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RESEARCH ARTICLE

Foraminiferal Distribution Pattern and its Ecological Implications in the Koswari and Van Islands of the Tuticorin Group of Islands

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Abstract

Objectives: The present investigation attempts to map the foraminiferal distribution pattern, its ecological significance, and the elemental composition of the Koswari and Van islands. **Methods:** Foraminiferal distribution patterns (both planktic and benthic) were recorded, and textural and geochemical analyses were carried out in the present study. **Findings:** The coastal environments are generally highly dynamic regions of the earth that possess imprints of global climatic variations. The islands of the Gulf of Mannar emerged during the last interglacial period. These islands are getting eroded due to the long-term impact of coral mining and climatic changes. The excess removal of corals from Koswari Island adversely affected the live coral cover of the Island. The Van island is in proximity to the Tuticorin coastal city and one-fourth of the Island has already become submerged due to several natural and anthropogenic factors. Both the islands are affected by the world coral bleaching event witnessed from 2014-2017. This study is an attempt to record how the foraminiferal assemblages of Koswari and Van islands responded to the world coral bleaching event. In the present investigation, we identified fifteen benthic foraminiferal species and two planktic foraminiferal species from both islands. The foraminiferal assemblages mark the abundance of *Neorotalia calcar, Quinqueloculina seminulum, Elphidium crispum, Amphistegina lessonii,* and *Rotalidium annectens*. The main ecological parameters which govern the foraminiferal distribution in these islands are coral reef flats, carbonate environments, and shallow coastal waters. *Neorotalia calcar* and *Quinqueloculina seminulum* are recorded as the most abundant species of both Koswari and Van islands. *N. calcar* prefers macroalgal mat as substratum, while the frequent occurrence of deformed tests and stress-tolerant species such as *Q. seminulum* indicate the influence of pollution in the coastal area. These recorded species are considered characteristic reef benthic foraminifers which prefer coarse sandy substratum. The other abundant species are *Elphidium crispum, Amphistegina lessonii,* and *Rotalidium annectens*, which are widely distributed in the inner shelf sediments of Tamil Nadu and Kerala coasts. Textural attributes of the Koswari and Van islands reflect its high energy environment, and the geochemical signature shows the high calcareous content with typical coral reef foraminifera associated with such sediment nature. **Novelty:** The study tried to map the effect of the global coral bleaching event of 2016 on Koswari and Van islands of the Tuticorin group of Islands in the Gulf of Mannar using foraminifera as a proxy.

Keywords: Foraminifera; Coral reefs; Ecology; Coral bleaching; Gulf of Mannar

1 Introduction

The Gulf of Mannar Biosphere Reserve stretches about 140 kilometers [1] from Tuticorin to Rameswaram in the SW-NE direction, (78° 50′ and 79°30′ E and 8°47′ and 9°15′ N) with the Bay of Bengal in the East, Rameswaram Island on the North-East, the Western Ghats on the West, and Kanyakumari on the South. The Vaippar, Guntar, Karamanayar, Nambiar, Vaigai, and Tamirabarani rivers control the drainage pattern of this region. The beaches of study area are mostly made of sand, coral rubbles, and shelly materials. There are 21 uninhabited coral islands situated around 8 km from the coast, running approximately parallel to the coastline. These islands are grouped into Tuticorin, Vembar, Keelakarai, and Mandapam. Mangroves, seagrass, seaweeds, and coral reef habitats abound in these places. Coral reefs cover 61.01 km^2 in the Gulf of Mannar, with fringing reef, patchy reef, shrubs, and coral pinnacles [2] In 1986, the Tamil Nadu government designated these islands and the adjacent shallow coastal waters to the Gulf of Mannar Marine National Park to safeguard marine species and the environment. The majority of previous research on the coral reef ecosystem of the Gulf of Mannar focused on the following topics like reef system's resilience, environmental monitoring using various factors, natural impacts on the reef system, radionuclides on marine biota, trace element studies, natural background radiation studies, and marine pollution studies [1–5]. A very few micropaleontological studies were conducted in the study region [6,7]. The present study maps the distribution pattern, ecological significance, and substratum preference of foraminifera in the Koswari and Van islands of the Gulf of Mannar.

