

The distribution of benthic foraminifera in coral reefs ecosystem of East Penjaliran Island, Seribu Islands, Indonesia

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Abstract. Natsir SM. 2022. *The distribution of benthic foraminifera in coral reefs ecosystem of East Penjaliran Island, Seribu Islands, Indonesia. Biodiversitas 23: 3073-3080.* East Penjaliran Island is located in the core zone of Seribu Islands Marine National Park and is included in the protected green area. The research shows the close relationship between benthic foraminifera and coral reef. Certain foraminifera has the same environmental requirement to live with coral reefs. Therefore, the study of foraminiferal assemblages is also very important to shed light on the environmental conditions for the growth of coral reefs through calculating the Foraminifera in Reef Assessment and Monitoring Index (FORAM Index/FI). Sampling was conducted in December 2016 around the coral reef ecosystems of East Penjaliran Island, Seribu Islands. A total of 37 species of benthic foraminifera were collected from the island with a diverse abundance. Based on the FI gained values on average of 3.18. It indicates that East Penjaliran Island is classified as an environmental change for coral reefs' growth. The condition was feasible for the growth of coral reefs, but it tends to be an unfavorable environment for their recovery. The benthic foraminifera assemblages can be classified into three major groups based on the Shannon diversity index and FI (i.e., Group A, Group B, and Group C) with their specific characteristics. Group A was characterized by coarse sand sediment and dwelled dominantly by opportunistic foraminifers such as *Elphidium advenum*, *Elphidium crispum*, and *Flintina bradyana*. Groups B and C have very fine sand sediment, but they dwelled by foraminiferal assemblages in different compositions. Group B was dominated by *E. crispum* and followed by several species of *Peneroplis*, but Group C dwelled abundantly by *E. advenum*, *E. crispum*, *Elphidium depressulum* and followed by symbiont-bearing foraminifera such as *Peneroplis planatus*.

Keywords: Benthic foraminifera, diversity, East Penjaliran, FORAM Index

INTRODUCTION

Seribu Islands is a sedimentary basin dating from the Mesozoic era and is bounded by a geanticline in the south and a stable shelf in the north. Based on the Map of the Regional Spatial Planning for the Seribu Islands Administrative District for 2010-2030, the area has 117 islands spread over the Districts of the South Seribu Islands and the North Seribu Islands, Jakarta Province, Indonesia. Most of the islands in the North Seribu Islands District are included in the protected Seribu Islands Marine National Park area.

Based on the Decree of the Director-General of Forest Protection and Nature Conservation of the Ministry of Forestry Number SK.05/IV-KK/2004, East Penjaliran Island is one of the islands located in core zone II. It is included in the protected green area of the Seribu Islands Marine National Park. The core zone is part of the national park area, which is absolutely protected, and no changes are allowed by human activities. However, human engineering of coastal systems can have unintended consequences for foraminifera assemblages. As a result, changes in foraminiferal assemblages (distribution, composition, relative abundance, and diversity of dead foraminifera) in the estuary occurred rapidly (Culver et al. 2019). While the Protected Green Area is part of a green area with natural characteristics that need to be preserved to protect local habitats and wider area.

Coral reef ecosystems dominate Seribu Islands Marine National Park waters. The waters are relatively better for coral reef growth than the southern part of the Seribu Islands area because of the low influence of pollution from the mainland. However, based on Giyanto and Soekarno (1997), the percentage of live coral cover in the waters of the Southern Seribu Islands is lower than in the central and northern parts. The influx of freshwater causes a decrease in the salinity of seawater, carried away by silt. It increases sedimentation, and other factors can reduce the percentage of live coral cover in the waters and increase the percentage of abiotic cover.

Intensive monitoring of the coral reefs' ecosystem and surroundings is very important because it has a very large function for various marine biota (Asmara et al. 2013). A simple method that can be applied to monitor the condition of coral reefs is by analyzing the diversity index of biota associated with coral reefs, such as benthic foraminifera. A method that has been developed is Foraminifera in Reef Assessment and Monitoring Index (FI) (Hallock et al. 2003). Foraminifera has been found abundant, especially in coral reef ecosystems. For example, about 30% of the total sediment that lay on Green Island, Great Barrier Reef, Australia is composed of benthic foraminifera, so these organisms are one of the contributors to the formation of coral reefs. Certain foraminifera requires similar water quality with various coral reef-forming biota and a fairly short life cycle to show rapid environmental changes. In

addition, foraminifera sampling has very little effect on coral reef ecosystems, so it is safe to preserve coral reefs. This study aims to determine the abundance of benthic foraminifera as an indicator of the waters of the coral reef area around the waters of the East Penjaliran Island, Seribu Islands, Jakarta Province, Indonesia.

