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Environmental factors controlling distribution of recent Textulariid formainifera in the Arabian Gulf

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ENVIRONMENTAL factors were assessed at 51 sampling locations in the Arabian Gulf and twelve Textulariid benthic foraminifers were identified. With the use of linear regressions and the partial least squares model (PLS), the effects of six environmental variables on the distribution of foraminifera were investigated. According to the Variable Importance for Projection (VIPs), the primary regulatory factor for the Textulariid distribution is dissolved oxygen. The latter validates the value of the benthic foraminifer oxygen index (BFOI) as a reliable bioindicator for reconstructing paleooxygenation. In addition, water temperature and depth are not very important. Other factors (such as pH, salinity, and chlorophyll) don't matter at all or little at all. Additionally, correlation studies and linear regression models between the environmental parameters and the diversity of foraminifera (Shannon Index) showed that DO has low, but significant, correlation ($r = 0.28$, $p < 0.05$)., while all other value have no correlation ($r < 0.2$, $p > 0.05$). A detailed taxonomic assessment is provided.

Keywords: Arabian Gulf, Textulariid, paleooxygenation, Foraminifera.

1. Introduction

According to Moodley et al. (2002), foraminifera are single-celled creatures that play a significant role in both food chains and biogeochemical cycles. Benthic foraminifera are relatively small, varied, global, sample-cheap, and abundant in comparison to other meiobenthic organisms (Hallock et al., 2003). Because they exhibit fluctuations in salinity, temperature, nutrient content, and other environmental conditions, benthic foraminifera are essential ecological indicators. With the use of these collections, scientists assess the condition of marine ecosystems and learn about past changes in the environment. Despite being low trophic level organisms in deep-sea communities, benthic foraminifera are a useful tool for assessing the dynamics of both modern and past deep-sea ecosystems due to their widespread presence and tight environmental adaptations (e.g., Gooday, 2003; Jorissen et al., 2007). Most of their investigations indicate a substantial potential for fossilization, with the exception of agglutinating tests employing organic cement, which decomposes rapidly after being buried in the sediment (Mackensen et al., 1995). The distribution of benthic foraminifera in the deep sea is largely influenced by the availability of food and the oxygen concentration of the pore waters and bottom waters due to the close interaction between processes in the surface ocean and the deep sea. Benthic foraminifera play a significant role in sedimentary environments and marine ecosystems, which encompass the Arabian Gulf. The United Arab Emirates and Saudi Arabia ring the Arabian Gulf, sometimes known as the Persian Gulf, a semi-enclosed body of water in the Middle East. It is surrounded by Saudi Arabia, Kuwait, Bahrain, Qatar, Iraq, and the United Arab Emirates. Seasonal variations, high temperatures, and salinity are some of the unique environmental conditions that affect the distribution and variety of marine life, especially benthic foraminifera. Understanding the importance of these microorganisms for paleoceanography, ecology, and the environment is the aim of study on benthic foraminifera in the Arabian Gulf. Benthic foraminifera shells, often known as tests, are particularly helpful for recreating ancient environmental conditions because they can be preserved in sediment layers. Seasonal variations, high temperatures, and salinity are some of the unique environmental conditions that affect the distribution and variety of marine organisms, especially benthic foraminifera.

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Understanding the importance of these microorganisms for paleoceanography, ecology, and the environment is the aim of study on benthic foraminifera in the Arabian Gulf. Benthic foraminifera shells, often known as tests, are particularly helpful for recreating ancient environmental conditions because they can be preserved in sediment layers. Benthic foraminifera studies in the Gulf started in the early 1960s, before the oil boom in the area. In a series of studies assessing the ecology, distribution, and systematics of the benthic foraminifera from multiple localities (Abu Dhabi, Khor al Bazam, Halat al Bahrani) in the southern Arabian Gulf, Murray (1965a, 1965b, 1966a, 1966b, 1966c, 1970a) identified 58 species of benthic foraminifera. Due to the lack of other known taxa with comparable traits, Quinqueloculina and Triloculina in particular were among the most well-known taxa with open nomenclature. Murray (1970b) identified 23 living species from the Abu Dhabi region using the rose bengal-ethanol staining technique. He attributed the low variety and significant individual numbers that were noticed there. Many of the species of benthic foraminifera that have been identified from previous studies are either described under open nomenclature or are only tentatively recognized. This deficiency is anticipated to alter as a result of the diligent work being done by the micropaleontology group at King Fahd University of Petroleum and Minerals (Saudi Arabia) to characterize and catalog new and endemic species (Amao et al., 2016b; Amao and Kaminski, 2016, 2017; Garrison, 2019; Kaminski and Fiorini, 2021).

Textularia is one genus of agglutinated group organisms with shells that live in marine habitats and are single-celled benthic foraminifera. Textularia shells have an impact on the makeup of marine sediments. On the seafloor, they are frequently found in sediments that have accumulated over time. According to Murray (2006), these species of epifauna are either freely moving within the sediment or adhered to the hard substrate. The distribution of Textularia species is influenced by the kind of sediment and its properties. Consequently, these microbes' shells are useful for studying marine environments from the past and today. The biogeographic distribution of Textularia is linked to marine environments, particularly those with shallow waters. Textularia species are found all over the world, and factors influencing their spread include salinity, temperature of the water, and substrate. It's crucial to keep in mind that the genus Textularia has several species, and that each species may have unique distribution patterns. Moreover, greater research in the fields of paleontology and marine biology may yield details about the biogeographic range and ecological preferences of Textularia. The current study aims to: 1) map the recent distribution of Textularid benthic foraminifera in the Arabian Gulf; and 2) identify the major environmental factor impacting the frequency distribution of Gulf's Textularid.

2. Study Area (Geography and oceanography)

The Red Sea Area (RSA) is a marginal sea that is shallow. From Shatt Al-Arab, the confluence of the Tigris, Euphrates, and Karun River in the northwest, to the Strait of Hormuz in the southeast, this semi-enclosed basin stretches for around 1000 km and has a surface area of roughly 239,000 km2. The northwest and west shores of the inner sea basin have shallower bathymetry.