2 Materials and Methods

Twenty-six grab samples were collected from the Koswari (8° 52′ 26.4" N, 78° 13′27.84" E) and Van island (8°50′16.8" N, 78° 12′ 36" E) of the Tuticorin group of islands during April 2016. Koswari Island (Figure 1, A) is 7 km away from the Tuticorin coast. The first island among the 21 islands of the Gulf of Mannar is Van Island (Figure 1, B). The islands are chiefly composed of sand deposits and fringing coral reefs.

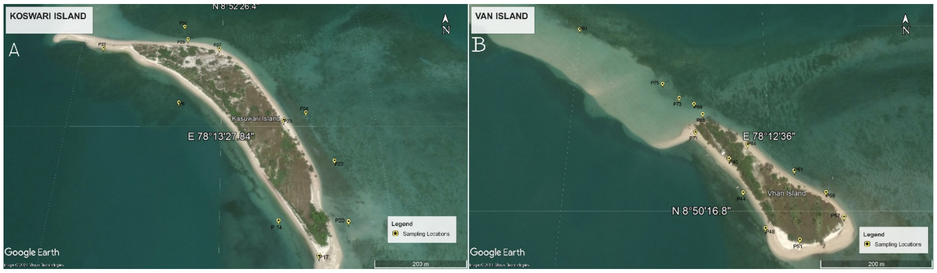

Fig 1. Sampling Locations A-Koswari Island, B-Van Island.

The present investigation focused on foraminifers, which make up a significant fraction of the biogenic component of the marine sediments. The following conventional micropaleontological technique was used to separate the calcareous tests from the matrix. The samples were soaked in 5% hydrogen peroxide for about twelve hours and then boiled. After wet sieving over a 63μm screen, samples were dried and stored in plastic containers. During sample preparation, considerable care was taken to avoid mechanical damage. Dried samples (63μm) were split into subsamples using a micro auto splitter to obtain appropriate aliquots containing sufficient numbers of foraminiferal specimens for qualitative and quantitative analysis. In the event of the rare occurrence of foraminifera, the whole sample was analyzed. Using a binocular stereo zoom microscope (WILD MZ 12.5), all specimens were identified, mounted on microfaunal assemblage slides, and counted. The identification was done upto species level using Leoblich and Tappan (1988), Jones (1994), Barker (1960), Cushman (1948), Murray (1991), Barun Sen Gupta (1999) and with all available literature. The species' surface ultrastructure and other morphological traits were studied using Scanning Electron Microscope (SEM) at National Institute for Interdisciplinary Science and Technology (NIIST), Thiruvanathapuram. Scanning Electron Micrographs of recorded foraminifers were prepared. After eliminating the carbonates by IN HCl and organic matter by 30% H_2O_2, the grain size analysis was performed on the samples of both islands using an automatic sieve shaker. The sediment samples were sieved with 18, 25, 35, 45, 60, 80, 120, 170, and 230 ASTM mesh. Unprocessed samples from both the islands were ground into fine powder for elemental analysis using X-ray fluorescence (XRF) at NIIST–Thiruvananthapuram. The powdered samples were placed in EDXRF spectrometers, and the fluorescence radiation emitted by the specimen was collected using an energy dispersive detector and a multichannel analyzer. The varied energies of the characteristic radiation from each of the individual sample elements are separated. Filters are employed between the sample and the detector to improve the signal, reduce the background, and focus on certain spectral regions.