MATERIALS AND METHODS

Study area

The location of the east Penjaliran island is in the northernmost cluster of the Thousand Islands, which is dominated by coral reef ecosystems. This small island is located at coordinates between 5.27°0"S-5.27°23"S and 106.32°42'E-106.33°10'E. The investigation station for foraminifera sampling consisted of 12 stations, including the northern, eastern, southern, and western groups of East Penjaliran Island (Figure 1).

Procedures

Fieldwork

The procedure consists of fieldwork, observation, and laboratory analysis. Sampling was conducted in December 2016 along 12 stations aligned to the East Penjaliran coastline. Surface sediment of each station was collected to the depth of a 20 cm layer of sediments using a Van Veen

Grab. A 100 gr of the sediments was then put into a plastic bag for further analysis in the laboratory.

Laboratory analysis

The samples' preparation, observation, and analysis were conducted at the Marine Geology Laboratory, Research Center for Oceanography, National Research and Innovation Agency, Jakarta. Sample preparation was carried out in several stages, including washing, picking, description, identification, sticking, and documentation. The samples were washed under running water over consecutive sieves of 0.063, 0.125, 0.25, 0.5, 1, 2, 4, and 8 mm and dried in an oven at 30°C. The dried samples were put into labeled plastic bags for further analysis. After washing and drying, the filter should be immersed in a methylene blue solution to prevent contamination by subsequent samples and washed. The next stage is picking by evenly spreading the washed samples on the extraction tray under the microscope. Then the collected foraminifera is stored on the foraminiferal slide. We did not apply rose bengal staining during the preparation stage because this study did not distinguish between live and dead foraminifera. The analysis was applied to all collected foraminifera shells. According to Murray (1973), the distribution and abundance of species received considerable attention, both living and dead species.

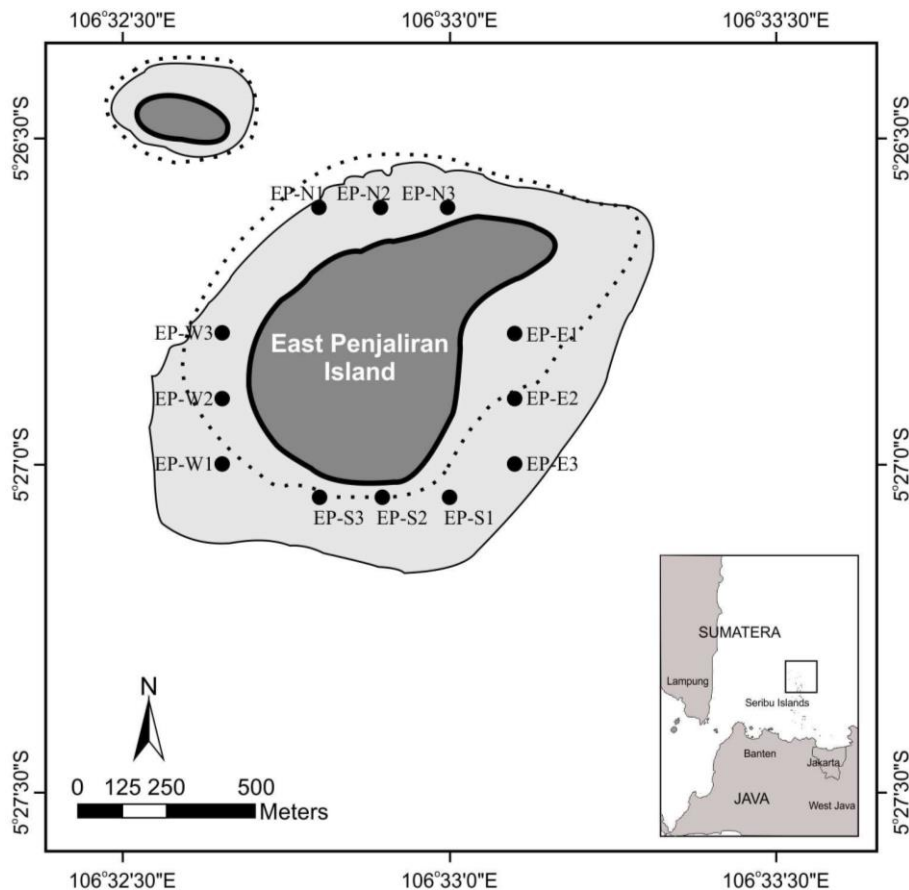


Figure 1. Sampling station in the coral reefs ecosystem of East Penjaliran Island, Seribu Islands, Jakarta, Indonesia