The Arabian/Persian Gulf is a late Pliocene to Pleistocene shallow tectonic depression that resulted from the Arabian and Asian plates colliding and compressing during the Zagros Orogeny (Fig. 1). This marginal sea is an extension of the Indian Ocean, covering an area of approximately 22,600 km2 (Kassler, 1973; Seibold et al., 1973). The Gulf is 1000 km long, 300 km wide at its broadest point, and 60 km long when it joins the Indian Ocean in the Strait of Hormuz. Its NW-SE axis is the length of it (Purser, 1973; Murray, 1991). Due mainly to salt diapirism or erosional relics of Quaternary processes, the Arabian Sea shelf is softer and wider than the rugged morphology of the Iranian coast (Kassler, 1973). Unfortunately, the presence of the Qatar Peninsula modifies the generally uniform Arabian shoreline by changing the patterns of sedimentation and water circulation in the southeast regions of the Gulf (Riegl and Purkis, 2012). Large storm beaches, supratidal zones, and sabkhas (evaporitic flats) are additional features of the coastline that are present in more exposed environments (Kassler, 1973; Purser and Seibold, 1973). Based on the most prevalent sediment types, the Gulf can be separated into two sedimentary realms: the northern Iranian realm is dominated by fluvial deposits, which is mainly supplied to the area through dust storms and river deltas in the far northern regions and along the eastern Iranian side, while the southern Arabian realm is dominated by autochthonous carbonate with siliciclastic admixture which are primarily of biogenic origin, as well as rock fragments that originate from beach rocks and submerged reef fiats (AI-Ghadban et al., 1996 and Riegl et al., 2010). One of the best examples of a mixed carbonate-siliciclastic ramp system is undoubtedly the Gulf. The sea floor is 35 meters deep on average, while near the Strait of Hormuz, it is 100 meters deep. The shelf break is increasingly approached by the sea floor. The interaction of the Arabian Peninsula and the Zagros Mountains also affects the underwater topography of the Gulf, which is typified by a generally gentle sea-floor gradient and a few bathymetric highs (particularly in the south) (Purser, 1973; Kassler, 1973). Agglutinated foraminiferal accumulation has been observed in the deeply submerged highs, particularly in the basin axis direction (Riegl and Purkis, 2012). Based on their origin, which can be attributed to either salt tectonics brought on by the Hormuz salt or the Zagros orogeny, the bathymetric highs are classified as coastal or central-basin types (Purser, 1973; Riegl and Purkis, 2012). While underwater terrain determines the thickness and texture of the sediment, biological populations determine the type of sediment, according to Kassler (1973). The Shatt Al-Arab River's delta forms the northwest beach, while numerous rivers that run across Iran's coastal region near the Zagros Mountains dominate the eastern flank. Significant amounts of terrigenous sediment are contributed by these rivers, which significantly affects the Gulf's sedimentology (Purser and Seibold, 1973; Alsharhan and Kendall, 2003). Many rivers, including the Arvand Rud (Shatt Al-Arab), Gamasb, Karun, Jarahi, Zohreh, Dalaki, Mend, Shur, Minab, Mehran, and Naband (Fig. 1), originate in the Zagros Mountains. These rivers are renowned for their regular "flash-floods." Due to these rivers' discharge of mud and fine sand, the sediment off the Iranian coast is primarily composed of marl, with a rising carbonate concentration farther from the coastline (Seibold et al., 1973). The Iranian River delta is intimately associated with a number of sedimentary structures in the eastern sector of the Gulf (Purser and Seibold, 1973; Kassler, 1973). The Gulf encounters extremes in summer salinity and warmth because of its sheltered location. It is situated in a region with a dry, subtropical climate. According to Clarke and Keij (1973), water temperatures in offshore areas range from 20 to 32 ◦C; in the western part of the Gulf, they are between 16 and 36 ◦C (John et al., 1990); and in lagoonal areas, they are between 15 and 42 ◦C (Purser and Seibold, 1973; Joydas et al., 2015; Kaminski et al., 2021). Substratum temperatures as high as 52 °C have been observed in the summertime on an intertidal mudflat (Kaminski and Garrison, 2020). These hot summers create intertidal "dead zones" (Kaminski et al., 2021) that are completely devoid of meiofaunal life. The tides are complex and might be diurnal, semi-diurnal, or mixed, according to Riegl et al. (2010).

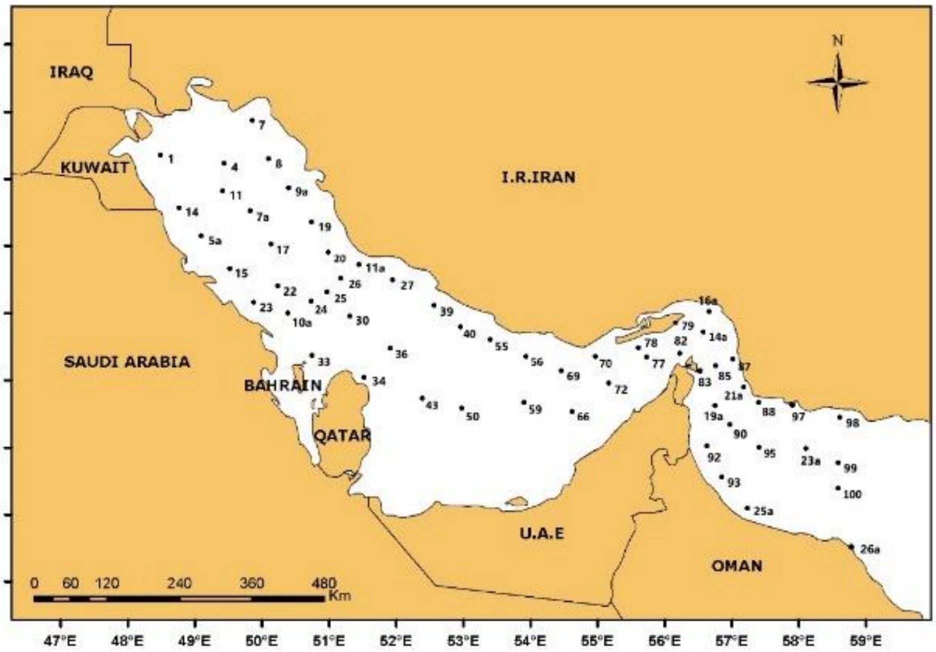

Fig. 1. Location map of the study stations in the Arabian Gulf area.

