DAVAO RESEARCH JOURNAL

P-ISSN 2244-4432
E-ISSN 2984-7125

Assemblages of Benthic Foraminifera in Pujada Island, Davao Oriental, Philippines

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ABSTRACT. The present study investigated the composition, density, abundance, and diversity of benthic foraminifera, and their relationship with various physico-chemical parameters such as pH, salinity, temperature, and sediment grain size. Foraminifera were collected from the intertidal zone using sediment cores and extracted from the sediments through sieving. The extracted foraminifera were stained with Rose bengal solution and preserved with buffered formalin. A total of 9,459 individuals of foraminifera were identified, consisting of 39 species classified into four orders, 16 families, and 21 genera. The top three most abundant genera were *Calcarina*, *Baculogypsina*, and *Amphistegina*. The comparison (ANOVA) of the abundance of foraminifera among the six stations revealed highly significant differences ($P= 0.000$; df= 38). Station 1 exhibited the highest diversity of foraminifera on Pujada Island, as indicated by an H' value of 3.06. Conversely, station 6 displayed the lowest diversity, with an H' value of 1.59. The pH, salinity, and temperature values are all within acceptable limits for seawater. The decreased diversity observed in some stations are attributed by various factors, like site disturbance (accessibility to many tourists and availability of beach resorts) and the variation in sediment grain size composition. The findings suggest that generally, Pujada Island remains an undisturbed coastal area. As a result, this study provides a baseline for future monitoring of the impacts of natural and human-induced activities in the region, thereby recommending the use of foraminiferans as bioindicators for marine health.

Keywords: Diversity, foraminifera, physico-chemical parameters, rose bengal

Submitted: 23 February 2022
Revised: 21 April 2022
Accepted: 1 May 2022
Published: 21 June 2022

https://davaoresearchjournal.ph

How to cite: Felix, M.A., Ybañez, C.O. Jr., Macusi, E.D. (2022). Assemblages of Benthic Foraminifera in Pujada Island, Davao Oriental, Philippines. Davao Research Journal, 13(1), 91-111. https://doi.org/10.59120/drj.v13i1.92

INTRODUCTION

Foraminifera is a group of heterotrophic, single-celled amoeboid protozoans that build a test shell (Beck Eichler and Barker, 2020). Test shells of foraminifera are composed of calcareous material, usually calcite or agglutinated particles collected from the environment (Borrelli et al., 2018). These protozoans reproduce by the alternation of sexual and asexual reproduction. Foraminifera inhabits a wide range of environments, from shallow brackish water to the deepest part of the ocean (Holzmann et al., 2021). They are among the most widely distributed meiofauna group in the marine ecosystem's benthic part (Punniyamoorthy et al., 2021). The World Foraminifera Database reports that there are 8,940 valid recent species and 40,935 valid fossil species of foraminifera. The total number of valid (fossil and recent) species recorded is 48,988 (https://www.marinespecies.org/foraminifera/). Furthermore, most species of foraminiferans are between 100 mm to 1000 mm, while some representatives are smaller or larger than 20 mm (Murray, 2014).

Foraminifera plays a crucial role in the biogeochemical cycles of both inorganic and organic compounds (du Chatelet et al., 2013). This is due to their ability to assimilate (Bird et al., 2020) and recycle nutrients (Vancoppenolle et al., 2022) and their role in the production and decomposition of organic matter (Smart et al., 2020). These microscopic marine organisms are significant in the cycling of carbon, nitrogen, and phosphorus (Ren et al., 2017; Lintner et al., 2020), which are essential elements for the growth and survival of marine ecosystems. Through their interactions with other organisms and the environment, foraminifera contributes significantly to the carbon cycle by facilitating carbon transfer between the atmosphere and the ocean (Mackensen and Schmiedl, 2019). Foraminifera have been identified as significant contributors to the formation of coral reefs (Prazeres et al., 2016). Calcifying foraminifera plays a crucial role in the growth and development of coral reefs by facilitating the formation of calcium carbonate structures that constitute the reef (Prazeres et al., 2017).

Foraminiferans are used in monitoring the health of the coastal and estuarine ecosystems (Sreenivasulu et al., 2019) and act as an early warning indicator for water pollution (Lacuna et al., 2013). Foraminifera serves as bioindicators due to their sensitivity to alterations in the environmental condition, rendering them useful for monitoring the quality of water (Prazeres et al., 2020). They become less numerous and diverse in response to anthropogenic stressors (e.g., pollution, eutrophication, and hypoxia) and changes in environmental parameters, including temperature and salinity (Dong et al., 2019). In instances where the aquatic environment or sediment inhabited by foraminifera is subjected to increased toxicity levels, such as in the aftermath of an oil spill or due to the influx of pollutants, it is common for the entire foraminifera community to change (Suokhrie et al., 2017). Furthermore, in the presence of environmental contamination, foraminifera may assimilate the pollutants into their shells (Youssef et al., 2017). Foraminifera may also shed light on paleoclimatology, paleogeography, paleoceanography, paleoenvironments, or a particular area's past environmental state (D'Onofrio et al., 2021). Foraminifera can be a valuable tool for monitoring the potential impacts of both natural and anthropogenic activities in the marine environment (Lacuna et al., 2013).

Although there is a growing amount of literature on foraminifera globally, the research on foraminifera in the Philippines remains limited, with no studies conducted in the southeastern Philippines region. Studies conducted on foraminifera in the Philippines include Lanao del Norte (Lacuna and Gayda, 2014), Iligan Bay (Lacuna et al., 2013), Iligan City (Lacuna and Alviro, 2014; Ganaway and Lacuna 2014; Unsing and Lacuna 2014), Zamboanga Sibugay (Oñate and Lacuna, 2015; Castañeto and Lacuna, 2015), Mindoro (Glenn-

DOI: https://doi.org/10.59120/drj.v13i1.92

Sullivan and Evans, 2001), Palawan (Förderer and Langer, 2019) and Nogas Island Antique (Gonzales et al., 2022). Hence, this study was conducted to address a knowledge gap by investigating the composition, density, abundance, and diversity of benthic foraminifera in Pujada Island, located in Davao Oriental, Southeastern Philippines. Additionally, the study examined physico-chemical parameters that may impact foraminifera assemblages. The data produced may serve as crucial baseline information for future assessment of the impacts of environmental changes caused by natural and man-made activities. Moreover, a fundamental requirement for advancing the utilization of foraminiferans as bioindicators for marine ecosystems is a thorough understanding of their behavior in their natural habitats. This study may also reveal the health status of the island and validate the efficacy of foraminifera as a potential tool for detecting a disturbance in the marine environment.

