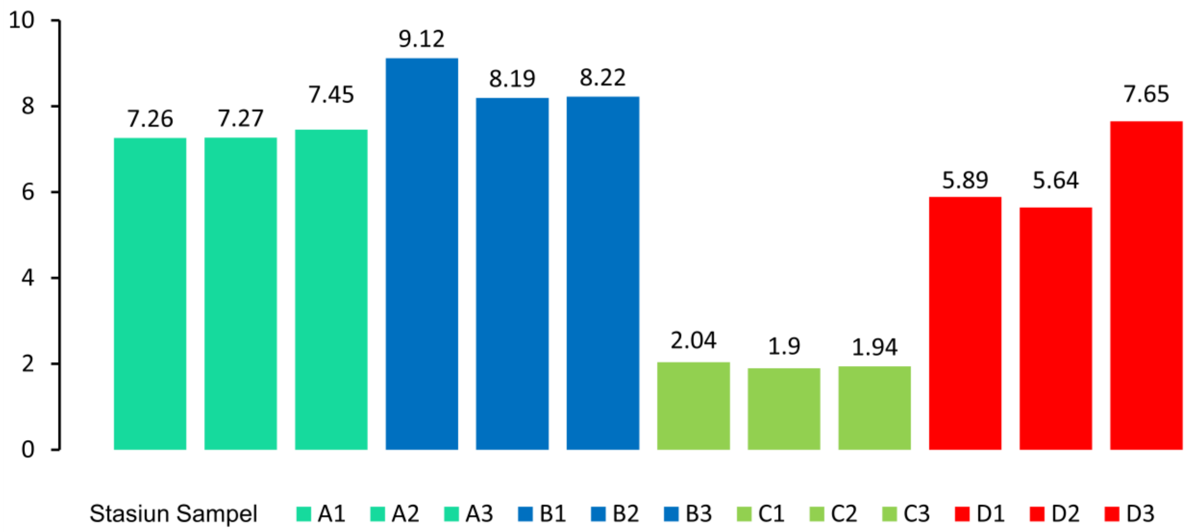

Figure 3. FoRAM Index in each sampling station (A: Meras; B: Molas; C: Sario; D: Malalayang).

three stations (Meras, Molas, and Malalayang), the indices were high, varying from 5.64 to 9.12. These values indicate that the water around the coral reefs in these areas of Manado Bay are conducive to reef growth (Hallock *et al.*, 2003). However, in contrast, at Station Sario all three samples showed low indices, varying from 1.90 to 2.04. This indicates that the water in the area is under stress and was not suitable for reef growth at the time of sampling.

Station Sario is especially interesting because the location was dominated by the genus *Triloculina* from the small and heterotrophic group. The station is located in front of central business area in Manado Bay and the presence of high proportion of small and heterotrophic group in sediments may indicate an increase in nutrient input to the area (Prazeres *et al.*, 2020). It is believed that there has been a local shift in benthic foraminiferal assemblages in Station Sario, from being dominated by larger benthic foraminifera to the small and heterotrophic dominance. Further study to monitor the foraminiferal assemblages in relation to the health of coral reef in that area is important.

The FoRAM Index has also been calculated in an area just to the northeast of Manado Bay, in the Bunaken Island coral reef area (Paringgi *et al*., 2018; Kalalo *et al*., 2020). Both studies report FoRAM Index values greater than 7, but interestingly at Bunaken the most dominant genus was *Amphistegina*, *Calcarina* the second most dominant, the reverse of the pattern seen in the healthiest areas in Manado Bay.

CONCLUSIONS

Based on the 4,124 specimens collected, the FoRAM Index, a proxy for the health of coral reefs, was quite high at three of four sample stations (indicating that the water in these areas is conducive for reef growth), while the index was found to be low at the fourth station close to the largest metropolitan area on the edge of Manado Bay (which suggested that the water was not suitable for reef growth).

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