Table 1. Sampling stations showing location, depth, and environmental parameters of East Penjaliran Island, Seribu Islands, Indonesia

Samples	Location		Depth (m)	Temperature (°C)	Salinity (ppt)	pH	Turbidity (m)
	Lat	Long					
EP-N1	5°26'36"S	106°32'48"E	34.5	29	32.28	7.9	10
EP-N2	5°26'36"S	106°32'54"E	34.5	30	31.548	7.98	9
EP-N3	5°26'36"S	106°33'0"E	34	30	32.297	8.3	10
EP-E1	5°27'12"S	106°33'6"E	33	29	31.2	7.9	10
EP-E2	5°27'6"S	106°33'6"E	33	30	32.2	7.9	10
EP-E3	5°27'0"S	106°33'6"E	33	30	31.711	8.4	10
EP-S1	5°26'57"S	106°33'0"E	30	29	31.25	7.9	10
EP-S2	5°26'57"S	106°32'54"E	30	30	32.1	7.9	10
EP-S3	5°26'57"S	106°32'48"E	29.5	31	32.121	8	13
EP-W1	5°27'0"S	106°32'39"E	28.5	29	32.12	7.95	8
EP-W2	5°27'6"S	106°32'39"E	28	30	31.972	7.49	9
EP-W3	5°27'12"S	106°32'39"E	28	30	32.116	8.3	11

The specimens were classified based on their morphology, such as shell shape, chamber shape, chamber formation, number of chambers, shell ornamentation, aperture slope, aperture position, and additional chambers. Furthermore, the collected specimens were identified to the species level using standard taxonomic references (Graham and Militante 1959; Barker 1960; Cushman 1969; Albani 1979; Loeblich and Tappan 1992). Next, the sticking and documentation were carried out by placing the selected specimen on a foraminiferal slide with a visible aperture position, dorsal, ventral, and side view, which was then documented under a microscope. The next stage is a systematic study and quantitative analysis to obtain abundance data.

Data analysis

The identified specimens were counted, recorded, and mounted on micropaleontological slides for reference. The remainder of each sample was air-dried and stored in a labeled plastic bag. The faunal diversity indices, such as species diversity (Shannon-Wiener, H'), species richness (Margalef, d'), Berger-Parker index (max π), and equitability index (Pielou, J'), were calculated using routines implemented in the PAST version 4.03 software.

The Foraminifera in Reef Assessment and Monitoring Index (FORAM Index/FI) analysis was applied to the specimens identified by genus level. The specimens were classified into three functional groups: Symbiont bearing, opportunists, and other small heterotrophic foraminifera. The portion of each group was calculated by dividing the number of specimens in each functional group by the total number of specimens obtained. Then, the FI is calculated by adding the portions of the three functional groups using the following formula (Hallock et al. 2003):

$$FI = (10 \times Ps) + (Po) + (2 \times Ph)$$

Where; FI: FI; Ps: N_s/T , where subscript "s" represents symbiont-bearing foraminifera. *Amphistegina*, *Heterostegina*, *Alveolinella*, *Borelis*, *Sorites*, *Amphisorus*, *Marginophora*; Po: N_o/T , where subscript "o" represents opportunistic foraminifera. *Ammonia*, *Elphidium*, several genera of Trochaminidae, Lituolidae, Boliviniidae, Buliminidae; Ph: N_h/T where subscript "h" represents

other small, heterotrophic foraminifera. Several genera of Miliolida, Rotaliida, Textulariida, and most except larger taxa noted above; T: Total number of specimens from each sample tested.

The results of the FI show that environmental conditions are associated with their suitability for coral reef growth. The interpretation of FI values based on the classification by Hallock et al. (2003) includes: $FI > 4$: indicates an environment conducive to reef growth; $3 < FI < 5$: indicates environmental change (Coefficient of Variation > 0.1); $2 < FI < 4$: indicates environment marginal for reef growth and unsuitable for recovery; $FI < 2$: indicates stressed conditions unsuitable for reef growth.

The foraminiferal species-environment relationship was explored through Canonical Correspondence Analysis (CCA) using PAST software. To understand the similarity of the foraminifera assemblages around East Penjaliran Island, a Q-mode cluster analysis was conducted. Cluster analyses were applied to all samples based on Ward's method to interpret the response of foraminiferal assemblages to the FI. The relative abundances of the collected species were treated in Q-mode, and R-mode hierarchical analyses based on euclidian distance correlation coefficients were also carried out using PAST software.

RESULTS AND DISCUSSION

Diversity index

The Shannon diversity index in all samples from the waters of East Penjaliran, Seribu Islands, was recorded to have almost the same value, ranging from 3.40 to 3.49. The lowest diversity value was recorded in the EP-S3 sample (3.40), collected from the southern part of the island. In contrast, the highest diversity value was recorded in the EP-E3 sample collected from the eastern part. The species evenness (J') and values ranged from 0.94 to 0.97 (Table 2).