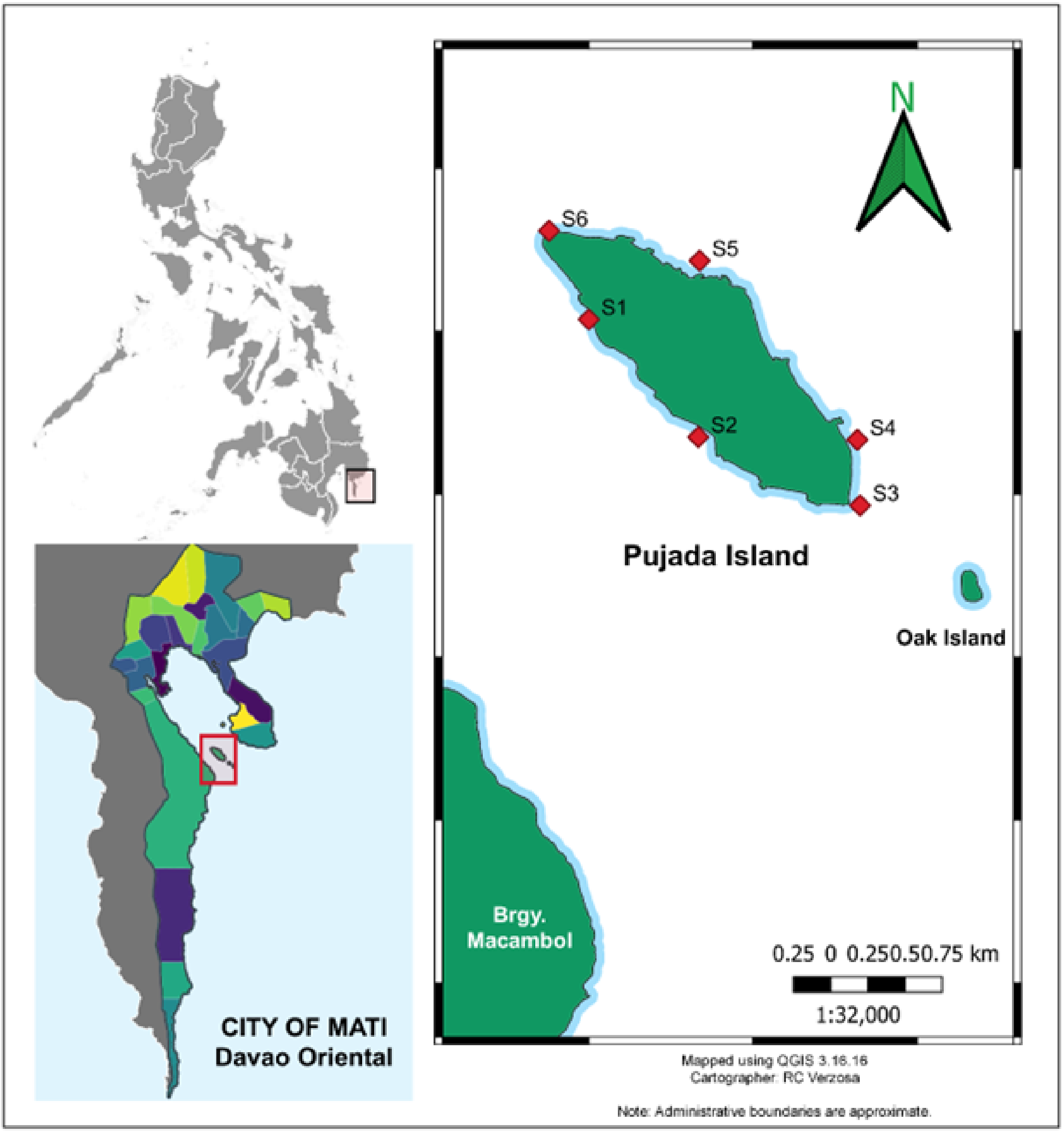

Figure 1. The geographical location of the six sampling stations from which foraminifera were collected.

METHODOLOGY

Pujada Island is located in the southeastern region of Mindanao. The coast has a long stretch of white sand beach. The island is 156 ha and approximately 17 km from the urban center of Mati, Davao Oriental, Philippines. On July 31, 1994, Pujada Island was declared part of a Marine Protected Area (MPA) under Proclamation no. 431 (Dizon et al., 2013). Six stations were established in the sampling site of Pujada Island (Figure 1). Coordinates were measured in each sampling station using Global Positioning System (GPS) device. The first station (S1) (6047'26.6" N, 126015'36.0" E) and a second station (S2) (6047'00.6" N, 126015'60.0" E) were established in the western part of the island, the third station (S3) (6046'45.5" N, 126016'35.5" E) in the southern part, the fourth station (S4) (6047'00.0" N, 126016'34.9" E) and fifth station (S5) 6047'39.6" N, 126016'00.3" E) in the eastern part and the sixth station (S6) (6047'46.2" N, 126015'27.3" E) in the northern part of the island.

Site Description

S1 has a sandy-gravel substrate and a notably short intertidal flat. Despite the size of its intertidal flat, this area has various seagrass and coral species. The waves are strong, and the water is deep at this site. S2 is also characterized by a sandy-rocky substrate and short tidal flats, making it unsuitable for recreational activities such as swimming. Consequently, it is less attractive to tourists. This station has strong waves and significant depth. S3 and S4 are characterized by sandy and rocky substrates. Among the stations, S3 and S4 had the strongest waves, water current, and considerable depth. The strong waves in these areas may be attributed to their geographical location, facing the Pacific Ocean. These sites are hard to access due to strong waves and are not ideal for swimming; hence they are not disturbed by anthropogenic activities. Stations 2, 3, 4, and 5 have pristine waters, highly abundant seagrasses, and corals. S6 has a sandy substrate and a low abundance of seagrass. This site is open for access by tourists and the community of Davao Oriental. It is also the docking area of ships that bring people and tourists to the island. This station is ideal for swimming due to the small waves and long intertidal flats. S6 is the only site that houses a beach resort which may potentially disturb this area.

Collection and Extraction of Foraminifera

In every station, three quadrats measuring 1 m x 1 m were laid parallel to the shoreline with an interval of 25 m for each quadrat (Figure 2). Three replicates of sediment samples were gathered in each quadrat using a corer measuring 5 cm in diameter and 20 cm in length. Sediments with foraminifera were randomly collected inside each quadrat using the corer plunge in the sediments up to 1 cm depth (Lacuna et al., 2013). The samples were placed in a labeled bottle and preserved with 10% Buffered formalin (Lacuna and Gayda, 2014). The application of Rose bengal to the sediments was carried out promptly after their collection and was gently mixed to ensure uniform staining of the foraminifera (Lacuna et al., 2013). Rose bengal stains foraminifera proteins and cytoplasm appearing in the microscope a pinkish and reddish hue (Raposo et al., 2016). Samples were stored for effective staining for 3 to 4 weeks (Lacuna et al., 2013). Only live samples of foraminifera were counted and included in the analysis. Rose Bengal was used technique to stain live samples of foraminifera (Parent et al., 2018). This technique differentiates between live and dead foraminifera, as the live specimens will exhibit a distinct pink coloration while the deceased specimens will remain unstained (Jennings et al., 2020). The sediment samples underwent a process of washing and sieving using a 1000 µm sieve to eliminate pebbles, as well as a 150 µm (Lacuna et al., 2013) and 63 µm (Murray, 2003) sieve to isolate foraminifera from the sediment. Foraminifera left in 150 µm, and 63 µm sieves were counted and recorded.

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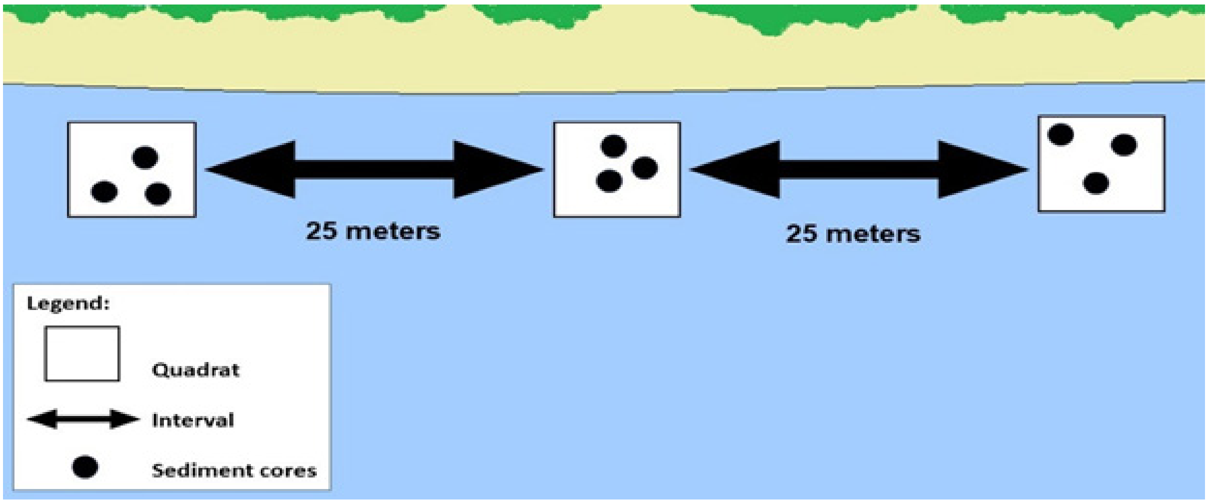

Figure 2. Establishment and collection of Foraminifera from the sediments in each station.

