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Research Article

BENTHIC MICROALGAL COMPOSITION AND SPECIES DIVERSITY IN EMBIKHAH KHOR AT MUKALLA COAST-GULF OF ADEN, YEMEN

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Abstract

This algological study was carried out during the duration from January to March, 2019 on the patterns of benthic microalgal species distribution and diversity and the community composition of the identified species that attached on artificial glass slides substrate in Embikhah Khor. On the basis of possible influence of land activities, four sampling stations were preselected to represent the khor area. As a result, 46 identified species from 27 genera under 18 families and 4 divisions were classified. The diatoms were the most diverse group with 31 species followed by the dinoflagellates (7), blue green algae (5) and green algae (3). The combination of these assemblages characterized by higher alpha species diversity and richness growth of diatoms. Higher significant ($p < 0.05$) ratio of pennate benthic diatoms compared to centric forms was recorded. The diatomic species which were the pioneering community of early ecological succession development indicated the relatively pristine nature of Embikhah Khor ecosystem. The gradual decrease in α- species diversity from station 4 to station 1 was inconsistent with organic load in each station. Strong positive correlation between beta diversity and turnover ratio was observed. Meanwhile, there was strong positive correlation (r^2= 0.8393) between alpha and beta diversity. Gamma diversity value which is influenced by alpha and beta diversity values was 26 taxa. Analysis of station similarity of community composition separated several clusters of stations at the different similarity level (71-86%). Amongst species composition, twenty of the record species were potentially harmful species, all of them found in low species diversity except *Navicula spp*, *Nitzschia spp* and *Peridinium spp*. Around 44% of alpha species diversity index covered byharmful microalgal species. Nevertheless, no harmful blooms have been reported or expected to appear in Embikhah Khor.

Keywords: Benthic Microalgae, Composition, Species Diversity, Embikhah Khor.

INTRODUCTION

The coastal zone is the most productive ecosystem. Microalgae either suspended in water as phytoplankton or attached in substrate as benthic microalgae comprises the major portion of primary productivity in the coastal zone. Benthic microalgae are important components of estuarine and coastal ecosystems (Longphuirt *et al.,* 2006; Semcheski *et al.,* 2016). They contribute significantly to primary productivity of shallow areas as the base of the food web and play an active role in the uptake of organic and inorganic nutrients (Riekenberg *et al.,* 2017; Moeira-Gonález *et al.,* 2020). The coastal zone of the northern part of Gulf of Aden (Yemen) continuously receives non treated wastewaters as a result of municipal, agricultural and industrial human activities (Saleh and Al-Halmi, 2021). Hadhramout coast is becoming subjected to increasing human pressures, most of which appear to have resulted in harmful environmental effects (Al-Gahwari, 2022). Throughout much of Hadhramout coast, Mukalla coastal zone is fast becoming the respiratory for wastes. Embikhah Khor as a part of Mukalla coast is recently suffers from several of wastes such as adjacent land-based wastes, sewage drainage of residents along the waterway, oil waste of vehicles, run-off during rainfall, disposal garbage and dumping of plastic and heavy construction and destruction solid wastes from surrounding areas. Benthic microalgae (periphyton) can reflect recent environmental conditions (Masseret *et al.,* 1998).