3 Result and Discussion

3.1 Faunal Characteristics

The Koswari and Van islands have areal extend of 7.70 ha and 3.6 ha respectively. Eleven samples from Koswari Island and fifteen samples from Van Island were analyzed for the present study. The current investigation enabled us to identify fifteen benthic foraminiferal species belonging to thirteen genera and two planktic foraminiferal species belonging to two genera from the Koswari and Van islands (Table 1). Foraminiferal assemblages mark the abundance of *Neorotalia calcar, Quinqueloculina seminulum, Elphidium crispum, Amphistegina lessonii,* and *Rotalidium annectens*. (Plates 1 and 2)

Table 1. List of recorded foraminifera from the Koswari and Van islands

Sl. No	Name of the Species
1	*Neorotalia calcar* (d'Orbigny in Deshayes, 1830)
2	*Quinqueloculina seminulum* Linnaeus, 1758
3	*Amphistegina lessonii* d'Orbigny 1832
4	*Elphidium crispum* Linnaeus, 1758
5	*Rotalidium annectans* Parker & Jones, 1865
6	*Quinqueloculina undulosa costata* Terquem, 1882
7	*Quinqueloculina striata* d'Orbigny in Guérin-Méneville, 1832
8	*Elphidium advenum* Cushman, 1922
9	*Ammonia beccarii* Linnaeus, 1758
10	*Triloculina laevigata* d'Orbigny, 1826
11	*Triloculinella obliquinodus* Riccio, 1950

Continued on next page

Table 1 continued

12	*Spiroloculina depressa* d'Orbigny, 1826
13	*Psuedoparalla bikiniensis* Cushman and ten Dam 1948
14	*Nonion fabum* Fichtel & Moll, 1798
15	*Eponides cribrorepandus* Asano & Uchio, 1951
16	*Globigerina bulloides* d'Orbigny, 1826
17	*Globigerinella siphonifera* d'Orbigny, 1839

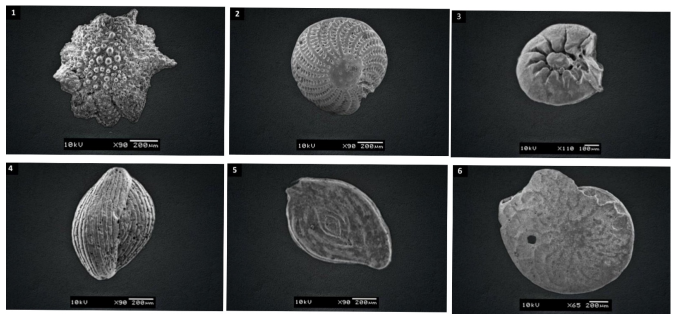

Plate 1: Scanning electron micrographs of the recorded foraminifers from the Koswari and Van island 1. *Neorotalia calcar* (×90), 2. *Elphidium crispum* (×90), 3. *Ammonia beccarii* (×110), 4.*Quinqueloculina striata* (×90) 5. *Spiroloculina depressa* (×90) 6. *Amphistegina lessonii* (×65).

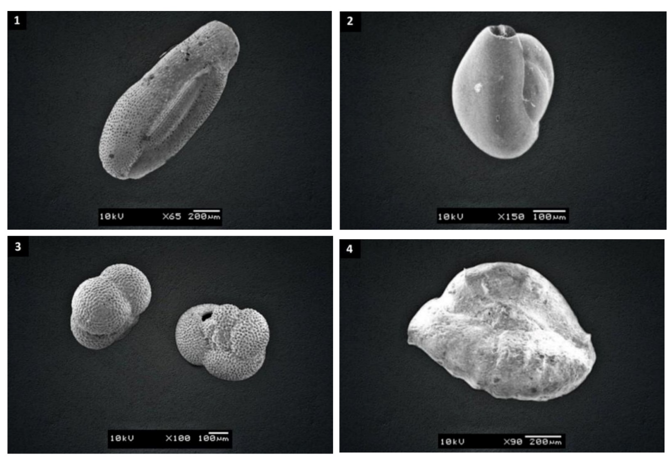

Plate 2: Scanning electron micrographs of the recorded foraminifers from the Koswari and Van island 1. *Triloculinella obliquinodus* (×65) 2. *Quinqueloculina seminulum* (×150) 3. *Globigerina bulloides* (×100) 4. *Quinqueloculina undulosa* costata (×90).