Identification of Foraminifera

Using a stereo-microscope, foraminifera were identified and classified to the lowest possible level based on their morphological structure (Lacuna et al., 2013). Representatives of various foraminifera species were handpicked under a stereo-microscope with an improvised picking tool and photographed with Amscope. Identification of foraminifera was made using the different taxonomic references of Murray (2003), Clark and Patterson (1993), Higgins and Thiel (1988), Culver et al. (2012), Patterson et al. (2010), Riveiros and Patterson (2007), Haig (1997), Scott et al. (2000), and http://www.foraminifera.eu.

Physico-chemical Parameters

This investigation assessed the physicochemical parameters such as pH, salinity, and temperature in situ. The salinity was measured in six stations with a refractometer, the pH level with a pH meter, and the seawater temperature with an alcohol thermometer. In addition, one kilogram of sediment samples was collected from each station for sediment grain size analysis. The Wentworth scale was used to identify the sediment size composition, which included gravel (2 - 4mm), coarse sand (0.5 - 1mm), fine sand (0.125 – 0.25mm), and silt (0.004 – 0.062mm), by sieving dried sediment samples on various mesh sizes (Blott and Pye, 2012).

Data Analysis

The recorded data from different stations were analyzed for the following components of biodiversity: species, density (individuals/area of corer) (El-Serehy et al., 2015), abundance (number of individuals of a particular genus/total number of individuals of all genera in each station x 100) (Mougeot et al., 2017), and diversity. In determining the diversity of foraminifera, Shannon-Wiener Diversity Index was used and was calculated using Paleontological Statistics (PAST) version 4.10 software. The data obtained from the different sampling areas were analyzed to test the significant differences in the abundance of foraminifera in various stations using analysis of variance (ANOVA). All statistical analysis were performed using Statistical Package for Social Science (SPSS) software (IBM, -SPSS version 21, Armink, N.Y.) The Cluster analysis was done using PRIMER – E (software version 6, Plymonth, U.K.) to compare the abundance of foraminifera among stations and species.

RESULTS AND DISCUSSION

Species Composition

Thirty-nine species belonging to 16 families and 21 genera were documented from the sand samples taken from six sampling stations in Pujada Island, Davao

Table 1. Species composition of foraminifera in six sampling stations in Pujada Island, Davao Oriental.

		Stations					
Family	**Species**	**1**	**2**	**3**	**4**	**5**	**6**
Ammoniidae	*Ammonia* sp.	-	-	-	+	+	+
Amphisteginidae	*Amphistegina bisirculata*	+	+	+	-	-	+
	Amphistegina haurina	+	+	+	+	-	-
	Amphistegina lessonni -	+	+	+	+	-	
Calcarinidae	*Baculogypsina sphaerulata*	+	+	+	+	+	-
	Calcarina calcar	+	+	+	+	+	+
	Calcarina defrancii	-	+	+	+	+	-
	Calcarina gaudichaudii	-	+	+	+	+	-
	Calcarina hispida	-	+	+	+	+	+
	Calcarina mayori	+	+	-	-	-	-
	Calcarina sp.	-	+	-	-	-	-
	Calcarina spengleri	+	+	-	+	-	-
	Neorotalia calcar	+	+	+	+	+	+
Cibicididae	*Cibicides pseudoungerianus*	+	+	+	+	+	+
	Cibicides refulgens	+	-	-	+	+	-
Cornuspiridae	*Cornuspira foliacea*	-	+	-	+	-	-
	Coscinospira arietina	+	+	+	+	+	+
Elphidiidae	*Elphidium advenum*	+	+	+	+	+	-
Eponididae	*Eponides* sp.	+	-	-	-	-	-
Gavelinellinae	*Gyroidina zelandica*	+	+	+	+	+	-
Hauerinidae	*Cycloforina* sp.	+	+	+	-	+	-
	Miliolinella sp.	+	+	+	+	+	+
	Quinqueloculina parkeri	+	+	+	-	+	-
	Quinqueloculina sp. 1	+	-	+	-	-	-
	Quinqueloculina sp. 2	+	-	-	-	-	-
	Triloculina sp.	+	-	+	-	-	-
Heronalleniidae	*Heronalleria lingulate*	+	+	-	-	-	-
Nonionidae	*Nonionella hantkeni*	+	+	+	+	+	+
	Nonionella limbatostriata	+	+	+	+	-	-
	Nonionella sp.	+	+	+	+	-	+
Peneroplidae	*Peneroplis bradyi*	+	+	+	+	-	+
	Peneroplis planatus	+	-	-	+	+	-
	Peneroplis sp.	+	-	-	+	+	-
Planulinidae	*Hyalinea balthica*	+	-	-	+	+	-
Rosalinidae	*Rosalina anomala*	+	-	-	-	-	-
Spiroloculinidae	*Spiroloculina* sp. 1	+	+	+	+	+	-
	Spiroloculina sp. 2	+	-	+	+	-	-
Textulariidae	*Textularia* sp. 1	+	+	+	+	+	-
	Textularia sp. 2	+	+	+	+	-	-
	Total	**32**	**28**	**26**	**28**	**22**	**11**

Oriental (Table 1 & Figure 3-6). A total of 9,459 individuals of foraminifera were recorded under the four orders, namely (1) Rotaliida with nine families (Ammoniidae, Amhisteginidae, Calcarinidae, Cibicididae, Elphidiinae, Gavelinellidea, Nonionidae, Planulinidae, and Rosalinidae), (2) Foraminiferida with three families (Cornuspiridae, Eponididae, and Heronalleniidae), (3) Milliolida (Hauerinidae, Peneroplidae, and Spiroloculinidae,), and (4) Textulariida with only one family (Textulariidae).