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The input of organic and inorganic chemicals affected the organisms, and directly or indirectly determined community composition (Round, 1991). Wan Maznah and Mansor (2001) reported that the relationship between environmental conditions and algal composition is hard to specify because of a high number of parameters exert a synergistic effect on population. Benthic microalgal biomass increases where enrichment of nutrient in coastal environment (Hillebrand and Sommer, 2000; Hillebrand and Kahlert, 2001; Bokn *et al.,* 2002). Periphytic algae, attach on artificial substrate and colonize all the habitats, have been extensively used in algological research (Stevenson and Pan, 1999) due to their simple collection, taxonomically diverse with short generation succession period and the rapidly and predictably response of species to environmental changes (Hill et al, 2000). Increased concern for ecological integrity of coastal and estuarine waters has prompted investigation into the accumulation of benthic microalgae on artificial substrata as an indicator of water quality(Cosgrove *et al.,* 2004). Periphyton communities respond to environmental stress primarily by changes in species composition (Rott, 1991). On the earlier studies, benthic microalgae have been used by some investigators such as Ho (1976) as indicators of human disturbance in the study areas, while other microalgal studies such as that one of Nather Khan (1991) conducted in relation to water pollution. Regarding the microalgae investigations in Yemen, most of studies (Alkershi and Menon, 2011; Al kawri and Majambo, 2014; Al-Gahwari & Baabbad, 2015, Ali Attaala & Bazar, 2016 and Aideed *et al.,* 2018) focused on phytoplankton communities. Literature searching related to studies on benthic microalgae in Yemen was done in this paper and focused on published scientific journals databases like Science Direct, Scopus and Springer using these keywords: benthic microalgae, periphyton, epilithic phytoplankton, microphytobenthos, phycoperiphyton, benthic diatomsepipelic diatoms and epilithic diatoms. The results of searching indicated that this study area has remained largely unstudied and only two studies on benthic microalgae were done. The first study of benthic diatoms in Bandar Aden at Aden coastal zone was done by Bafana and Witkowski (1995), and the other study of phycoperiphyton for Embikhah Khor in Mukalla coastal zone was done by Al-Gahwari *et al.* (2022). Therefore, it is important to study Embikhah Khor especially from the marine perspective of Mukalla coastal zone to provide adequate information and appropriate knowledge about taxa classification and distribution, community structure as primary producers, species diversity and composition of benthic microalgae colonized on artificial substrates (glass slides).

MATERIALS AND METHODS

Study Area

Embikhah Khor as one of the most important khors and just the only unique area for the mangrove habitat in Hadhramout Coastal Zone, is located at latitude 14° 50' 69" N, and longitude 49° 07' 13" E on the northwest of Mukalla City at Hadhramout Governorate in Yemen (Figure 1). It is a shallow, narrow, saltwater creek or channel and cut off from the sea along the year except for few months. Rainfall and run-off are the main supplying sources of water in this channel in wet season (Figure 1). Samples of benthic microalgae were collected weekly during the period between January and March, 2019 from four sampling stations selected along 0.26 Km^2 khor area, which include the areas disturbed by human activities. Station 1 (S1) was located at the beginning of the khor and could be considered as the mouth of the channel passing the runoff water during wet season and one of the outlets discharging the surrounding area sewage. Station 2 (S2) was the area of solid wastes destruction dumping in one of the habitats of mangal community. Heavy silting and stoning causing mangrove trees ecosystem disturbance was the result of this dumping. Station 3 (S3) which is situated in the intensive available area of mangrove trees influences by small sewer discharge from nearby area. Station 4 (S4) was located at the end of the khor waterbody toward the seashore. It was selected as a control station because it was far away from most human activities wastes.