The seasonal Shamal (north) wind causes significant amounts of siliciclastic aeolian sediment to be carried into the Gulf by mostly northwesterly winds (Riegl et al., 2010). Due to its shallow nature, the majority of it, with the exception of the Iranian shore, lies within the photic zone (Murray, 2006). Due to the frequent high temperatures, strong winds, and low precipitation, there is little precipitation (3–8 cm/yr) but a lot of evaporation (140–500 cm/yr) (Reynolds, 1993). Salinity is characterized by a seasonal gradient that runs both horizontally and vertically because there is no marine buffer (Reynolds, 1993). The Gulf can also be divided into two realms based solely on variations in the salinity of the surface waters (Fig. 2): a less salinized realm in the north influenced by fluvial input and a more salinized realm in the south due to high rates of evaporation of the surface waters entering the Gulf through the Strait of Hormuz (salinity ~36.5). Salinity quickly rises to about 40 in the central parts of the Gulf and falls to about 36.5 at the Shatt Al-Arab due to dilution from freshwater inflow (Riegl et al., 2010; Sheppard et al., 1992, 2010). There is also a discernible west-to-east gradient along the Gulf axis, with the Arabian side becoming more salinized. A few of lagoons and embayments southeast of Qatar have salinities exceeding 50 (Murray, 1970a), while Half-Moon Bay on the Saudi coast has salinities over 60 (Joydas et al., 2015; Arslan et al., 2016). Due to the formation of diverse microhabitats by discrete geomorphological changes and gradients in physicochemical properties, benthic foraminifera display distinctive patterns of distribution and variation (Amao, 2016; Amao et al., 2018a, 2018b, 2019).

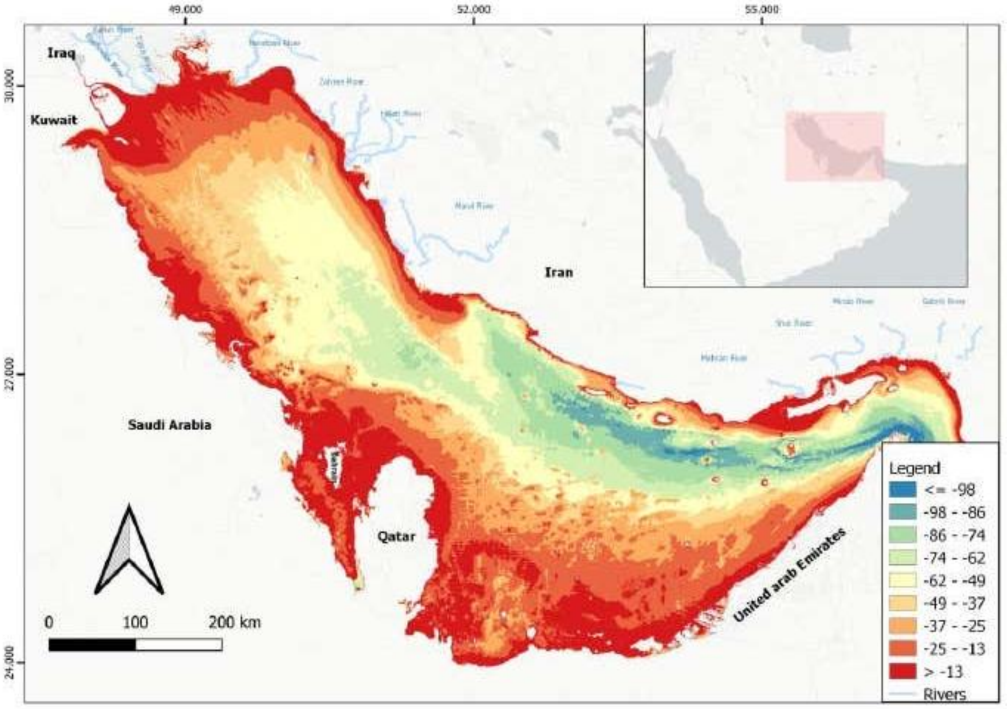

Fig. 2. Bathymetry of the Arabian Gulf after Amao et al., 2022.

3. Material and Methods

3.1. Samples collection

In order to prevent the degradation of the living portion of the test, 51 core top sediment samples that were collected from various stations in the Arabian Gulf by the Regional Organization for the Protection of the Marine Environment (ROPME) oceanographic cruise were preserved with 4% formaldehyde and seawater buffered with sodium borate (20g of NaBO4) at the time of collection. Six different factors were measured at the Wach station. Here, you may find the instrument, model, and factory measurements for each. These variables are shown in Table 1.

3.2. Laboratory analyses

The formula $W= [(P1- P2)]/P2* 100$ was used for each sample to determine its wetness; P1 stands for the sample's weight (g), W for the sample's wetness, and P2 for the sample's weight after drying. The sample in the wet sediment is equivalent to 5g dry weight for foraminiferal examination. The formula for calculating the amount of wet sediment required at each station was $Ps = ([W/100] +1) * 5$, where Ps is the amount of wet sediment sample required, which is equivalent to 5g of dry sediment mass. The conventional approach was used to study the foraminifera. At the time of collection, rose bengal stain was added to the conserved samples in order to distinguish between living and dead foraminifera. After being stained for 48 hours, the samples were gradually dried and rinsed with distilled water using a 0.063mm sieve to get rid of any leftover stain. The test wall of dead specimens either becomes pale pink in color or stays unstained, while the protoplasm of specimens that were alive at the time of collection is stained bright red. The materials were examined under a microscope in a lab after being sieved through 0.063–0.5mm meshes. Specimens larger than 0.063 mm were chosen in order to get a minimum of 300 test results. The fully cleaned sample did not yield 300 tests except in very unusual circumstances. The populations of both dead and living foraminifers were included in the analysis. A light microscope and a scanning electron microscope were used to classify the foraminiferal tests down to the species level, resulting in high-quality monographs for the chosen tests. Monographs by Hottinger et al. (1993), Cimerman and Langer (1991), Sgarrella and Moncharmont (1993), Loeblich and Tappan (1994), Pillar and Haunlod (1998), Albani and Barbero (1990), Jones, 1994, and Cherif et al., 1997 were used to help with the taxonomic identification.