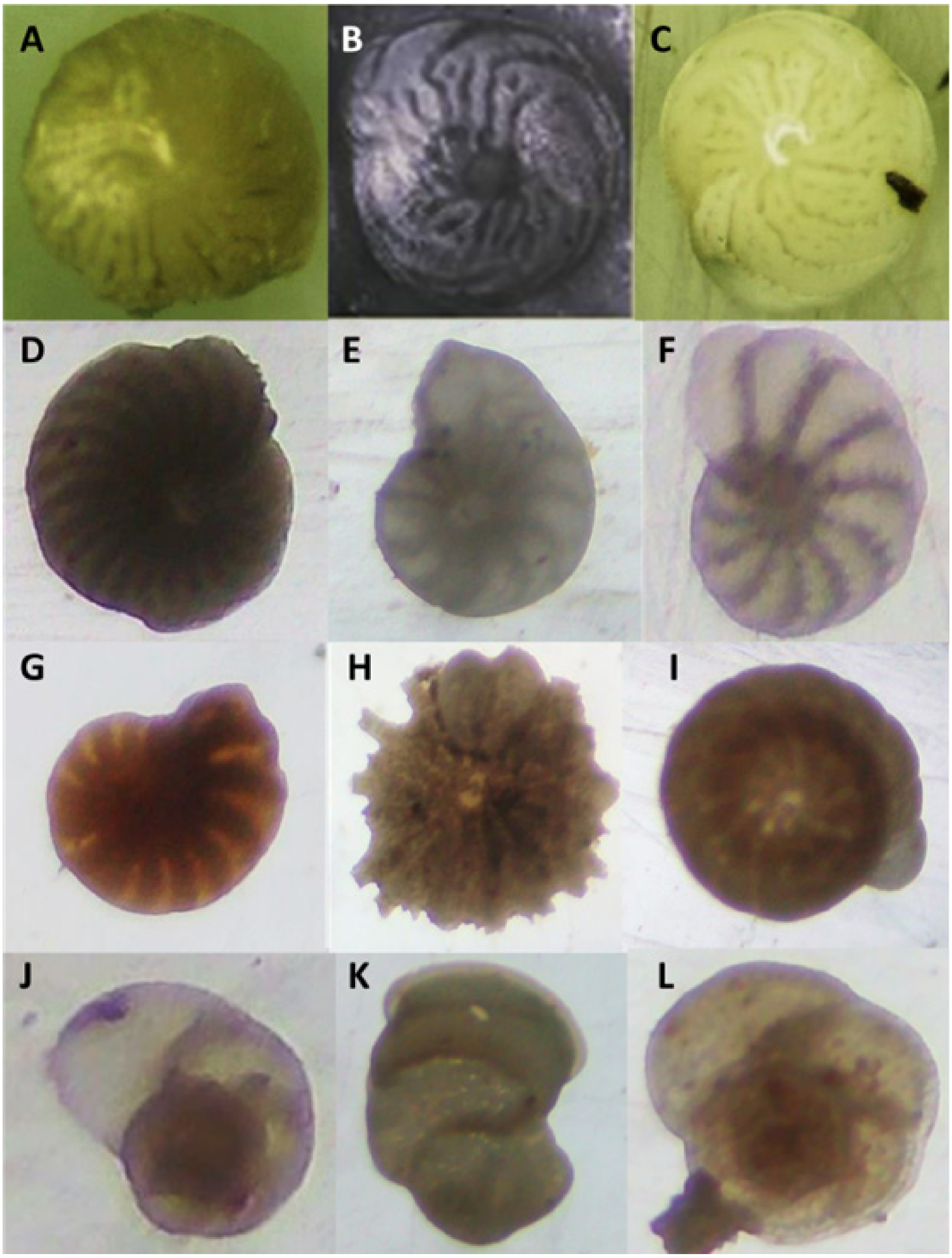

Figure 3. *Amphistegina bisireculata* (A); *Amphistegina lessonni* (B); *Amphistegina hauerina* (C); *Elphidium advenum* (D); *Hyaline balthica* (E); *Cibicides refulgens* (F); *Cibicides pseuduongerianus* (G); *Neorotalia calcar* (H); *Ammonia sp.* (I); *Rosalina anomalia* (J); *Heronallenia lingulata (*K); *Eponides sp.* (L) (100xx, LPO).

DOI: https://doi.org/10.59120/drj.v13i1.92

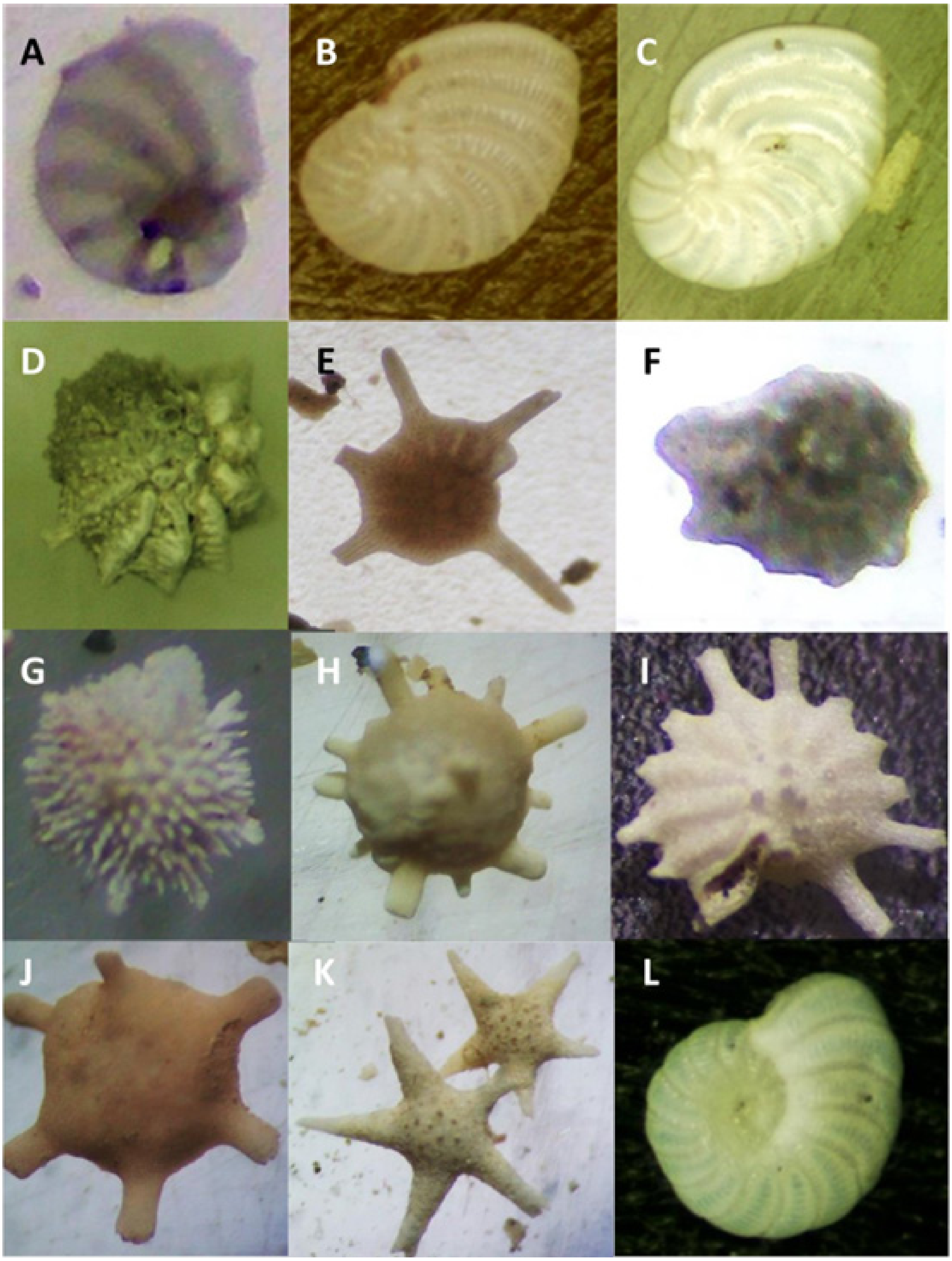

Figure 4. *Nonionella hantkeni* (A); *Nonionella sp.* (B); *Nonionella limbatostriata* (C); *Calcarina mayori* (D); *Calcarina gaudichaudii* (E); *Calcarina calcar* (F); *Calcarina hispida* (G); *Calcarina spengleri* (H); *Calcarina defrancii* (I); *Calcarina sp.* (J); *Baculogupsina sphaerulata* (K); *Gyroidina zelandica* (L) *(100xx, LPO).*