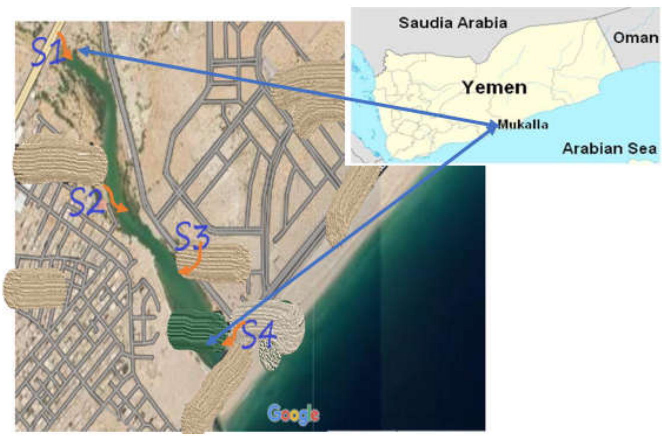

Figure 1. Location of sampling in Embikhah Khor ar Mukalla coastal zone in Yamen

Sampling of Benthic Microalgae

Glass slides as artificial substrates were placed in each station and left submerged in the khor. The slides were positioned just below the surface of shallow water where light was maximum to encourage benthic microalgal growth. These slides were removed from each station and lightly brushed and rinsed with distilled water into polyethylene bottle. Samples in polyethylene bottles were preserved with 7% formalin and transported to the Faculty of Environmental Sciences and Marine Biology labs to keep for further study. The benthic microalgal analysis was carried out on TV microscope, JVC Labscope type. The microalgae were identified using that microscope with other three Wagtech compound microscopes under 10, 40 and 100 X magnification. The benthic microalgae were identified as far as possible down to the species level with the help of taxonomic keys, drawings and descriptions based on Chapman and Chapman (1981), Shamsudin (1990), Yamagishi & Kanetsuna (1991), Tomas (1997) and Chihara & Murano (1997).

Species Diversity and Composition

The biological diversity and composition of the algal community was determined as below:

Alpha, Beta and Gamma Species Diversity Indices (Whittaker, 1960; Whittaker, 1972) Alpha diversity (α-diversity) is the total number of species in particular ecosystem or station. Beta diversity(β-diversity) is the total number of unique species in each station compared with another. It allows to compare diversity between two ecosystems (stations) using the following formula:

β-diversity = $(S_1–C_{1\&2})+ (S_2– C_{1\&2})$; $(S_2 – C_{2\&3}) + (S_3 – C_{2\&3})$; $(S_3 – C_{3\&4}) + (S_4 – C_{3\&4})$; $(S_1 – C_{1\&4}) + (S_4 – C_{1\&4})$; $(S_1 – C_{1\&3}) + (S_3 – C_{1\&3})$ and $(S_2 – C_{2\&4}) + (S_4 – C_{2\&4})$.

Where: S_1, S_2, S_3, and S_4 are the total number of species in station 1, station 2, station 3 and station 4 respectively, while $C_{1\&2}$, $C_{2\&3}$, $C_{3\&4}$, $C_{1\&4}$, $C_{1\&3}$ and $C_{2\&4}$ are the total number of common species that observed in each two stations.

Gamma diversity (γ-diversity) is a measure of the overall diversity for the different ecosystems (stations) within a region (Embikhah Khor). It describes the diversity of species that can be found in the whole area (Andermann *et al.,* 2022). Gamma diversity was calculated as below:

γ-diversity = $(S_1 + S_2+ S_3 + S_4) – (C_{1\&2} + C_{2\&3} + C_{3\&4} + C_{1\&4})$.

Turnover Rate (TR)

Turnover rate was calculated by the following formula:

TR= [(A + B)/ C] x 100 % (Zacharia *et al.,* 2011). Where: A is the total number of unique species in one station; B is the total number of unique species in another station and C is γ-diversity. The scores have been multiplied by 100 to give a percent scale.

Sørenson's Similarity Index (SSI)

According to Sørenson (1948), this index was computed to find out the percent of species similarity between stations using the following formula:

SSI= [2C/ (A + B)] x 100 %. Where: (a) and (b): are the number of species at stations A and B respectively, and (c): the number of species occurring at both stations A and B. The scores have been multiplied by 100 to give a percent scale.

Taxa Composition (DC)

The percentage composition of each taxon(division) was calculated using the following formula:

TC = (Total taxon species/Total microalgal species) x 100 % (Al-Gahwari *et al.,* 2022).

Statistical Analysis

SPSS and Excel statistical programs were used to analyze the obtained data.

Prior to biological variables analysis, ANOVA was used to detect statistically significant differences in the benthic microalgal components between stations. Tukey's test was performed at a significance level of $P< 0.05$ to detect differences between stations when results of analysis of variance (ANOVA) were significant. Similarity and dissimilarity analysis was run to compare the results at all stations. The correlation between α-diversity and β-diversity was determined.

RESULTS AND DISCUSSION

Benthic Microalgal Identification

The number of identified benthic microalgae that collected from the fixed artificial substrates in Embikhah Khor were 46 species. The identified species occurred at all sampling stations was summarized in Table 1.