3.3. Statistical analyses

The statistic used to quantify species variety in a community is the Shannon variety Index, also known as the Shannon-Wiener Index. This index, represented by the letter H, is computed as follows: $H = -\Sigma pi * \ln(pi)$, where pi is the percentage of species i in the community as a whole. The Partial Least Squares (PLS) model was implemented to measure the impact of every physicochemical parameter. Bloemsma et al. (2012) claim that the PLS model is capable of producing reliable proxy data for environmental attributes. To measure the impact of each physicochemical parameter on the metal concentrations, loadings or VIPs (Variable Importance for the Projection) and the strength of the fitted model (Q2) were employed. When determining relevant variables and their degrees of effect, the PLS model is more trustworthy than alternative methods—especially when the sample size is small. When the predictor variables are very collinear (multicollinearity; see Carrascal et al., 2009; Abdelhady et al., 2019), the PLS model can be utilized, in contrast to other regression techniques. The distribution of foraminifera was found to be influenced by the environment using Canonical Correspondence Analysis (CCA). The relationship between the physicochemical factors and the diversity and distribution of benthic foraminifera (Shannon index) was examined using a linear regression analysis. A one-tailed t-test was employed to assess the significance of the correlation.

a. Results

4.1. Systematics

Phylum: Protozoa
Class; Foraminiferea, Lee, 1990
Order: Textulariida Lankester, 1885.
Suborder: Textulariina Delage and Hérouard, 1896
Family: Textulariidea, Ehrenberg, 1838
Genus: *Bigenerina* D'Orbigny, 1826
Bigenerina nodosaria D'Orbigny, 1826 (Fig. 3.A)

Table 1. Water quality for Foraminifera analysis in collected sediments during ROPME Oceanographic Cruise Winter 2007.

Station	**Water Depth (m)**	**Temperature (C°)**	**Salinity (%)**	**Q2 (ppm)**	**PH**	**Chlorophyll (µg/l)**	**Species**	**Individuals**	**Dominance**	**Fisher-alpha**	**Shannon**
14	24	16.58	40.43	7.54	8.28	8	4	15	0.3	1.8	1.3
1	13	17.08	37.77	8.25	8.49	9	12	50	0.1	5	2.3
7	13	17.41	40.49	7.96	8.42	7	4	17	0.3	1.6	1.4
5	21	17.62	41.07	8.07	8.25	3	5	26	0.2	1.8	1.5
7	54	17.97	41.07	7.14	8.24	0	3	9	0.4	1.6	1.1
4	41	17.97	41.07	7.39	8.42	3	5	11	0.3	3.5	1.4
8	42	18.05	40.79	7.46	8.41	6	7	26	0.2	3.1	1.9
11	44	18.38	40.98	7.05	8.24	6	9	25	0.1	5	2.2
9	47	18.56	40.62	7.47	8.24	6	9	48	0.1	3.3	2
23	43	18.59	40.97	6.59	8.2	0	0	0	0	0	0
20	63	18.76	40.36	7.14	8.21	7	2	7	0.5	0.9	0.7
19	57	18.89	40.53	7.06	8.22	6	7	35	0.2	2.6	1.9
33	14	18.93	44.07	7.31	8.17	0	0	0	0	0	0
15	21	18.93	40.96	6.98	8.21	0	3	21	0.3	1	1.1
17	60	19.03	40.78	6.94	8.24	2	3	6	0.4	2.4	1
10	26	19.24	40.89	7.27	8.19	2	8	31	0.1	3.5	2
24	65	19.29	40.78	6.8	8.2	0	0	0	0	0	0
22	57	19.4	40.75	6.56	8.2	0	1	5	1	0.4	0
26	73	19.43	40.31	6.96	8.19	2	7	19	0.2	4	1.9
34	14	19.63	41.04	7.08	8.18	11	12	62	0.1	4.4	2.4
25	67	19.68	40.54	6.51	8.18	0	4	8	0.3	3.2	1.4
36	52	19.99	40.78	6.69	8.15	4	6	18	0.2	3.2	1.7
30	71	20.18	40.52	6.66	8.16	4	9	19	0.1	6.7	2.2
43	33	20.69	40.45	6.67	8.19	4	11	47	0.1	4.5	2.1
11	17	20.97	39.94	6.92	8.2	0	0	0	0	0	0
50	39	21.03	40.75	6.4	8.2	2	1	2	1	0.8	0
40	86	21.2	40.21	5.88	8.13	4	1	4	1	0.4	0
39	77	21.3	40.23	5.82	8.1	0	0	0	0	0	0
27	54	21.47	39.98	7.01	8.14	0	4	18	0.3	1.6	1.3
66	42	21.68	41.49	6.19	8.38	8	5	14	0.2	2.8	1.6
59	42	21.68	40.96	6.22	8.41	14	9	61	0.2	2.9	1.8
25	50	21.69	36.33	2.65	7.76	7	2	14	0.5	0.6	0.7
55	86	21.79	40.28	5.29	8.13	4	1	4	1	0.4	0
56	93	21.86	40.3	5.6	8.37	14	3	14	0.3	1.2	1.1
72	72	22.01	40.55	5.45	7.2	7	6	22	0.2	2.7	1.8
69	75	22.05	40.34	5.66	8.37	2	3	14	0.4	1.2	1
88	65	22.09	36.61	5.83	8.14	0	0	0	0	0	0
21	57	22.28	36.47	5.39	7.93	0	0	0	0	0	0
79	45	22.39	37.02	6.59	8.18	13	6	44	0.2	1.9	1.7
98	50	22.54	36.51	5.16	7.94	8	2	15	0.5	0.6	0.7
97	54	22.55	36.54	5.64	7.95	0	0	0	0	0	0
14	64	22.56	36.91	5.48	7.92	0	3	15	0.4	1.1	1.1
93	67	22.63	36.56	4.83	7.93	0	4	22	0.3	1.4	1.3
85	104	22.65	39.59	4.93	7.93	8	3	14	0.4	1.2	1
78	45	22.66	37.31	6.09	8.15	0	0	0	0	0	0
26	53	22.66	36.51	5.11	7.88	26	12	101	0.1	3.5	2.4
70	44	22.74	38.3	6.41	8.18	0	5	21	0.2	2.1	1.5
16	30	22.76	36.74	6.17	7.96	0	0	0	0	0	0
83	95	22.77	39.79	4.96	7.94	15	10	66	0.1	3.3	2.3
77	61	22.81	38.96	4.83	8.11	0	0	0	0	0	0
87	26	23.14	36.54	6.35	7.95	0	0	0	0	0	0

Occurrence in RSA: Stations number, 1.4.7.8.11.14.9A.19.30.34.39.43.50.55.56.59.66.72.79.26A.98.25A.83. It is found in 13m- 95m depth (Table 1).