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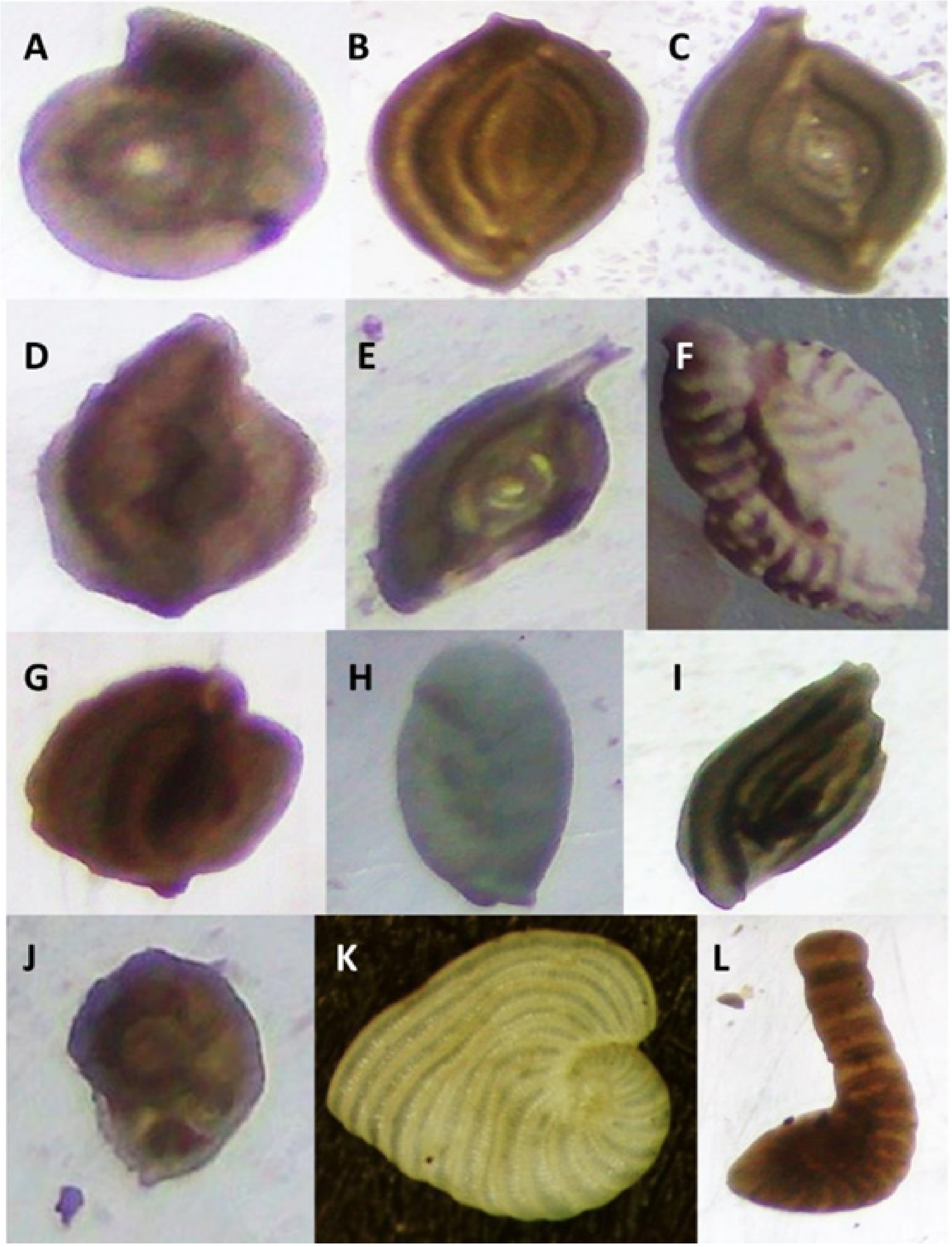

Figure 5. *Cornuspira foliacea* (A); *Spiroloculina sp. 1* (B); *Spiroloculina sp. 2* (C); *Quinqueloculina sp. 1* (D); *Quinqueloculina sp. 2* (E); *Quinqueloculina parkeri* (F); *Miliolinella sp.* (G); *Triloculina sp.* (H); *Cycloforina sp.* (I); *Peneroplis sp.* (J); *Peneroplis bradyi* (K); *Coscinospira areitina* (L) *(100xx, LPO).*

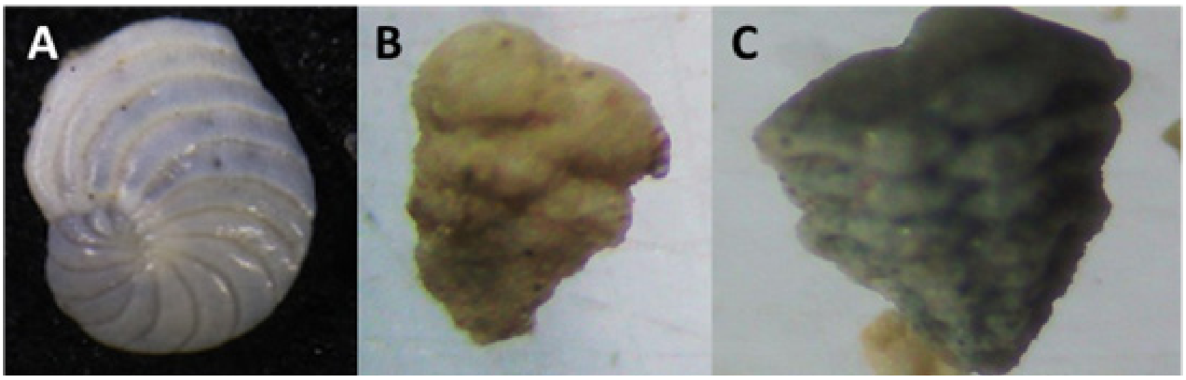

Figure 6. *Peneroplis planatus* (A); *Textularia sp. 1* (B); *Textularia. sp. 2* (C) *(100xx, LPO).*

Density and Abundance

The population density of foraminifera in the sediments in the coastal area of Pujada Island is depicted in Figure 7. The findings reveal that S1 had the highest population density, with 3,085 ind/cm2, while S6 had the lowest density, with 570 ind/cm2. S1 presents a formidable challenge for tourists to engage in swimming because of the strong waves and considerable depth, resulting in reduced disturbance in this area. The high density of foraminifera in S1 may indicate that it has pristine marine water compared to the other stations. Foraminifera are bioindicators that may reflect the overall state of ecological health of marine ecosystems (Prazeres et al., 2020).

S6 exhibited the lowest population density versus the other stations. The low diversity in the S6 may be attributed to the site disturbances like the accessibility of the area to a large number of tourists and locals and the presence of a beach resort. Beach resorts may generate waste, including plastic bottles and food packaging (Ryan, 2020). Discharging sewage and wastewater (washing, bathing, and flushing toilets) from beach resorts can contaminate the water and sediments (Elenwo and Akankali, 2015). When these wastes are not properly treated, they may contain harmful bacteria and chemicals (Metcalf et al., 2023). These pollutions can have detrimental effects on the foraminifera community (Suokhrie et al., 2017) and endanger the health and safety of beachgoers.

The abundance of foraminifera varies differently in all stations which may indicate that each species has environmental preference (Figure 8). The top three most abundant species of foraminifera in all stations were *Calcarina* (26%), *Amphistegina* (22%), and *Baculogypsina* (17%). In both shallow and deep ocean habitats, *Calcarina, Amphistegina,* and *Baculogypsina* make up a major component of the benthic populations, especially in tropical waters (Parker and Gischler, 2011; Renema, 2018). These genera demonstrate a preference for warm, shallow marine environments that are linked with reefs and shelves, much like other large, bottom-dwelling foraminifera (Gonzales et al., 2022). They are predominantly present in substantial quantities in the Indo-Pacific Ocean, where it has been utilized for assessing the paleoecology of past sand sediments (Renema, 2018). The high prevalence of *Calcarina, Amphistegina,* and *Baculogypsina* in the study area of Pujada Island could be attributed to its geographical position in the Indo-Pacific region.

Diversity

Among all study sites presented in table 2, S1 exhibited the highest diversity index (H'=3.06) while S6 had the lowest diversity index (H'=1.59). The computed high diversity index in station may suggest