FORAM index assessment

The results of the FI assessment ranged from 3.15 to 3.65 (Table 3). Therefore, the waters of East Penjaliran Island are considered an environmental change.

Table 2. Benthic foraminiferal diversity indices at sediment sampling stations of Esat Penjaliran, Seribu Islands, Indonesia

Samples	Depth	Species richness (Margalef, d')	Equitability index (Pielou, J')	Berger-Parker (Max, pi)	Species diversity (Shannon-wiener, H')
EP-N1	34.5	4.992	0.9481	0.06863	3.424
EP-N2	34.5	5.117	0.9608	0.06426	3.469
EP-N3	34	5.082	0.9602	0.07963	3.467
EP-E1	33	4.998	0.9514	0.07223	3.436
EP-E2	33	5.129	0.963	0.06714	3.477
EP-E3	33	5.111	0.9653	0.06021	3.486
EP-S1	30	5.109	0.9549	0.06789	3.448
EP-S2	30	5.071	0.9551	0.06854	3.449
EP-S3	29.5	5.079	0.9418	0.07101	3.401
EP-W1	28.5	5.095	0.9452	0.08027	3.413
EP-W2	28	5.157	0.9611	0.06413	3.471
EP-W3	28	5.121	0.9551	0.06637	3.449

Table 3. The proportion of symbiont-bearing, opportunistic, heterotrophic groups of benthic foraminifera and FI on the East Penjaliran Island waters, Seribu Islands, Indonesia

Samples	Proportion			FI
	Ps	Po	Ph	
EP-N1	0.21	0.30	0.49	3.39
EP-N2	0.23	0.23	0.54	3.61
EP-N3	0.23	0.25	0.52	3.57
EP-E1	0.20	0.30	0.50	3.33
EP-E2	0.23	0.24	0.53	3.62
EP-E3	0.21	0.26	0.53	3.39
EP-S1	0.23	0.26	0.51	3.61
EP-S2	0.21	0.28	0.51	3.38
EP-S3	0.21	0.30	0.50	3.35
EP-W1	0.18	0.32	0.50	3.15
EP-W2	0.23	0.25	0.53	3.57
EP-W3	0.24	0.26	0.51	3.65

Species-environment relationship

Canonical Correspondence Analysis indicated a significant correlation between foraminiferal assemblages, depth and sediment texture.

Cluster analysis

The results indicated that the benthic foraminifera assemblages could be classified into three major groups (i.e., Group A, Group B, and Group C). The twelve samples make up three groups based on the Shannon diversity index and FI, including Groups A, B, and C (Figure 3). The members of each group lie on several parts of the island, including Group A consists of stations EP-N1 (northern), EP-E1 (eastern), EP-S3 (southern), and EP-W1 (western). Meanwhile, group B consists of stations EP-N2, EP-N3 (norther), EP-E2 (eastern), and EP-W2 (western). Group C consists of two stations in the southern part of the island, namely EP-S1 and EP-S2, and in the east and south, respectively represented by stations EP-E3 and EP-W3.

Discussion

The results showed that a total of 37 species of foraminifera which included 16 genera, were collected. The collected benthic foraminifera are members of the suborders Rotaliina and Milioliina. Suborder Rotaliina is a

calcareous or calcareous test wall foraminifera, has pores and contains elements of manganese and calcite. This group has a hyaline shell with pores, spines, and pigments that make it look clear, so it is called perforate calcareous. Meanwhile, foraminifera from Miliolina have porcelain walls or porcelaneous tests containing manganese and calcite elements, and without pores, so they are also called imperforate calcareous or non-porous limestones. Rotaliina is predominantly collected in sediments rich in organic matter in shallow water. They build their shell chemically depending on the availability of nutrients. Therefore, their proportion decreases with increasing water depth (Bolotovskoy and Wright 1976; Murray 2006). The research area is shallow water dominated by coral reef ecosystems, so it is suspected that it has sufficient nutrient content as a test building material. This allows them to grow and develop better than other types of foraminifera.

Calculation of the Shannon diversity index in all samples from the waters of East Penjaliran, Seribu Islands, was recorded to have a slightly different value, ranging from 3.40 to 3.49. The lowest diversity value was obtained from the EP-S3 sample (3.40) collected from the southern part. In contrast, the highest diversity value was recorded in the EP-E3 sample collected from the eastern part of the island. This condition is also slightly different from other parameters such as Evenness which ranges from 0.81 to 0.88, and Equitability which ranges from 0.94 to 0.97 (Table 2).