Table 1. The occurrence of identified benthic microalgal species at four sampling stations during the study period (common = +++; Moderate = ++; Rare = +; Absent = -)

Species	Stations			
	1	2	3	4
Bacillariophyta(Diatoms)				
Amphora crassa	-	+	+	++
Amphora spectabilis	+++	+++	+++	+++
*Asterionella glacia*lis	-	+	-	-
Bacteriastrumdelicatulum	-	-	++	+++
Chaetoceros sp	-	+	++	+++
Coscinodiscus sp	-	-	++	++
Cymatopleura sp	+++	+++	+++	+++
Cymbella sp1	+	-	+	+
*Cymbella sp*2	+	-	-	+++
Fragilaria oceanica	+++	+++	+	+
Fragilaria sp1	+	+	+	+
Fragilaria sp2	+	+	+	+++
Guinardia striata	-	-	-	+
Melosira moniliformis	-	+	-	-
Navicula distans	+++	+++	+++	+++
Navicula gracilis	+++	+++	+++	+++
Navicula punctata	+++	+++	+++	+++
Navicula rectangulata	+++	+++	+++	+++
Nitzschia closterium	+++	+++	+++	+++
Nitzschia marina	+++	+++	+++	+++
Nitzschia sicula	+	+	+	++
Pleurosigma angulatum	+++	+++	+++	+++
Pleurosigmacapense	+++	+++	+++	+++
Pleurosigmadirectum	+++	+++	+++	+++
Pleurosigmaelongatum	+++	+++	+++	+++
Pleurosigmapelagicum	+++	+++	+++	+++
Rhizosolenia robusta	+	++	+++	+++
Surirella sp	+	-	+	-
Synedra rumpens	-	-	+	+
Synedra ulna	+	-	+	-
Thalassionemanitzschioides	+++	+++	+++	+++
Chlorophyta (Green algae)				
Ankistrodesmus falcatus	-	-	-	+
Desmidium sp	-	-	-	+
Stigeoclonium sp	-	-	+	+
Dinophyta (Dinoflagellates)				
Ceratium furca	-	-	++	+
Ceratium longipes	-	-	+	-
Peridinium cinctum	-	-	-	+
Peridinium gatunense	++	++	+	+
Peridinium orientale	++	+	-	-
Gonyaulax schilleri	-	+	+	-
Gonyaulax sp	+	+	-	-
Cyanophyta (Blue green algae)				
Anabaena sp	+	++	-	-
Oscillatoria sp1	++	+	-	-
Oscillatoria sp2	++	++	+	+++
Trichodesmium sp	++	++	+	+
Tolypothrix sp	-	-	-	+

Table 2. Taxonomic composition of benthic microalgae recorded in Embikhah Khor during the study period