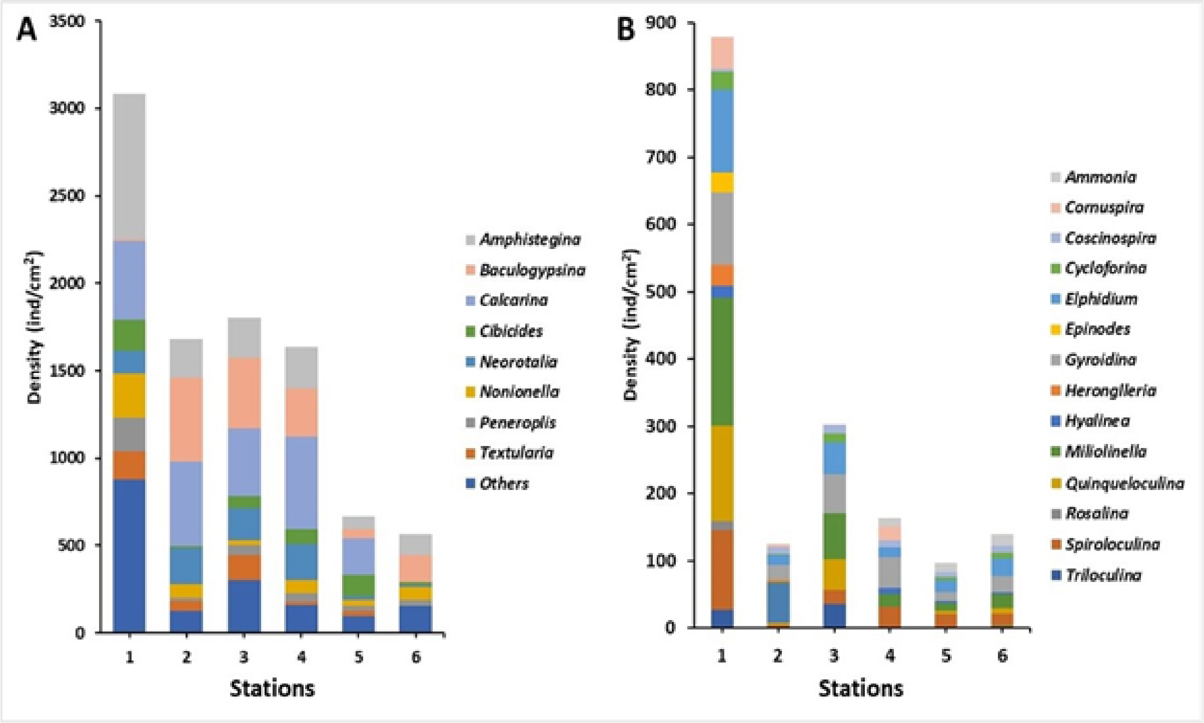

Figure 7. Population density of the foraminifera in six stations: A. Top eight genera B. genera of foraminifera composing the "others".

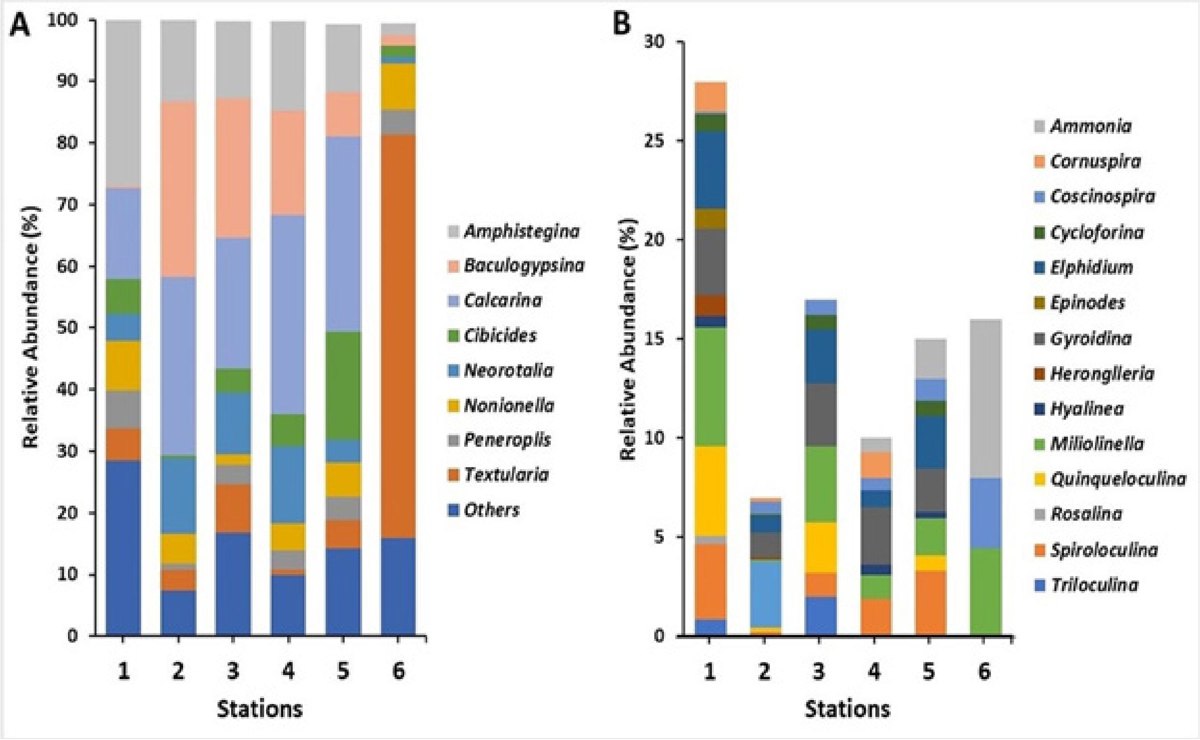

Figure 8. Relative abundance of the foraminifera in six sampling stations: A. Top eight genera B. genera of foraminifera composing the "others".

Table 2. The diversity profile of the six sampling stations in Pujada Island.

	Station					
	1	**2**	**3**	**4**	**5**	**6**
Total no. of species	32	28	26	28	22	11
Total no. of individuals	3085	1685	1805	1641	673	570
Shannon-Wiener Diversity Index (H')	3.06	2.39	2.70	2.75	2.76	1.59

that this area is not disturbed, in contrast, S6's low diversity may indicate poor water quality. Anthropogenic issues such as pollution (Suokhrie et al., 2017) and sediment disturbance caused by tourists and visitors tramping or stepping on the sediments have a negative impact on foraminifera (Eichler and de Moura, 2020). S6 is the station with the highest number of beachgoers due to its small waves, long intertidal flat, and the presence of a beach resort. As such, it can be inferred that among all stations, S6 has been the most disturbed area. The frequent stepping on the sediments and the existence of pollution from the beach resort of S6 may lead to habitat degradation, which may cause low diversity of foraminifera in this station.

Physico-chemical Parameters

The results show that the water quality parameters such as pH (8), salinity (33-35 ppt), and temperature (28.9-30.6 OC) (Table 3), are within the standard range that marine faunal communities can thrive (DENR, 2008). The pH level observed among stations were similar (pH=8) and was within the normal range for coastal water. Low pH values restrict the presence of calcareous foraminifera in sediment pore water (Martins et al., 2019). Ocean acidification can lead to a reduction in pH levels within the oceans (Hurd, 2015). The absorption of carbon dioxide (CO2) by seawater has the potential to increase the acidity of the ocean (Jiang et al., 2019). Anthropogenic activities have led to elevated atmospheric CO2 levels, resulting in the dissolution of more CO2 into the ocean (Das and Mangwani, 2015). This phenomenon leads to a reduction in pH levels, thereby increasing the ocean's acidity. The dissolution and destruction of calcareous tests may be promoted by low pH levels (< 7.5) when combined with the reactivity of biogenic carbonates (Kawahata et al., 2019; Dong et al., 2020). A substantial decrease in pH significantly impedes the calcification ability of benthic foraminifera (Saraswat et al., 2011). The pH of the marine environment in which foraminifera reside is extremely important to their survival because it affects both their ability to calcify and their capacity to survive. The average standard pH value for seawater is 8.1 (Noisette and Hurd, 2018). The ideal pH for foraminifera varies depending on the species. Some species can tolerate a wide range of pH levels, while others are more sensitive to changes in pH (Saraswat et al., 2015).

The area being sampled has a salinity of 33-35 ppt, which is within the normal range of ocean salinity, which ranged from 33-37 ppt (Swift, 1993). The average salinity level in oceans and seas is 35 ppt (Glenn et al., 1998). However, it exhibits spatial and temporal variability across various oceans and seas (Torregroza-Espinosa et al., 2021). The fluctuation of salinity varies in both horizontal and vertical dimensions, which is influenced by depth (Omstedt and Axell, 2003). The impact of salinity stress on foraminifera can result in a reduction in their population size (Debenay et al., 2000). Some foraminifera, such as those with hyaline shells, can survive in low salinity (Ostrognay and Haig, 2012). Hyaline shells are frequently described as having a glassy appearance, having pores that penetrate the entire wall, and being made up of interconnecting CaCO3 microcrystals (Wetmore, 1996).

Table 3. The physico-chemical parameters recorded in six stations in the study area.