Based on the classification of functional groups in Hallock et al. (2003), most of the collected benthic foraminifera in East Penjaliran Island waters are other small heterotrophic foraminifera groups. This group was found with an average of 50.44%, while symbiont-bearing foraminifera and opportunists respectively reached 18.44% and 29.12%. Symbiont-bearing foraminifera in these waters include *Calcarina*, *Operculina*, *Peneroplis*, and *Sorites*. Of the several genera, the species collected in abundance were from the genus *Peneroplis* represented by three species, including *P. carinatus*, *P. pertusus*, and *P. planatus*. The three species were found on average more than 50 individuals at each station, except in the western part of the waters of the East Penjaliran Island with a depth of 28.50 m, which only reached 47 individuals.

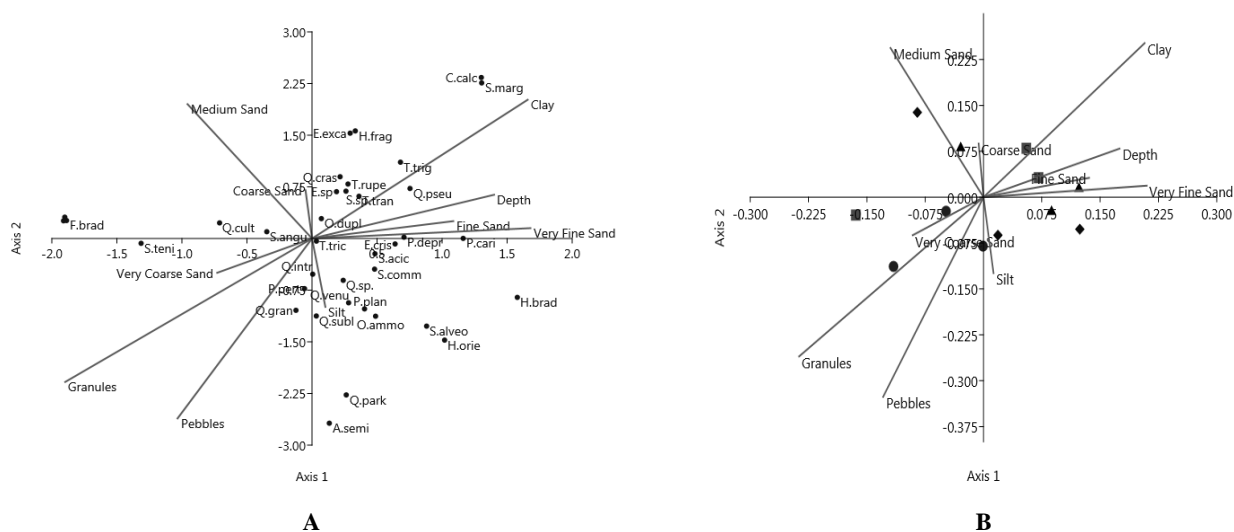


Figure 2. Canonical Correspondence Analysis between environmental variables and foraminifera species/samples from East Penjaliran shallow water: (A) Species-Environmental biplot and (B) Sample-Environmental biplot (variance of data along axis-1: 30,29% and axis-2: 18,51%). A.semi: *Adelosina semistriata*; C.calc: *Calcarina calcar*; E.adve: *Elphidium advenum*; E.cris: *Elphidium crispum*; E.depre: *Elphidium depressulum*; E.exca: *Elphidium excavatum*; E.sp: *Elphidium* sp.; F.brad: *Flintina bradyana*; H.brad: *Hauerina bradyi*; H.frag: *Hauerina fragilissima*; H.orie: *Hauerina orientalis*; O.ammo: *Operculina ammonoides*; O.dupl: *Orbitolites duplex*; P.cari: *Peneroplis carinatus*; P.pert: *Peneroplis pertusus*; P.plan: *Peneroplis planatus*; P.depr: *Pyrgo depressa*; Q.cras: *Quinqueloculina crassa*; Q.cult: *Quinqueloculina cultrata*; Q.gran: *Quinqueloculina granulocostata*; Q.intr: *Quinqueloculina intricata*; Q.park: *Quinqueloculina parkery*; Q.pseu: *Quinqueloculina pseudoreticulata*; Q.sp.: *Quinqueloculina* sp.; Q.subl: *Quinqueloculina sublineata*; Q.venu: *Quinqueloculina venusta*; S.alveo: *Schlumbergerina alveoliniformis*; S.teni: *Sigmoilina tenuis*; S.marg: *Sorites marginalis*; S.acic: *Spirolina acicularis*; S.sp.: *Spirulina* sp.; S.angu: *Spiroloculina angulata*; S.comm: *Spiroloculina communis*; T.rupe: *Triloculina rupertiana*; T.tran: *Triloculina transversestriata*; T.tric: *Triloculina tricarinata*; T.trig: *Triloculina trigonula*