Division	Family	Species	Morphological Type
Bacillariophyta	Naviculaceae	*Amphora crassa*	Pennales
		Amphora spectabilis	Pennales
	Fragilariaceae	*Asterionella glacia*lis	Pennales
	Chaetocerotaceae	*Bacteriastrumdelicatulum*	Centrales
		Chaetoceros sp	Centrales
	Coscinodiscaceae	*Coscinodiscus sp*	Centrales
	Surirellaceae	*Cymatopleura sp*	Pennales
	Naviculaceae	*Cymbella sp1*	Pennales
		*Cymbella sp*2	Pennales
	Fragilariaceae	*Fragilaria oceanica*	Pennales
		Fragilaria sp1	Pennales
		Fragilaria sp2	Pennales
	Rhizosoleniaceae	*Guinardia striata*	Centrales
	Melosiraceae	*Melosira moniliformis*	Centrales
	Naviculaceae	*Navicula distans*	Pennales
		Navicula gracilis	Pennales
		Navicula punctata	Pennales
		Navicula rectangulata	Pennales
	Nitzschiaceae	*Nitzschia closterium*	Pennales
		Nitzschia marina	Pennales
		Nitzschia sicula	Pennales
	Naviculaceae	*Pleurosigma angulatum*	Pennales
		Pleurosigmacapense	Pennales
		Pleurosigmadirectum	Pennales
		Pleurosigmaelongatum	Pennales
		Pleurosigmapelagicum	Pennales
	Rhizosoleniaceae	*Rhizosolenia robusta*	Centrales
	Surirellaceae	*Surirella sp*	Pennales
	Fragilariaceae	*Synedra rumpens*	Pennales
		Synedra ulna	Pennales
	Thalassionemataceae	*Thalassionemanitzschioides*	Pennales
Chlorophyta	Family	Species	Morphological Type
	Oocystacaeae	*Ankistrodesmus falcatus*	Single cell and Filamentous
	Desmidiaceae	*Desmidium sp*	Filamentous
	Chaetophoraceae	*Stigeoclonium sp*	Filamentous
Dinophyta	Family	Species	Morphological Type
	Ceratiaceae	*Ceratium furca*	Dinokont
		Ceratium longipes	Dinokont
	Peridiniaceae	*Peridinium cinctum*	Dinokont
		Peridinium gatunense	Dinokont
		Peridinium orientale	Dinokont
		Gonyaulax schilleri	Dinokont
		Gonyaulax sp	Dinokont
Cyanophyta	Family	Species	Morphological Type
	Nostocaceae	*Anabaena sp*	Filamentous
	Oscillatoriaceae	*Oscillatoria sp1*	Filamentous
		Oscillatoria sp2	Filamentous
	Microcoleaceae	*Trichodesmium sp*	Filamentous
	Scytonemataceae	*Tolypothrix sp*	Filamentous

The classifications of species were found under 27 genera and 18 families (Table 2). These classified species, genera and families were recorded under 4 divisions as following: Bacillariophyta, Dinophyta, Cyanophyta, and Chlorophyta. A total of 14 species under 6 genera observed in this study were the common and abundant at all stations. They were:

Amphora spectabilis, *Cymatopleura sp*, *Navicula distans*, *Navicula gracilis*, *Navicula punctata*, *Navicula rectangulata*, *Nitzschia closterium*, *Nitzschia marina*, *Pleurosigma angulatum*, *Pleurosigmacapense*, *Pleurosigmadirectum*, *Pleurosigmaelongatum*, *Pleurosigmapelagicum* and *Thalassionemanitzschioides*.

The qualitative data results of species community point out on the Bacillariophyta dominance followed by Dinophyta, Cyanophyta and Chlorophyta which is in accordance with Al-Gahwari *et al.* (2022) study for same khor. Other previous investigators such as Alindonosi *et al.* (2021) found in his study that Bacillariophyta (diatoms) are the most common and dominant benthic species in marine ecosystem.

Bacillariophyta (Diatoms)

The division of Bacillariophyta was the first major group classified in this study. This dominant group in the benthic microalgal assemblages represented 67 % of the total species encountered in this study (Figure 2).

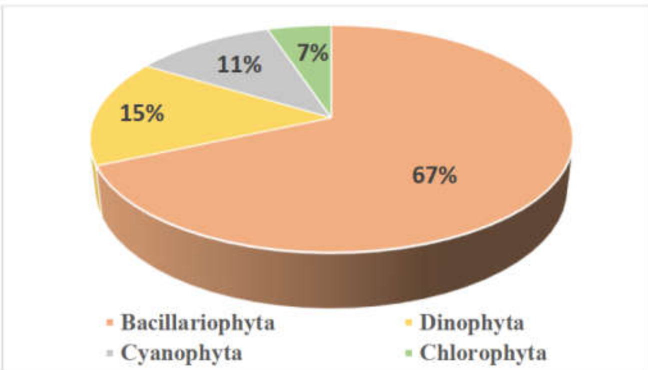

Figure 2. The benthic microalgal composition at all sampling stations during this study