Of the recorded species, *Neorotalia calcar, Quinqueloculina seminulum, Elphidium crispum,* and *Amphistegina lessonii* are the most abundant species in both the islands (Figure 2). The species *Neorotalia calcar* is the most dominant species in all sampling locations of both the islands (Figure 3). *N. calcar* is a warm shallow water benthic foraminifera associated with coral reefs and shelves. A study from the Lakshadweep Archipelago stated that *Neorotalia calcar* and *Amphistegina lessonii* are strongly associated with the aquatic plant *Thalassia hemprichii,* found abundantly in the Gulf of Mannar region. *Neorotalia calcar* is a large benthic foraminifera having macroalgae as substratum preference [8]. In the Gulf of Mannar region, coral growth is favoured by an increase in algal cover and high fish densities 103 [3]. When these massive macroalgal mats block sunlight penetration, the symbiont algae expels since it is unable to do photosynthesis. The higher nutrient influx in the coastal region from various industrial effluents has increased the algal cover [9]. This algal cover has to be cleared off by the grazing reef fishes. Overfishing in the area has led the algae to thrive. The reef destruction caused by anthropogenic activity like illegal coral mining for limestone industries [10] and the global coral bleaching event of 2016 has ultimately reduced the reef cover and adversely affected reef fishes. These scenarios led to increased algal surface and depletion of the remaining corals. The symbiont-bearing calcarinids thus withstand the bleaching event and increase their count due to the presence of the macro-algal mats. *Amphistegina lessonii* is a typical light-dependent reef-dwelling foraminifera that hosts symbionts[(11)]. This species has no substratum preferences[(8)]and has a shallow water depth range of 0-50 m. This is also abundant in tropical coral reef areas and areas with a high percentage of $CaCO_3$. The test is sensitive to heavy metal pollution, and zinc exposure causes visual alteration such as bleaching and dark brown spots in the test[(11)]. This genus also bleaches under high temperatures or high irradiance levels[(12)]. This leads to Amphistegina Bleaching Index (ABI), proposed by Pamela Hallock[(13)] and coined by Sylvia Spezzaferri[(14)], being used as a photo inhibitory stress indicator in coral reef ecosystems. The distribution pattern of *A.lessonii* in the Koswari and Van islands shows low abundance, contrary to other foraminifers (Figures 2 and 3). The less abundance of *A.lessonii* throws light on the health of the coral reefs, and it may be because the sampling was carried out during the global coral bleaching event that occurred in 2016. The anthropogenic activities discussed above also have adverse effects on coral reefs and together cause a lesser abundance of *A.lessonii* in the Koswari and Van islands. *Quinqueloculina seminulum* is a small heterotrophic and 3rd order opportunistic foraminiferal species. It is abundant and distributed widely in the inner shelf sediments of the Tamil Nadu coast. It shows higher abundance in the Koswari and Van islands (Figures 2 and 3) despite the global coral bleaching events. This species thrives in a silty sand substrate with a high concentration of calcium carbonate ($CaCO_3$>21%). An increase in its population is observed with $CaCO_3$. *Quinqueloculina* can play an important role in its proliferation during this adverse time because they have a special wall that is effective in its adaptation to environmental changes such as salinity and temperature[(15)]. The high tolerance level, the silty to sandy nature of sediments, and the high percentage of $CaCO_3$ is the reason for the abundance of *Q.seminulum*. *Elphidium crispum*, an opportunistic shallow-water benthic foraminiferal species, also shows its abundance in both the Koswari and Van islands (Figures 2 and 3). It is the rarest species and prefers normal marine salinity conditions, constituting up to 2% of faunas in relatively sheltered subtidal sand[(16)]. Like *Q.seminulum*, *E.crispum* also showed its presence, higher than normal due to stress conditions prevailing in the area.