Table 4. The composition of sediment grain size of East Penjaliran, Seribu Islands, Indonesia

Samples	Pebbles	Granules	Sand					Silt	Clay
			Very Coarse	Coarse	Medium	Fine	Very fine		
EP-N1	1.04	6.37	15.46	26.10	18.14	20.13	5.49	2.10	5.18
EP-N2	3.15	4.47	9.81	17.79	5.96	22.18	20.55	13.25	2.84
EP-N3	2.25	5.43	14.31	18.71	10.91	19.59	19.95	4.56	4.29
EP-E1	1.29	4.42	21.98	31.97	20.22	6.79	6.40	4.62	2.33
EP-E2	7.05	4.80	28.84	37.77	8.37	6.57	2.64	2.20	1.76
EP-E3	0.85	4.47	8.98	23.56	24.38	23.97	6.31	6.15	1.38
EP-S1	6.43	9.32	16.12	23.70	12.43	17.38	6.56	6.29	1.78
EP-S2	10.68	9.74	18.98	23.39	9.60	13.80	6.22	6.70	0.89
EP-S3	14.17	9.82	20.37	22.92	9.05	11.26	5.67	6.50	0.23
EP-W1	1.94	6.49	16.22	23.43	19.29	18.78	6.50	6.80	0.55
EP-W2	1.51	6.19	12.41	23.51	16.89	24.31	6.53	6.99	1.64
EP-W3	0.85	4.47	8.98	23.55	24.37	23.96	6.31	6.14	1.38

Peneroplis is one of the characteristics of coral reef waters, which was also collected by Fajemila et al. (2015) abundantly in Moorea, French Polynesia. In addition, several opportunistic benthic foraminifera are also collected abundantly from these waters. Likewise, A'ziz et al. (2021) also collected several species of the genus *Peneroplis* abundantly on Tioman Island, Southern South China Sea, along with *Amphistegina*, *Calcarina*, and *Operculina*. Likewise, in a study by Nurdin (2014) on

Kotok Besar, Kotok Kecil, and Bongkok Islands, Seribu Islands, *Peneroplis* was found to be dominant along with *Amphistegina*, *Calcarina*, *Discorbis*, and *Baculogypsina*. These genera typically characterize reef flats and fore slopes of reefs' environment. On the other side, the abundance of the genera *Operculina* and *Quinqueloculina* found in the area also shows the influence of tidal and terrestrial currents from the surrounding islands.

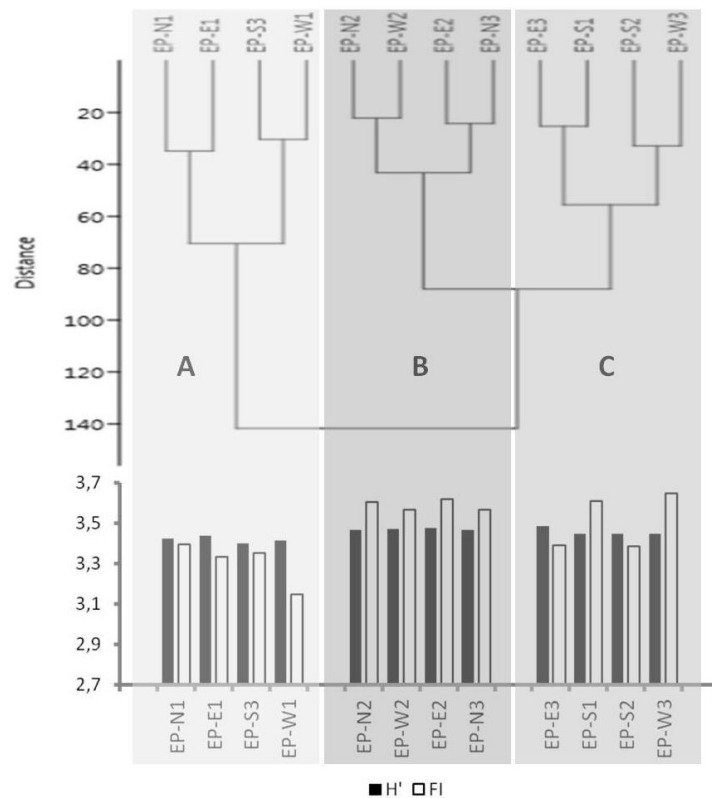


Figure 3. Dendrogram from hierarchical cluster analysis and the association of cluster groups with Shannon diversity index (H') and FI