Physico-chemical parameters	**Station**					
	1	**2**	**3**	**4**	**5**	**6**
pH (pH)	8	8	8	8	8	8
Salinity (ppt)	33	34	34	35	33	35
Temperature (°C)	29.5	30.4	28.4	29.3	28.9	30.6
Sediment grain size	-	-	-	-	-	-
Gravel (%)	50	29	22	23	43	19
Coarse sand (%)	30	10	28	20	22	10
Fine sand (%)	13	37	22	27	14	40
Silt (%)	7	24	28	30	21	31

The seawater's temperature in the study area falls within the range that is typical for coastal waters. Temperature fluctuations in the ocean may result from changes in the weather (Maloney and Chelton, 2006) and the runoff from rivers (Chen et al., 2009). Temperature can influence the survival, diversity, growth, shape, and feeding behaviors of intertidal foraminifera (Li et al., 2019; Wukovits et al., 2017; Schmidt et al., 2011). According to Deldicq et al. (2021), the temperate foraminifera *Haynesina germanica* reduced their activity (e.g., metabolic and motility behavior) by up to 80% under high-temperature conditions while remaining active at natural temperature. When subjected to hyperthermic stress (36°C), all individuals of *H. germanica* remained burrowed in the sediments, and the photosynthetic activity of their sequestered chloroplasts decreased. Recovery investigations showed that foraminifera exposed to high thermal regimes partially recovered once hyper-thermic stress stopped.

The grain size of sediment exhibits variability across different stations, as presented in Table 3. The diversity observed at each station may be reflected by the variation in sediment grain size. S6 has the highest silt concentration (31%) and the lowest diversity of foraminifera. This may imply that the presence of a high amount of silt may have a potential impact on the reduced abundance and diversity of foraminiferans. Radwell and Brown (2006) have reported that the population of foraminifera can be negatively impacted by the high silt composition of a habitat. This is attributed to the reduction in the spaces between sediments that serve as their habitat and the availability of food and organic matter on the sediment floor of the ocean (Altenbach and Sarnthein, 1989; Radwell and Brown, 2006). Still, little is known about the effect of sediment grain size on the density and diversity of foraminifera.

Cluster Comparison of Foraminifera

The result of One way ANOVA of the abundance of benthic foraminifera among the six stations showed high significance (Table 4). This suggests that species are not evenly distributed in all stations. In order to compare the percentage of similarities among all foraminiferal species, a cluster analysis was used (Figure 9). The cluster analysis was used to group similar variables or attributes of interest nto sets or clusters. Family Calcariniidae (*C. gaudichaudii* and *C. defrancii*) are similar to each other in terms of abundance because they share the same number of similarities and *C. hispida* holds the linkage between *C. gaudichaudii* and *C. defrancii.* This linkage emphasizes that it has almost and the same similarity 85%. Further, data indicated

DOI: https://doi.org/10.59120/drj.v13i1.92

Table 4. Result of one-way ANOVA.

Source	DF	Adj SS	Adj MS	F-Value	*P*-Value
Factor	38	53. 73	1.4140	12.13	0.000

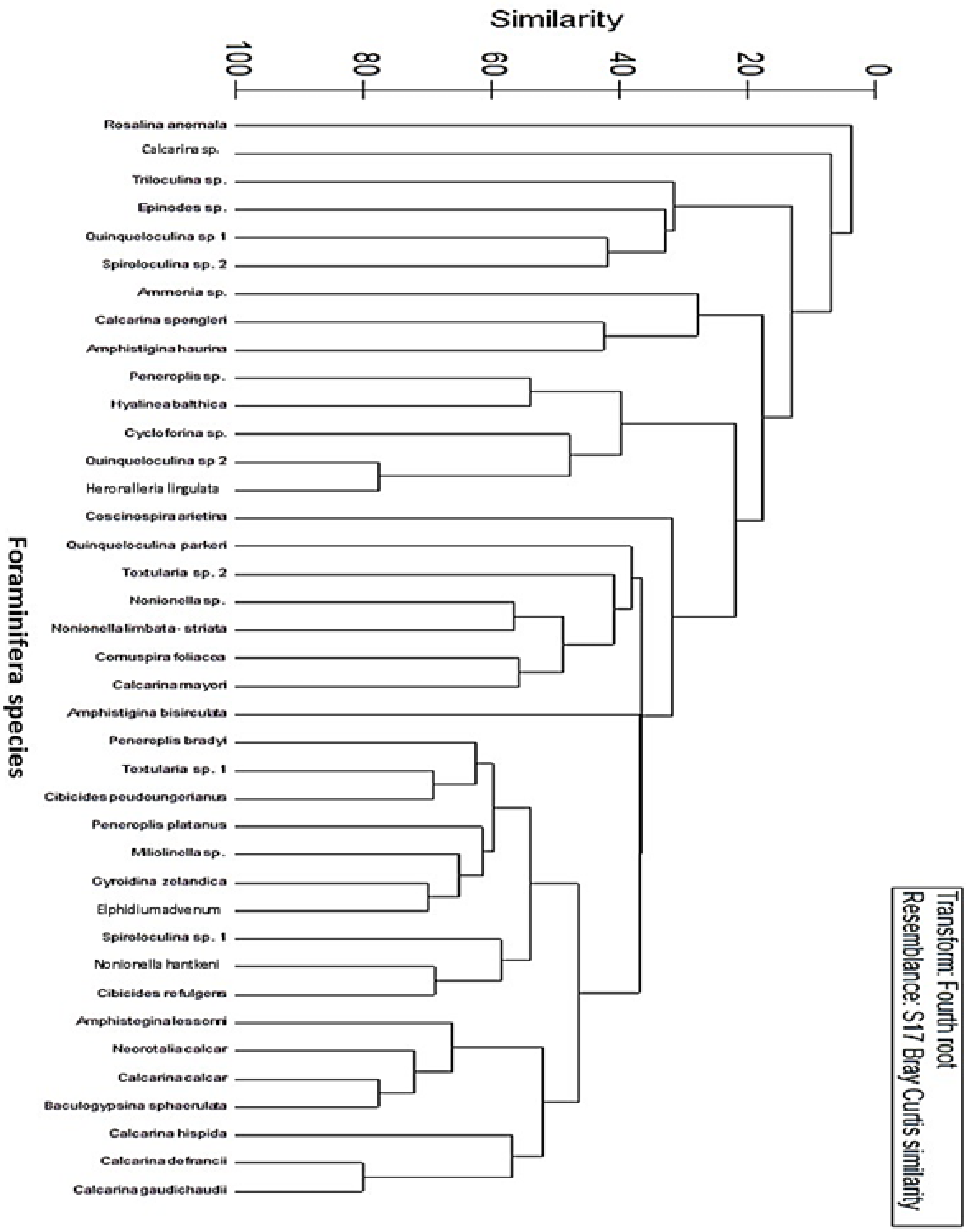

Figure 9. Cluster analysis of foraminiferal species (abundance) in six different sampling sites.