This to indicate that microalgae in Embikhah Khor are characterized by higher species diversity and growth of diatoms. Similar results of pelagic diatoms were also documented by other previous studies of Hadhramout coastal zone such as Al-Gahwari and Baabbad (2015) and Ali Attaala and Bazar (2016). Diatom comprised 17 genera and 31 species (6 centric and 25 pennate) including 8 unidentified species (Table 1 and 2). In general, members of both classes may be found in either fresh or salt water, though centric forms tend to predominate in marine habitats, while pennate diatoms are more typical of freshwater environments. Centric forms are common in the plankton, and pennate forms are common in the benthos (Dodds and Whiles, 2019). Generally, filamentous, chain forming and colonial diatoms dominate benthic microalgae, while the smaller forms constituted of unicellular pennate and centric diatoms. The centric -to- pennate genera ratio approximately averaged 1:4, where by the majority of diatom species were pennales (25 species) and the rest (6 species) were centrales. Similar results of higher ratio of pennate to centric benthic diatom classes was widely observed in coastal areas (Balasubramaniam *et al.,* 2017; Dodds and Whiles, 2019; Sas *et al.,* 2022). Pennate diatoms can be found free-living in and on sediment (MacIntyre and Cullen, 1995). This to indicate that the frustules may be attached to form chains or filaments of many cells. This result agreed with what MacIntyre and Cullen (1995) and Sas *et al.* (2022) stated that the pennate diatoms are the most attached diatoms to the sediments. Benthic algae are known to migrate in response to light stimulus, as well as migration related to diel and tidal cycles (Thornton *et al.,* 2002). Thus, benthic microalgae composition usually contains significant numbers of phytoplankton as was found at some stations; there can be as many green algae and centric diatoms in the water column. This may be due to the movement of phytoplankton species from the surface water towards the khor bottom. Benthic microalgal dynamics were followed trying to distinguish changes in natural generation succession. The growth of microalgal cells and colonization on glass slides as artificial substrates started by pennate diatoms as the pioneering community of early ecological generation succession. The species succession of centric diatoms was clearly appeared after pennate species and earlier than the spatial occurrence of blue green algal, dinoflagellates and green algal species.

Table 2 is represented the diatomic genera and species were all classified under 9 families. Two families recorded the highest number of genera and species. These are Naviculaceae (4 genera and 13 species) and Fragilariaceae (3 genera and 6 species). The number of species (19 species) under these two families contributed as much as 61 % of the total diatomic species while the other families (7 families) constituted the remaining 39 %. Species composition of the genera showed that the highest number of species was identified for the genus *Pleurosigma* (5 species) followed by *Navicula* (4 species) and then *Fragilaria* as well as *Nitzchia* (3 species). These species are the dominant species throughout the period of study. The genera which recorded 2 species are *Amphora*, *Cymbella* and *Synedra*. The rest of the genera (10 genera) recorded only one species in each genus.

Dinophyta (Dinoflagellates)

This division was the second major group among all the benthic microalgae found during this study. Dinoflagellates were represented by 2 families, 3 genera and 7 species including 1 unidentified species(Table 2). The number of Dinophyta species represented 15 % of the total benthic microalgal species found in this study (Figure 2). The majority of the dinophytes was Peridiniaceae. The first genus containing 3 species was *Peridinium*. The genera *Ceratium* and *Gonyaulax* comprised 2 species per each. *Peridinium* contributed as much as 43 % of the totaldinoflagellate species while the other 2 genera constituted the rest 57 % dinoflagellates species. *Peridinium gatunense* was the dominated species at all study stations while the other species were fluctuated from station to another. Similar results have been reported by other researchers such asRouf (1997) and Wan Maznah (2001).

Cyanophyta (Blue green algae)

A total of 4 genera and 6 species (5 unidentified species) were classified under 4 families (Table 2). Cyanophyta is considered the third major group of benthic microalgae in this study. The cyanophytic species covered 11 % of the total benthic microalgae species composition (Figure 2). Anton and Suibol (1999) reported results of less than 10 % to 6 % of blue green algae composition in their total phytoplankton samples. The presence of this percentage of blue green algae tends to indicate organic pollution in the studied areas as documented by Anton and Suibol (1999). The families were classified during this study are Nostocaceae, Oscillatoriaceae, Micrycoleaceae and Scytonemataceae. Two species under Oscillatoriaceae covered 40 % of the total cyanophytic species composition while the other three species under Microcoleaceae, Nostocaceae and Scytonemataceae covered 60 %. Species under Oscillatoriaceae were *Oscillatoria sp1* and *Oscillatoria sp2* while species under Microcoleaceae was just *Trichodesmium sp. Anabaena sp* was only the species under Nostocaceae, and *Tolypothrix sp* was the only cyanophytic species identified under Scytonemataceae.