Occurrence in world: Mediterranean, Timor Sea.

Bigenerina aspratiis Loebelich and Tappan, 1994 (Fig. 3.I)

Synonymoy here!

Occurrence in RSA: Stations number, 1.7.4.8.11.14.9A.19.30.34.39.59.66.79.26A. It occurs in 13m-77m in depth.

Remarks:

Distribution: Mediterranean, Timor Sea.

Genus: *Sahulia* Loeblich and Tappan, 1985

Sahulina barkeri (Hofker, 1978) (Fig. 3.K)

Occurrence in RSA: Stations number, 1.11.5A.15.17.10A.26.39.34.43.56.59.69.26A.85.83. It occurs in 13m- 104m.

Occurrence in world: Mediterranean Sea, Timor Sea.

Genus*:* *Textularia* Defrance, 1824

Textularia truncate Höglund, 1947 (Fig. 3.L)

Occurrence in RSA: Stations number, 1.8.11.9A.20.22.10A.30.34.43.59.66.72.79.26A.93.83. It occurs in 13m- 95m in depth.

Occurrence in world: Mediterranean Sea.

Textularia agglutinans D'Orbigny, 1839 (Fig. 3.B)

Occurrence in RSA: Stations number: 1.7.4.11.5A.7A.9A.15.19.20.22.10A.26.27.30.34.36.43.72.79.26A.25A.93.83. It occurs in 13m- 104m in depth.

Occurrence in world: Timor Sea, Mediterranean.

Textularia bocki Höglund, 1947 (Fig. 3.C)

Occurrence in RSA: Stations number1.7.4.8.11.5A9A.17.19.20.10A.25.30.33.34.36.43.
70.79.26A.83.14A. It occurs in 13m- 95m in depth.

Occurrence in world: Mediterranean Sea.

Textularia conica D'Orbigny, 1839 (Fig. 3.H)

Occurrence in RSA: Stations number, 1.8.11.14.5A.7A.9A.15.19.10A.27.30.34.36.43.79.26A.83. It occurs in 13m- 95m in depth.

Occurrence in world: Mediterranean Sea.

Textularia foliacea Heron – Allen and Earland, 1915 (Fig. 3.D)

Occurrence in RSA: Stations number, 1.8.34.43.66.26A.83. It occurred at depths from 13m- 95m.

Occurrence in world: Mediterranean

Textularia oceanica Cushman, 1932 (Fig. 3.E)

Occurrence in RSA: Stations number, 1.8.11.9A.10A.30.34.43.59.66.70.72.26A.85.83. It occurs in 13m- 104m in depth.

Occurrence in world: Mediterranean Sea.

Textularia pseudogramen Champan and Parr, 1937 (Fig. 3.J)

Occurrence in RSA: Stations number 1.7.11.9A.5.19.10A.25.26.27.30.34.36.43.59.69.70.72.26A.83. It occurs in 13m-104m in depth.

Occurrence in world: Beagle Gulf, eastern Timor Sea, Arabian Gulf.

Textularia pseudorugosa Lacroix, 1932 (Fig. 3.M)

Occurrence in RSA: Stations number 1.4.8.11.7A.9A.15.10A.25.26.30.34.36.43.59.70.79.26A.93.85.83. It is found in depth ranging between 13m- 104m.

Occurrence in world: Mediterranean Sea

Textularia secasensis Lalicker and McCulloch, 1940 (Fig. 3.N)

Occurrence in RSA: Stations number, 1.8.11.9A.10A.25.26.27.30.34.43.59.66.72.79.26A.93. 83.. It occurs in 13m- 95m in-depth.

Occurrence in world Eastern Timor Sea.

Textularia sica Lalicker and Bermudez 1941 (Fig. 3.F)

Occurrence in RSA:

Stations number1.4.11.5A.9A.17.19.20.26.30.34.43.59.70.79.26A.83. It occurs in 13m- 95m depth.

Occurrence in world: Mediterranean Sea.

Textularia porrecta Brady, 1884 (Fig. 3.G)

Occurrence in RSA: Stations number, 1.11.9A.17.19.20.10A.25.30.34.36.43.59.70.72.26A.93.83. It occurs in 13m - 95min depth.

Occurrence in world: Mediterranean Sea.