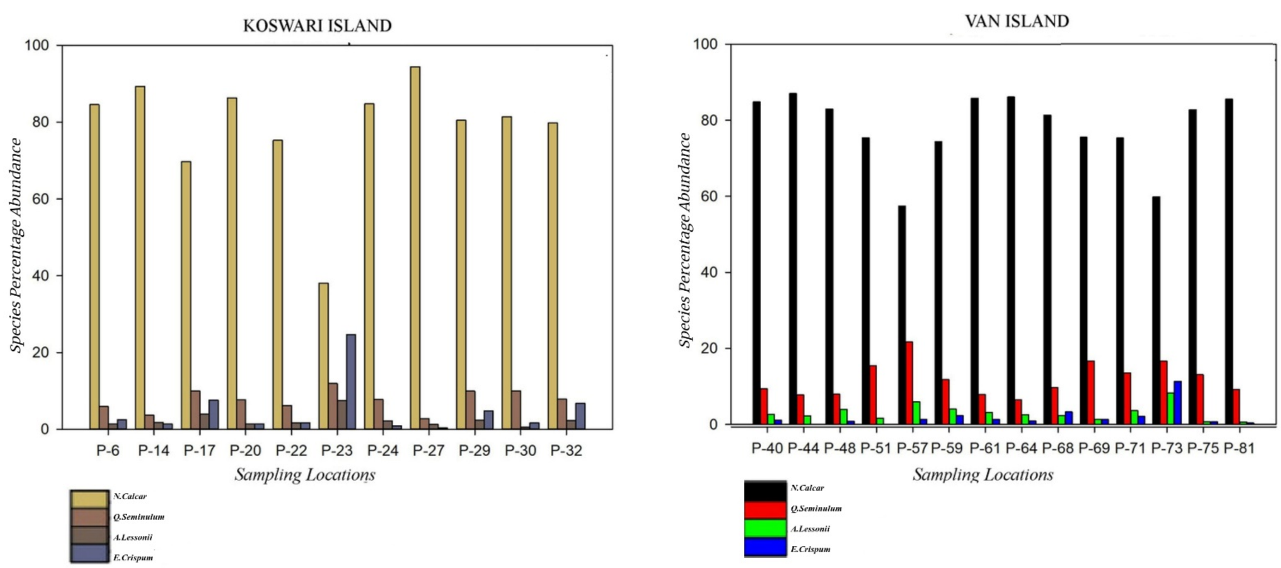

Fig 2. Percentage abundance of *Neorotalia calcar*, *Quinqueloculina seminulum*, *Elphidium crispum* and *Amphistegina lessonii* from the Koswari and Van islands.

3.2 Textural Characteristics

Grain size is the most limiting factor for the foraminifera[(17)] to thrive as the abundance increases with reducing the grain size. The textural attributes from the islands indicate that a significant fraction of the sediments belongs to coarse to medium sand (Figure 4). The faunal records also support the view that the substratum preference for the dominant foraminifers is medium to coarse sand, inferring that area is under the influence of high-energy wave action. Productivity and transport are the two factors that determine the number of shells collected. The larger benthic foraminifers do not live on the sandy bottom near the beaches but prefer firm substrate in high-energy environments close to the front of coral reefs. This led to an abundance of large-sized

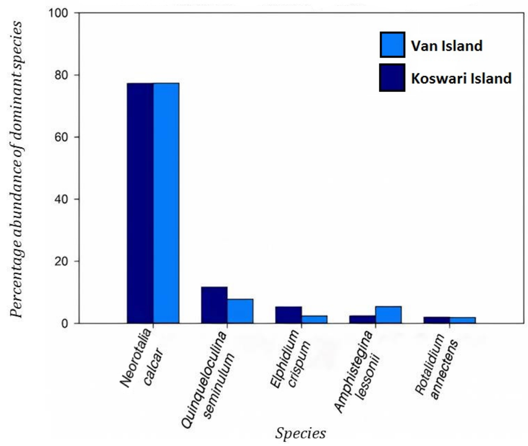

Fig 3. Graph showing a comparison between percentage abundance of foraminifera from Koswari and Van islands.

benthic foraminifers found on the reef crest or in the transition zone between the crest and the reef moat, which is covered with filamentous macroalgae. Empty tests are transported by the high water energy acting at the reef crest. The direction and intensity of currents connecting the production area (reef crest and transition to the moat) with the depositing area determine this transport[17].