Chlorophyta (Green algae)

This group was classified to 3 families, 3 genera and 3 species including 2 unidentified species (Table 2). Species of this division represented 7 % of the total benthic microalgal species composition encountered in this study (Figure 1). Similar results have been reported by other researchers such asRouf (1997) and Wan Maznah (2001). Table 1 is shown the three species; *Ankistrodesmus falcatus, Desmidium sp, Stigeoclonium sp* that classified under the three families; Oocystacaeae, Desmidiaceae and Chaetophoraceae, respectively.

SpeciesComposition and Diversity

Spatial variation of microalgal composition were observed during the period of study. Among the four stations, lowest number of species of 30 and 31 were recorded at stations 1 & 2 which affected by wastewater discharge while the highest number (34 and 36) of species were recorded at stations 3 & 4 which were not directly affected by any wastes from human activities (Table 3).This fluctuation in the total numbers of benthic microalgal species reflect changes in α- species diversity of the taxa at all sampling stations (Table 4). However, the stations 4 and 3 which had higher numbers of microalgaerecoded higher α- diversity of the taxa while the stationsthat were near the sources of freshwater input had lower values of α- diversity. Yang *et al.* (2018) suggested in their study that the spatial factors play important roles in influencing the benthic algal distribution. Anton *et al.* (1998) reported that the periphytic algae such as *Desmids*, *Ankistrodesmus*, *Tolypothrix* were found in high nutrient habitats.Thebenthic microalgal composition was totally dominated by diatoms (Bacillariophyta) which constituted the value of 67% of the total benthic microalgal composition at all the sampling stations (Figure 2). The result (67%) of diatom composition suggests that water quality of Embikhah Khor is still to be good. Some previous studies have stated that benthic microalgae biomass and primary production can equal or exceed that of water column (Nelson, 1999; Cahoon and Cook, 1992). The rest of the divisions together amounted to 33% of the total benthic microalgae composition at all the sampling stations. Although the number of non-diatom species was limited, all the taxa encountered were important in the formation of microalgae community structure. However, the presence of a comparatively high percentage (15% and 11 %) of dinoflagellates and blue green algae tend to indicate that there is a slight an organic pollution (Figure 2).

The community structure ofbenthic microalgae consisted of 31 diatomic species, 7 dinoflagellate species, 5 blue green species and 3 green algal species (Table 3). Microalgal assemblages survive widely in benthic habitats (Janousek, 2009). Diatoms are considered as a vital component of benthic microalgae community in coastal zones being typically the dominant taxon diverse in terms of species numbers in such environments. Although bacillariophyte (diatoms) species representation was higher than other classified divisions species, but all together provide information concerning the general nature of the microalgal composition and the formation of benthic microalgal community structure. The benthic microalgae that were identified from artificial substratum during this study were similar to those identified from stony substratum by Al-Gahwari *et al.* (2022). The number of diatom species at stations 1, 2, 3 and 4 were 23, 23, 27 and 27. Diatom species composition at all stations were significantly different ($P< 0.05$) and categorized to two groups fluctuated in species number. This fluctuation showed the levels of dissimilarities between the stations in species diversity. From dinoflagellates results obtained, stations 2 and 3 recorded the same highest variation of its total species numbers (4) compared to the other two stations recorded the same smallest variation of its total species numbers (3).Gradually decreasing trend in cyanophytes species number observed from station 1 to station 4. The maximum species number (4) was recorded at stations 1 and 2 which were exposed to effluent from human activities followed by 3 species at station 4 and the minimum species number (2) was recorded in station 3. The species number sometimes simply shows the stressed habitats i.e., highly polluted waters have smaller species number complements than the bulk of water which are intermediate (eutrophic) (Patrick and Roberts, 1979). Chlorophytes species were recorded either in very low diversity and rare occurrence such as in station 4 or surprisingly totally absent as it was in stations 1 and 2.Species identified during this study were not all common species in coastal waters. It is significant to note that some freshwater benthic microalgal species were mainly recorded in this study. These species were *Batrachospermum sp*, *Ankistrodesmus falcatus*, *Desmidium sp*, *Stigeoclonium sp*, *Anabaena sp*, *Oscillatoria sp1* &*sp2*, *Trichodesmium erythraeum*, *Trichodesmium sp* and *Tolypothrix sp*. (Tomas, 1993).