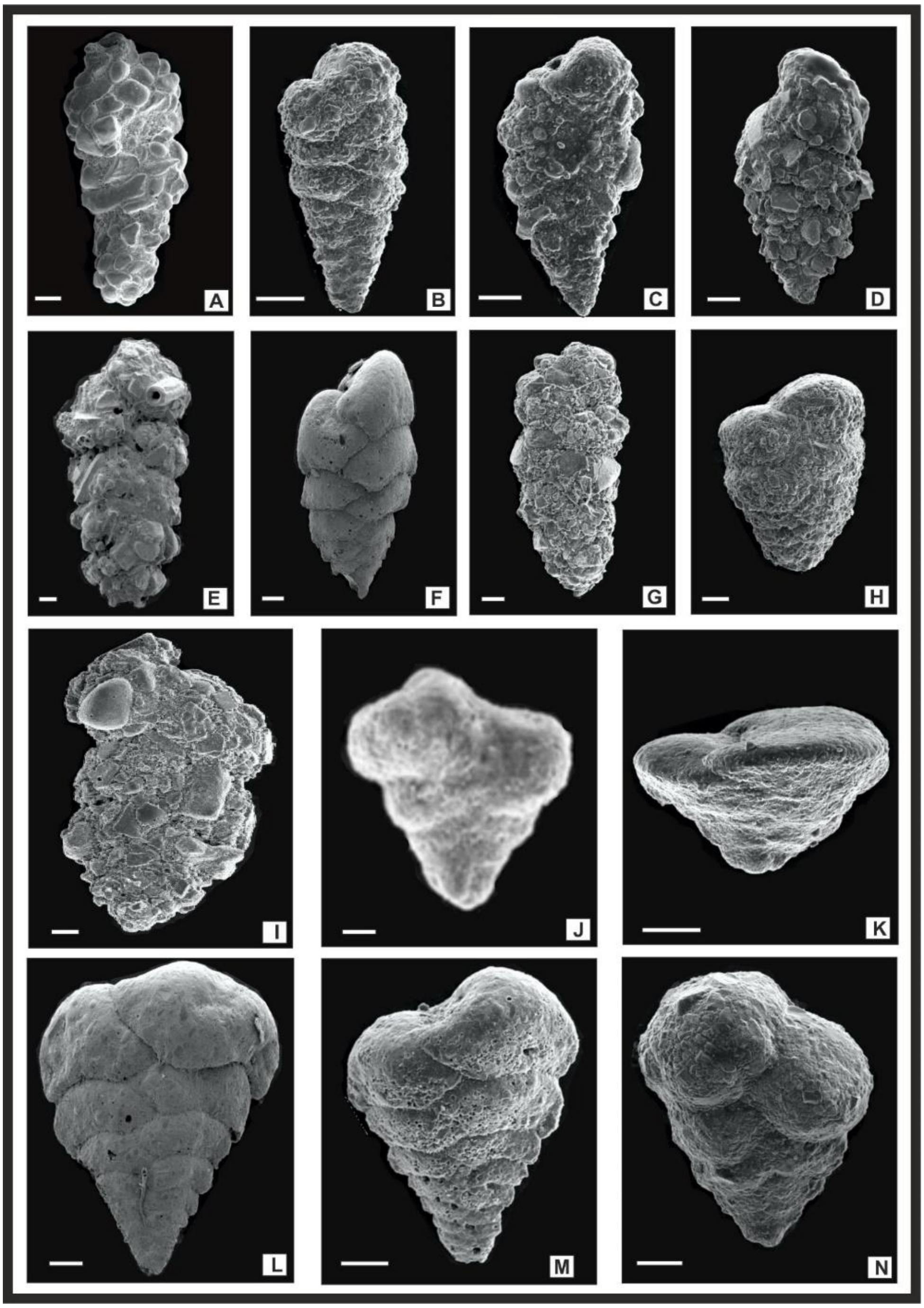

Fig. 3 Scan Electron Microscope Photographs of the recent benthic foraminifera in the Arabian Gulf.

A) *Bigenerina nodosaria* D’Orbigny, 1826,
B) *Textularia agglutinans* D'Orbigny, 1839
C) *Textularia bocki* Höglund, 1947
D) *Textularia foliacea* Heron-Allen and Earland, 1915
E) *Textularia oceanica Cushman*, 1932
F) *Textularia sica* Lalicker and Bermudez 1941
G) *Textularia porrecta* Brady, 1884
H) *Textularia conica D’Orbigny,* 1839
I) *Bigenerina aspratiis* Loebelich and Tappan**,** 1994
J) *Textularia pseudogramen* Champan and Parr, 1937
K) *Sahulina barkeri* ((Hofker)Hofker 1978)
L) *Textularia truncate* Höglund, 1947
M) *Textularia pseudorugosa* Lacroix, 1932
N) *Textularia secasensis* Lalicker and McCulloch, 194

Table 2. Recent Textulariid foraminifera distribution in the Arabian Gulf.

Station	*Bigenerina aspratilis*	*Bigenerina nodosaria*	*Sahulina barkeri*	*Textularia agglutinans*	*Textularia pseudogramen*	*Textularia porrecta*	*Textularia sica*	*Textularia pseudorugosa*	*Textularia conica*	*Textularia foliacea*	*Textularia oceanica*	*Textularia secasensis*	**SUM**
14	3	2	3	0	0	0	0	0	7	0	0	0	**15**
1	2	2	5	12	5	4	3	3	4	3	4	3	**50**
7	4	3	0	6	4	0	0	0	0	0	0	0	**17**
5	0	0	3	8	4	0	3	0	8	0	0	0	**26**
7	0	0	0	4	0	0	0	3	2	0	0	0	**9**
4	2	1	0	5	0	0	1	2	0	0	0	0	**11**
8	3	3	0	0	0	0	0	3	5	5	4	3	**26**
11	0	2	4	3	3	3	0	2	3	0	3	2	**25**
9	3	3	0	8	0	6	6	3	1	0	6	12	**48**
23	0	0	0	0	0	0	0	0	0	0	0	0	**0**
20	3	4	0	0	0	0	0	0	0	0	0	0	**7**
19	3	3	0	9	4	6	5	0	5	0	0	0	**35**
33	0	0	0	0	0	0	0	0	0	0	0	0	**0**
15	0	0	0	8	0	0	0	5	8	0	0	0	**21**
17	0	0	2	0	0	3	1	0	0	0	0	0	**6**
10	0	0	2	6	5	3	0	4	3	0	4	4	**31**
24	0	0	0	0	0	0	0	0	0	0	0	0	**0**
22	0	0	0	5	0	0	0	0	0	0	0	0	**5**
26	0	0	2	4	2	3	4	2	0	0	0	2	**19**
34	3	5	3	2	8	7	5	2	9	6	7	5	**62**
25	0	0	0	0	2	2	0	2	0	0	0	2	**8**
36	0	0	4	3	3	2	0	1	5	0	0	0	**18**
30	2	2	0	2	3	0	2	2	2	0	2	2	**19**
43	0	2	2	2	6	8	10	1	8	4	3	1	**47**
11	0	0	0	0	0	0	0	0	0	0	0	0	**0**
50	0	2	0	0	0	0	0	0	0	0	0	0	**2**
40	4	0	0	0	0	0	0	0	0	0	0	0	**4**
39	0	0	0	0	0	0	0	0	0	0	0	0	**0**
27	0	0	0	4	2	0	0	0	7	0	0	5	**18**
66	4	4	0	0	0	0	0	0	0	2	2	2	**14**
59	6	5	3	0	24	8	9	2	0	0	2	2	**61**
25	0	7	0	7	0	0	0	0	0	0	0	0	**14**
55	0	4	0	0	0	0	0	0	0	0	0	0	**4**
56	5	5	4	0	0	0	0	0	0	0	0	0	**14**
72	4	3	0	4	5	2	0	0	0	0	0	4	**22**
69	0	0	2	0	6	0	0	0	0	0	6	0	**14**
88	0	0	0	0	0	0	0	0	0	0	0	0	**0**
21	0	0	0	0	0	0	0	0	0	0	0	0	**0**
79	6	7	0	9	0	0	4	6	12	0	0	0	**44**
98	0	8	0	0	0	0	0	0	7	0	0	0	**15**
97	0	0	0	0	0	0	0	0	0	0	0	0	**0**
14	0	0	0	7	0	4	4	0	0	0	0	0	**15**
93	0	0	0	8	0	6	0	4	0	0	0	4	**22**
85	0	0	8	0	0	0	0	3	0	0	3	0	**14**
78	0	0	0	0	0	0	0	0	0	0	0	0	**0**
26	12	9	5	8	10	12	11	6	9	7	5	7	**101**
70	0	0	0	0	2	4	7	4	0	0	4	0	**21**
16	0	0	0	0	0	0	0	0	0	0	0	0	**0**
83	0	5	10	6	8	9	6	6	0	6	4	6	**66**
77	0	0	0	0	0	0	0	0	0	0	0	0	**0**
87	0	0	0	0	0	0	0	0	0	0	0	0	**0**
SUM	**69**	**91**	**62**	**140**	**106**	**92**	**81**	**66**	**105**	**33**	**59**	**66**	**970**