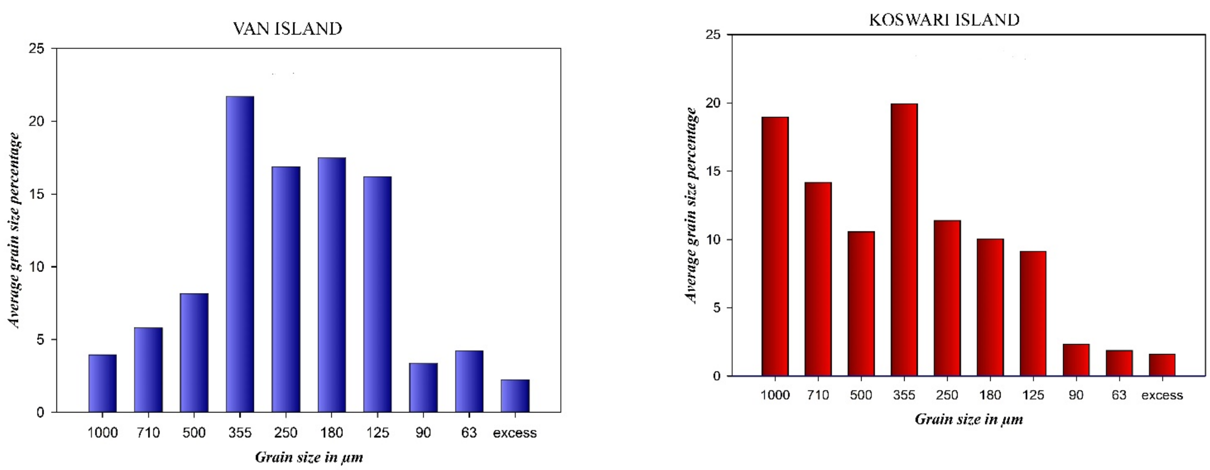

Fig 4. Textural attributes of Koswari and Van island

3.3 Geochemistry

The elemental analysis from the EDXRF shows a high concentration of CaO in both the islands (Figure 7). In Koswari Island, Sample p-24 shows the maximum value of CaO (87.07%). The samples p-22, p-23, p-30, p-32, and p-6 also show high values of CaO. The second abundant oxide identified is SiO_2, and its maximum value is recorded (32.39%) at p-27. The third abundant oxide is MgO, and p-23 shows the maximum value (2.73%). MnO is the minimum abundant oxide in the study area. In Van Island, sample P-59 shows the highest abundance of CaO (83.43%). The samples p-73, p-44, p-71, p-68, and p-57 also show a high amount of CaO. The second abundant oxide identified is SiO_2, and sample p-48 shows the maximum value (25.78%). The third abundant oxide is MgO, and sample p-57 shows the maximum value (2.8%). K_2O and MnO are present in the least amount. Significant oxide concentrations from both the islands show an abundance of CaO following SiO_2, MgO, Fe_2O_3, and Al_2O_3. The distribution of major oxides is found in a similar order in Koswari and Van islands (Figure 5).