Several opportunistic benthic foraminifera collected in the East Penjaliran are members of the genera *Elphidium* and *Flintina*. The genus collected *Elphidium* in these waters consisted of 6 species, namely *Elphidium* sp., *E. advenum*, *Elphidium craticulatum*, *E. crispum*, *E. depressulum* and *E. excavatum*. Almost all of these species were found abundant at all sampling stations but *Elphidium* sp. and *E. excavatum* collected no more than 30 individuals. On the other hand, *E. craticulatum*, which was found in more than 100 individuals in the southern part of East Penjaliran Island with a depth of 30 m, was the most common species collected compared to other species. On average, these species were collected as many as 84 individuals and recorded the highest compared to other species. Minhat et al. (2016) have collected abundantly species from the genera *Elphidium*, *Pararotalia*, and *Ammonia* in the waters of Johor, Malaysia, representing the inner-shelf environment. Likewise, a study by Culver et al. (2012) collected abundant *Elphidium* in the Setiu Estuary and Lagoon, Terengganu Malaysia, and by Nurruhwati et al. (2020) collected this species abundantly from Tunda Island Waters, Banten.

The other group is another small heterotrophic foraminifera that is neither included in the opportunist group nor Symbion-bearing foraminifers. This group dominates the eastern stream, with the number of species reaching 31 species. The species most commonly collected are members of the genus *Quinqueloculina*, represented by 9 species with almost the same numbers in all sampling stations. *Quinqueloculina* is a member of the Suborder Milioliina that inhabits shallow waters. Johnson et al.

(2019) recognized this genus as abundant together with *Elphidium* in the central region of the Great Barrier Reefs, Australia. Likewise, *Quinqueloculina* was also identified as abundant at a depth of 26-32 m on Belanda Island, Seribu Islands (Natsir 2010), in the coral reefs of Caye Caulker, Belize (depth 30-50 m) (Emrich et al. 2017) and in Qeshm Island, Persian Gulf by the depth of 5-7 m (Olad et al. 2021). These species are indicators of shallow marine water ecosystems, as collected in Waigeo waters, West Papua, at a depth of 3-11 m and in Damar Besar Island, Seribu Islands, at depth of 10.48-12.20 m (Natsir et al. 2012; Natsir 2014). This species was also collected abundantly in the waters of the Tambelan Islands at a depth of 22.52 as in this study location with a fine sediment type of substrate (Natsir and Muchlisin 2012). However, the number of individuals found in these species was not followed by the number of individuals. The average number of individuals of each species from this group was found to be no more than 38 individuals. This affects the FI values obtained at each sampling station and in general.

The FI of these waters is relatively the same, with an average of 3.18. The FI values ranged from 3.13 to 3.27. The highest values were obtained from the north part of the island, while the lowest values were recorded in the east and south with the same value (Table 3). Thus, these waters are sufficient for coral reef growth but are also included in transitional environments. This indicates that the waters around East Penjaliran Island tend to be less conducive to the recovery process in the event of damage to coral reefs. Due to such conditions, maximum efforts are needed to maintain the health of coral reefs in this area to remain

sustainable. This is based on environmental conditions that provide little possibility for coral reefs to recover in the event of degradation (Hallock et al. 2003).

Many factors affect the distribution and abundance of benthic foraminifera, including depth, turbidity, temperature, salinity, pH, and sediment type as the substrate (Murray 2006; Renema 2008). In addition, the foraminiferal assemblages are affected by the types of sediments that influence the ability of benthic foraminifera to dwell in and with nutrient availability. The most abundant benthic foraminifera are generally recognized in the fine sand sediment collected from the waters adjacent to the mainland characterized by the coral reefs community (Natsir 2012).

Based on the field observations, the East Penjaliran Island waters are dominated by coarse sand and a few fine grains of sand with coral fragments and mollusks. These sediments are very suitable for benthic foraminifera to live and grow. According to Murray (2006), crevices formed in coarser-grained sediments, including coral and mollusk fragments, are very important as shelters from the impact of hydrodynamic energy such as currents and waves. However, this is not the only factor that affects the distribution and abundance of foraminifera, including symbiont-bearing foraminifers.

Another significant factor is the water depth level associated with other parameters, such as hydrostatic pressure, temperature, light, pH, oxygen, and carbon dioxide. The existence of coral reefs also plays a very important role in the distribution of foraminifera, especially because their habitat is always associated with conditions with sufficient sunlight. This results in high oxygen content and nutrient supply, which is very beneficial for foraminifera populations (Gustiantini and Usman 2008).