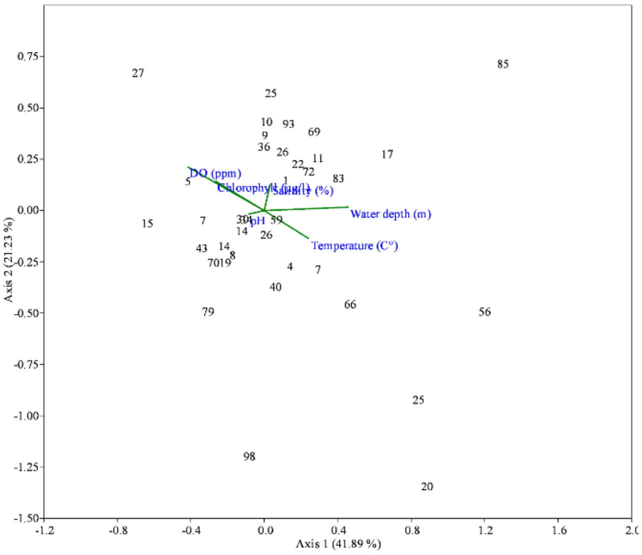

Fig. 4. Canonical correspondence analysis (CCA) plot shows the environment-faunal relationship in the Arabian Gulf.

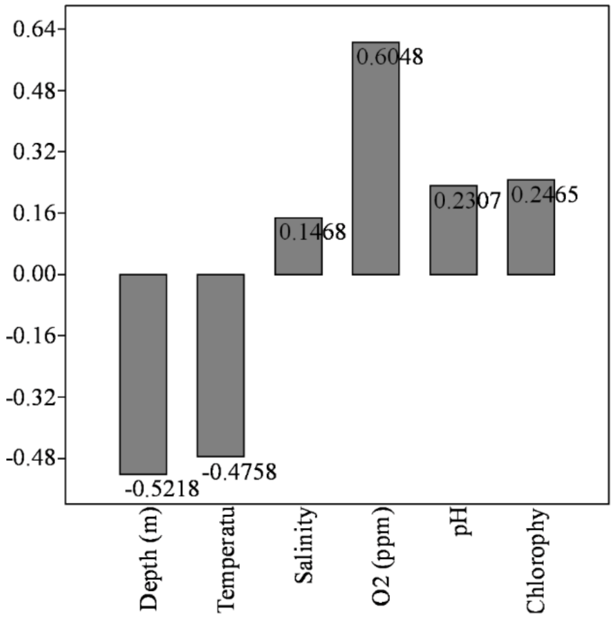

Fig. 5. Variable Importance of Projection (VIPs) of the Partial least Square (PLS) model of the six measured environmental parameters and the recent Textulariid formainifers in Arabian Gulf. Only Dissolved Oxygen (DO), water depth and temperature have marked importance.