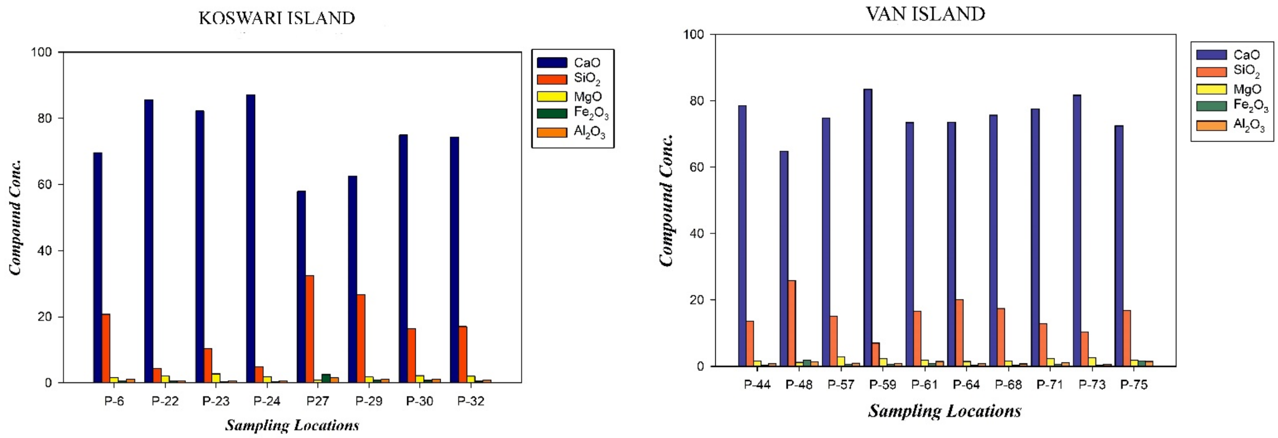

Fig 5. Distribution of major oxides in Koswari and Van island

4 Conclusion

From the Koswari and Van islands, we recorded fifteen benthic foraminiferal species belonging to thirteen genera and two planktic foraminiferal species belonging to two genera. The species *Triloculinella obliquinodus* is found only on Koswari Island. Major benthic foraminiferal species like *Neorotalia calcar, Quinqueloculina seminulum, Elphidium crispum*, and *Amphistegina lessonii* are distributed abundantly in both the islands in the same order. Ecological implications of the Koswari and Van islands indicate its coral nature with the occurrence of coral reef foraminifera *Neorotalia calcar* and *Amphistegina lessonii*. These are typical coral reef foraminifera found in the region. The increased nutrient flux and degradation of reefs due to anthropogenic activities would have increased the abundance of macro algae. The global coral bleaching event also degraded the reefs and caused macro algae to proliferate. These combined reasons caused *Neorotalia calcar* to thrive in numbers. *Amphistegina lessonii* is usually affected by minute changes in the water column, and the higher sea surface temperature might have severely affected them. The low abundance of *A.lessonii* indicates that reef health is in bad condition, and it may be because the sampling took place during the global coral bleaching event of 2016. Silty to the sandy substrate, a high percentage of $CaCO_3$, and an increased tolerance level favours the abundance of *Quinqueloculina seminulum* in the islands despite the global coral bleaching event. In the present investigation, the frequent occurrence of deformed tests and stress-tolerant species such as *A.beccarii, Q.seminulum, N.fabum,* and *E.crispum* indicate the influence of pollution in the inshore area. Grain size analysis indicates that coarse to fine sandy with medium-sized sands dominate most of the sampling locations. This shows the high energy condition prevailing in the region. The direction and intensity of currents determine the source of tests that were released by reproduction or death. Major oxide concentrations from both the islands show CaO as the most abundant one following SiO_2, MgO, Fe_2O_3, and Al_2O_3. The order of abundance of oxides matches in both the islands. Sizeable benthic foraminifera contributes about 5% to modern reef-scale carbonate sediment production. Systematic monitoring of reef health will be crucial as the global bleaching events will double in the coming decades. The routine seawater analysis will provide insights into hydrographic parameters controlling the region's nutrient cycles, temperature, total dissolved salts, salinity, pH, and dissolved oxygen patterns. This will eventually provide ways to mitigate any unwanted source altering the normality in the region.

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