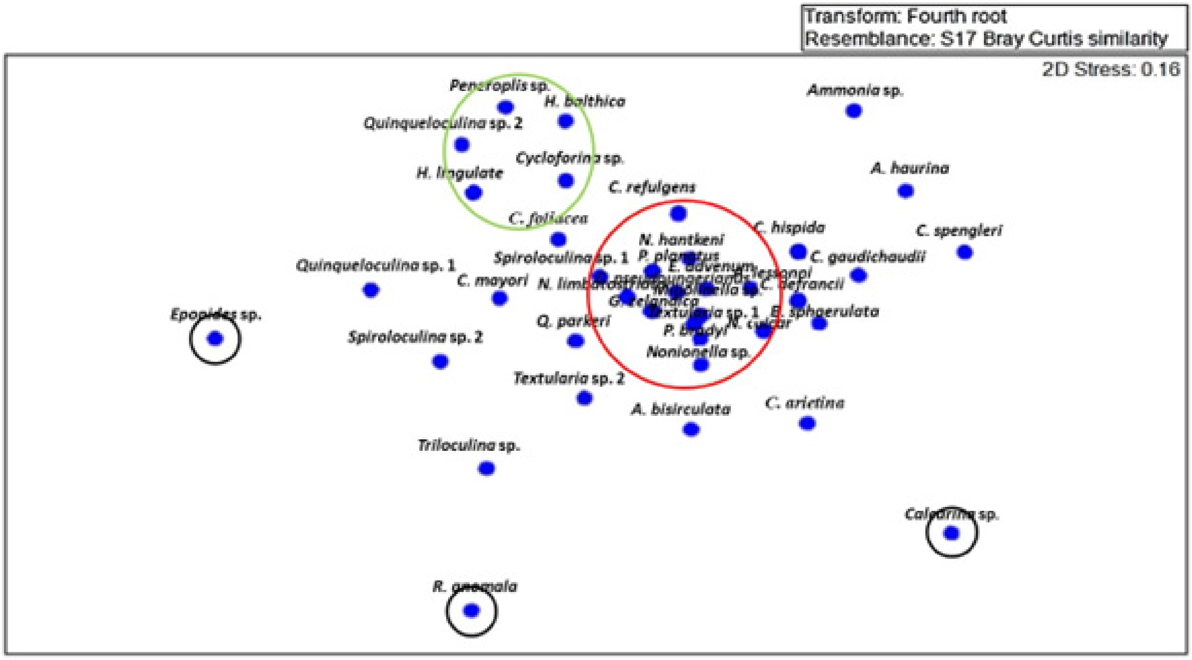

Figure 10. Non-Multidimensional Scaling (nMDS) of different foraminiferal species in all six stations (habitats).

that the *Rosalina sp.* has the lowest number of similarities (3%) among all species in all stations. It was suggested that *R. anomala* was less diverse in the sampling area. On the result of cluster analysis, it was also visualized that the linkage between *A. lessonni* and the Family Calcariniidae (*B. sphearulata* and *C. calcar*) has almost the same in terms of similarities (70%). Natsir et al. (2012), reported that *A. lessonni* and *C. calcar* (Family Calcariniidae) are identified as a functional group of symbiont-bearing Foraminifera which requires the same water quality as coral-forming organisms.

The encircled part (Figure 10) (red outline color) suggested that they share almost the same number of similarities. While the black one is very far from each other suggesting that these foraminiferal species are quite distinct compared to other species. On the other hand, each station also undergoes the method of clustering (Figure 11). Findings show that stations 4, 5, 2, and 3 have the same number of similarities while S6 has the lowest number of similarities indicating that this station has the lowest number of foraminiferal taxa.

The cluster diagram presented suggests the effect of the environmental parameters on the community structure (species diversity) of benthic foraminifera from the different sampling stations (Lacuna et al., 2013). In this investigation, three clusters were identified: cluster 1 (S6), cluster 2 (S1), and cluster 3 (S4, S5, S2, and S3), each of which may contain various species (Figure 11). S4, S5, S2, and S3 formed Cluster 3, indicating that these stations may have shared or similar foraminifera species. Stations of cluster 3 were characterized by pristine waters, highly abundant seagrasses, and coral communities. Foraminifera inhabit pristine aquatic marine environments with remarkable species diversity (El Kateb et al., 2020). On the other hand, S1 is described as pristine water, but compared to the other stations' station 1 is characterized by sandy-gravel sediment. The sandy-gravel sediment composition might be the reason for becoming S1 as a separate cluster from other stations. Foraminifera have different sediment grain size preferences (Stefanoudis et al., 2016). Moreover, S6 is characterized by disturbed water may be attributed to anthropogenic activity like the presence of beach resorts

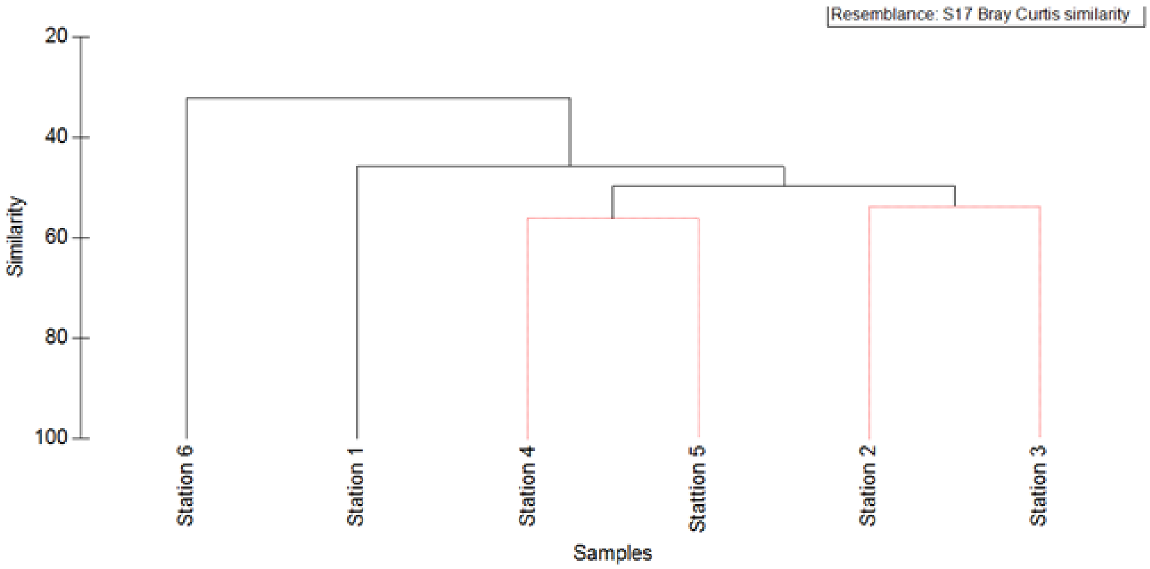

Figure 11. Cluster analysis shows similarities in species diversity between each station in the sampling site in Pujada Island.

in the sampling area. The impact of anthropogenic activities on foraminifera has been a subject of scientific inquiry due to its potential to alter the ecological dynamics of these organisms (Martins et al., 2019). The environmental changes brought about by pollution can lead to a decrease in the abundance and diversity of foraminifera populations (Suokhrie et al., 2017). This phenomenon has been observed in various studies, indicating the susceptibility of foraminifera to pollution-induced stressors. Nevertheless, S6 has a low abundance of seagrass, which may be the cause of the low diversity of foraminifera in this station. Foraminifera have been discovered on seagrass and are regarded as promising and valuable indicators of the health of seagrass meadows (Mariani et al., 2022). The investigation of foraminiferal abundance in seagrass meadows has been explored by many authors (El Kateb et al., 2020).

CONCLUSION

The foraminifera assemblages showed variability and formed three clusters: cluster 1 (S6), cluster 2 (S1), and cluster 3 (S4, S5, S2, and S3). This could imply that each cluster had a different set of species that preferred different physico-chemical parameters. A total of 39 foraminifera species under 16 families were identified and classified in the six sampling stations of Pujada Island, Davao Oriental. The most abundant genera of foraminifera were *Calcarina, Baculogypsina,* and *Amphistegina*. The highest diversity was observed in S1(H' 3.06), while the lowest diversity was observed in S6 (H' 1.59). Physico-chemical parameters including temperature, salinity, and pH are within the standard range for coastal water. Sediment grain size varies between stations, which may be the most important factor influencing foraminifera assemblages. The number of benthic foraminifera varied significantly across all stations, indicating that dispersal was not even. Thus, this demonstrates how species of foraminifera respond differently to environmental factors. Foraminifera can be used to examine the health of marine ecosystems; hence, based on the data, Pujada Island can be regarded as an undisturbed area except for S6, which had the lowest diversity recorded. There are indications that Pujada Island has been subject to anthropogenic threats and if appropriate conservation measures are not taken, this situation may escalate into a more severe state. Therefore, it is recommended to carry out annual assessments and monitoring within this area to facilitate the formulation and implementation of strategies aimed at the conservation and management of Pujada Island.

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