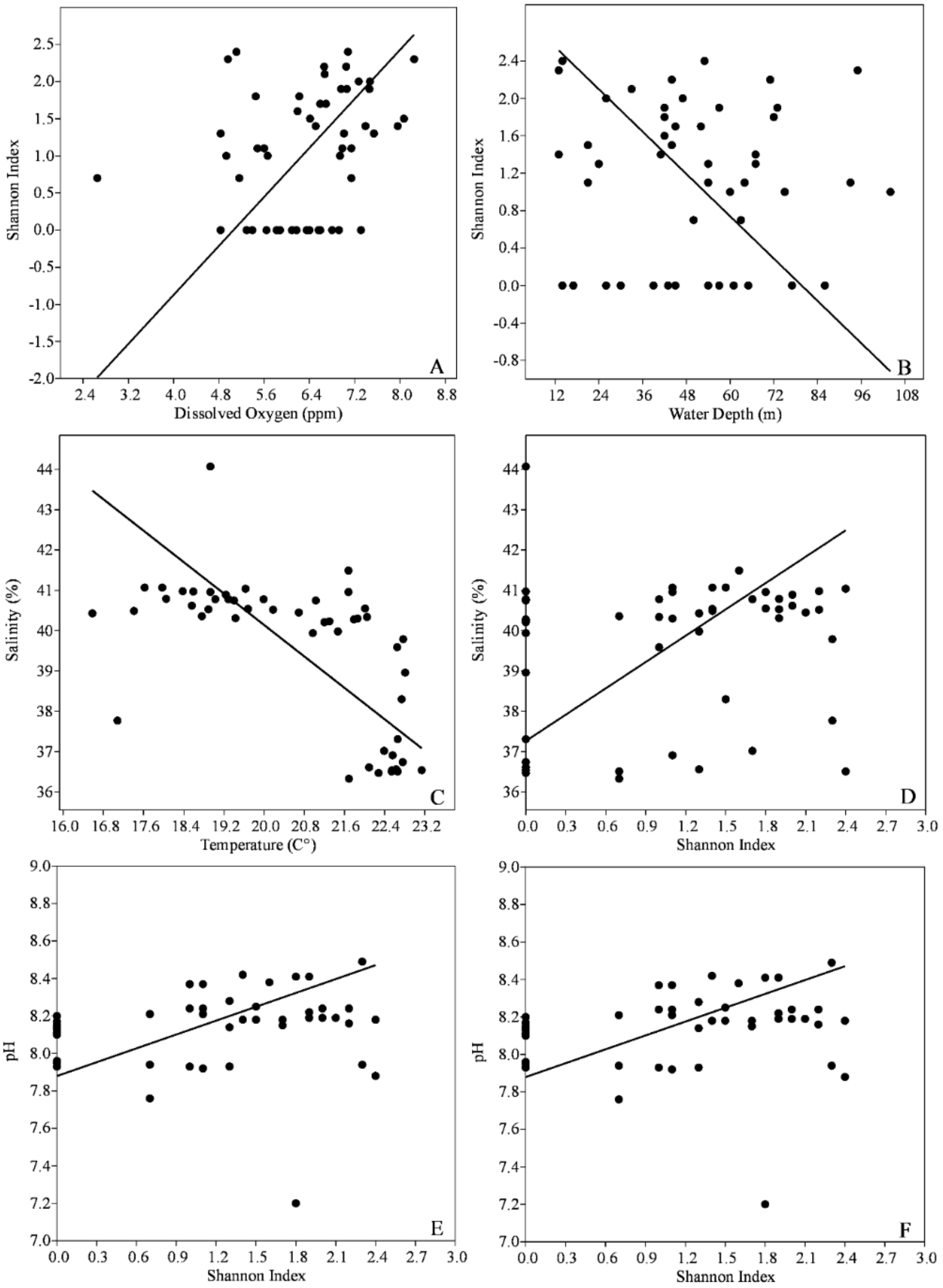

Fig. 6. Linear regression models between Shannon Index and: A) Dissolved oxygen, B) Water depth, C) Salinity, D) Temperature, E) pH, F) Chlorophyl. The only significant correlation was found with Dissolved oxygen (r = 0.28, p = 0.019).

5. Discussion

The present study's findings corroborate earlier research indicating that the benthic foraminifera community in the Arabian Sea is primarily regulated by bottom water dissolved oxygen (e.g., Hermelin and Shimmield, 1990; Nigam et al., 2007; Schumacher et al., 2007; Caulle et al., 2015; Singh et al., 2021). For the purpose of recreating paleooxygenation, Kaiho (1994) created the Benthic Foraminifers Oxygen Index (BFOI) (see Jain et al., 2019; 2023; Kranner et al., 2022 Yuan et al., 2023). In the Marmara Sea, Kaminski (2012) discovered a strong correlation between measured and BFOI-estimated DO values, demonstrating the reliability of the BFOI as a paleooxygen proxy. Schmiedl et al. (2023) state that the deep-sea faunas of the Arabian Sea are remarkably precessionally variable and rather diverse. These variations can be attributed to the impact of deep waters that are rich in oxygen at lower bathyal and abyssal depths, as well as differences in food fluxes caused by the monsoon and the degree of the oxygen minimum zone. The relative variety and resilience to changes in the oxygen minimum zone strength can be attributed to the prevalence of infaunal species, which have the ability to store and respire nitrate. The relationship between bottom-water temperature and deep-sea benthic diversity has been noted by Tittensor et al. (2011) and Yasuhara and Danovaro (2016). Temperature affects the physiology and metabolism of several species. According to predicted situations, abyssal temperatures could rise by as much as 1 °C, there would be a significant drop in pH, and subsurface waters would continue to lose oxygen. This process is expected to be most intense at intermediate water depths and cause oxygen minimum zones to expand (Danovaro et al., 2017; Levin et al., 2021). Nevertheless, no correlation was discovered in this instance based on temperature, which might be the consequence of the research sites' much smaller range of fluctuation (5 degrees; 17–22; Table 2). Environmental variables primarily affect the composition of the foraminiferal assemblages, according to Cherif et al.'s (1997) study of the regional distribution of recent benthic foraminifera assemblages and their relationship to the significant geographical characteristics of the surrounding lands in the Arabian Gulf. The Iranian Shelf's fauna has a high degree of diversity (average Yule-Simpson diversity index for the assemblage 39.2) due to the substantial nutrients supplied by drainages in the topographically elevated Iranian hinterland. The fauna of the Arabian Shelf has extremely low diversities (average Yule-Simpson diversity index for the ensemble 16.1) due to the absence of active drainage in the arid Arabian coast. The foraminiferal fauna demonstrates moderate diversities and significant proportions of agglutinated species in the deepest areas of the study sites. The Strait of Hormuz has the lowest diversities (Yule-Simpson diversity index: 14.9), whereas the mouth of Shatt Al-Arab has the highest diversities (Yule-Simpson diversity index: 62.9). This suggests that the amount of nutrients provided by drainages debouching in a landlocked basin is a significant factor determining the makeup of foraminifera in bottom sediments. The foraminiferal assemblage that was mostly visited by Textulariina or Rotaliina was found in the deeper sections of the Central Basin of the Arabian Gulf (Cherif et al. 1997). Furthermore, the highest percentage of Globigerina (planktic foraminifera) is found in it, indicating that it is closest to the ocean. With silt and clay accounting for around 20% of the total sediment weight, deeper habitats (water depth >40 m) exposed to open sea conditions have the highest percentages, specimen counts, and species diversity of textulariids in the overall foraminiferal fauna. Frequencies drop in seagrass areas, highly muddy, "soupy" sediments, and on coarse substrates (Haunold, 1999).

Nine Textulariid genera were identified by Amao et al. (2022), of which twenty species are Textularia. On the other hand, for Textularia, we have only found 3 Textulariid genera and 9 species here. Since we counted the same number of people, sample size is the reason for this discrepancy. This implies that a significant variable that can change the foraminifera's diversity pattern in contemporary oceans is sample size. Similarly, Mamo (2016) discovered that only 5 percent of the foraminiferal species known to exist in Australia's Great Barrier Reef are Textulariids.

6. Conclusion

Textularia species are a widely distributed group of agglutinated epifaunal benthic foraminifera in the Arabian Gulf. The findings of the paleoenvironment study, which made use of linear regression models and a correlation test between the environmental parameters and the Shannon Index of foraminifera diversity, indicate that the Arabian Sea's benthic foraminifera community is significantly regulated by the amount of dissolved oxygen in the bottom water. The lack of association between water temperature and depth may be due to the study sites' extremely small range of fluctuation. Salinity, pH, and chlorophyll also don't matter very much or at all.

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