East Penjaliran has a depth level of 28.5 to 34.50 m. This condition can still be tolerated by benthic foraminifera that can live up to the outer neritic area with a depth of 200 m. On the other hand, foraminifera are organisms with a high tolerance for temperature that varies from 40°C to 20°C. Temperature affects shell growth, especially in agglutinated walled foraminifera. In cold climates, this group has a large shell, and conversely, it has a maximum shell in the tropics. The temperature recorded during the study on East Penjaliran Island ranged from 29.10 to 29.37°C, which is normal for foraminifera growth.

The most commonly collected benthic foraminifera from East Penjaliran Island belongs to the Suborder Milioliina. Suborder Milioliina has a low salinity tolerance. A salinity of fewer than 32 ppt will cause these foraminifera to be unable to maintain their pseudopodia. The regional salinity and sedimentary conditions appear to have major influences on benthic environments in the coastal waters of Penang National Park and the surrounding area (Minhat et al. 2014). However, this did not occur in the collected foraminifera during the study because the salinity was normal for foraminiferal growth. Environmental conditions around East Penjaliran Island are relatively stable and uniform, with salinity and pH ranging from 31.20-32.36 ppt and 7.65-7.95, respectively. The substrate types in most of these waters consist of sand and

coral fragments which are very good for the growth of benthic foraminifera.

Canonical Correspondence Analysis (CCA) indicated a significant correlation between foraminifera distributions, depth, and sediment texture. The distribution pattern of species tends to be parallel to the depth pattern. The number of species abundance tends to increase with increasing depth. However, the sampling station distribution pattern tends to be even, not following the depth trend. The depth at each sampling station did not significantly differ, ranging from 28-34.5 m. This is slightly different from the results of a study by Dewi and Saputro (2013), which states that the depth and type of sediment affect certain distributions of foraminifera which are interrelated with other parameters that affect foraminifera life. This is fathomed that the depth of the sampling location is relatively the same. However, the type of sediment in this study influenced the distribution of the collected species. Most of them are collected from sand sediment, namely very fine sand to very coarse sand. The study on the inner shelf off Kelantan by Azmi et al. (2020) showed the compositional changes in benthic foraminiferal assemblages are in response to changes in sediment substrate with increasing depth.

In addition, according to Gupta and Machain-Castillo (1993), the type of substrate may affect the oxygen content in the marine environment. Furthermore, they stated that benthic foraminifera utilize oxygen present at the sediment-water interface and in pore water. This "habitat oxygen" level can be significantly suppressed where the sediment is rich in organic matter, because oxygen is consumed in the natural chemical transformation of carbon compounds. In some fine-grained substrates, decomposition of organic matter can cause dysoxia or suboxic and even anoxia within a few centimeters of the sediment-water interface. A study by Rabalaist et al. (1991) in Gupta and Machain-Castillo (1993) showed the dominance shift of benthic foraminifera in the Gulf of North Mexico, which normally found *Ammonia beccarii* and *Elphidium gunteri* abundant at a depth of 20-60 meters, but during seasonal hypoxia, these two species were only represented by empty shells, while live foraminifera found were *Nonionella opima*, *Fursenkoina* sp. and *Hanzawaia concentrica*. Generally, the sediment type of East Penjaliran Island waters was not significantly different, dominated by fine to coarse sand. All stations have very low clay percentages, 2.02% on average. Thus, it is fathomable that there is no significant difference in the oxygen content on the study site, as proven by the collection of several species of *Elphidium* at all stations.

The results indicated that the benthic foraminifera assemblages would be classified into three major groups based on the Shannon diversity index and FI (i.e., Group A, Group B, and Group C) (Figure 3). Group A's mean diversity was 3.419. The assemblages were characterized by high dominance of opportunistic foraminifers such as *Elphidium advenum*, *Elphidium crispum*, and *Flintina bradyana*, and one symbiont bearing species, *Peneroplis planatus*, then they produced an average FI of 3.31. The sediments at group A stations were dominated by coarse sand.

Group B has a mean Shannon diversity index of 3.471, slightly higher than that in the previous group. *Elphidium* dominated the assemblages, but with different species, such as *Elphidium crispum*, *Peneroplis planatus*, *Triloculina rupertiana*, and *Peneroplis carinatus* resulting in an average FI of 3.59. Group B sediments have been dominated by fine sand and coarse sand.

The mean value of the Shannon index of group C is between the last two groups and the mean value of FI, which respectively reach 3.458, and 3.51. The sediments were dominated by sand, including very fine sand, fine sand, medium sand, and coarse sand, in the sampling station. The foraminiferal assemblages were dominated by *Elphidium crispum*, and *Elphidium advenum*, *Elphidium depressulum* and followed by symbiont-bearing foraminifera such as *Peneroplis planatus*.

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