The highest number of bacillariophytes genera and species were recorded under Naviculaceae family followed by Fragilariaceae family while for Dinophyta was under of Peridiniaceae family. Other families under all classified taxa were mostly recorded less numbers of genera and species (Table 2).Although there is a slightly significant difference ($P< 0.05$) in genera numbers between stations but the most predominant genera at these four stations were *Pleurosigma*, *Navicula*, *Nitzschia* and *Fragilaria*. Among the dinoflagellates, the common genera were *Peridinium* and *Gonyaulax*. Blue green algae species numbers at stations (1&2) which were near the source of fresh water was found to be expectedly higher than that near the coastal area stations (3&4). Commonly, the predominant genera at these four stations were *Trichodesmium*, *Oscillatoria* and *Anabaena*. In terms of green microalgae species present, it was apparent that two species, *Ankistrodesmus falcatus* and *Desmidium sp*were absent at stations 1, 2 and 3 and *Stigeoclonium sp* was found at stations 3 and 4. Surprisingly, the microalgal species of green algae were not expected to classify at station 4. Faria *et al.* (2021) found that microalgae natural community was dominated by green algae in one of the shallow lakes of southern Brazil.

Table 3.The benthic microalgal species numbers at all sampling stations during this study

Division	Species Nos.	Stations			
		1	2	3	4
Bacillariophyta	31	23	23	27	27
Dinophyta	7	3	4	4	3
Cyanophyta	5	4	4	2	3
Chlorophyta	3	0	0	1	3
Species Total Nos.	46	30	31	34	36

Of the 4 stations identified, station 1 followed by station 2 recorded the lowest levels of α-diversity (30 and 31 respectively), while the level (36) at station 4 was slightly higher than the level (34) at station 3 (Table 3). A trend of decreasing species number and so α- species diversity occurred at stations 1 and 2 that were far from seaside, while higher richness in species and α- species diversity was found at stations 3 and 4 that did not receive effluent from human activities (Table 4). This trend appears to be inconsistent with the amount of organic matter and so nutrients in each station. This is interesting since such inputs are often reduced diversity of benthic microalgae. Stewart (1995) reported that a typical response to anthropogenic stress was a decrease in the number of species and diversity. An ANOVA run followed by Tukey's test indicated that the level of α-diversity at station 4 (control station) was significantly higher ($P< 0.05$) than the levels at the other three stations. Indeed, this significant result may be due to the difference between stations in availability, distribution and alpha diversity levels of blue green algae, dinoflagellates and green algal species.

The results are not surprising at all if one realizes the influence of various human activities wastes particularly at stations 1 and 2. On the other hand, station 4 which was located quite a distance from the waste discharge sources would not have much anthropogenic input to its waters. Saeck *et al.* (2019) stated that microalgae are key indicators of habitat condition and biodiversity. Changes in diversity of benthic microalgae have been used to indicate physico-chemical conditions of surface water (Stevenson, 1984; Cazaubon *et al.,* 1995).

Table 4. Species diversity at four sampling stations during the study period

Diversity Index	Stations			
	1	2	3	4
Alpha (α) Diversity	α = 30	α = 31	α = 34	α = 36
Beta (β) Diversity	$\beta_{1\&2}$ = 9 $\beta_{4\&1}$ = 18	$\beta_{2\&3}$ = 16 $\beta_{1\&3}$ = 15	$\beta_{3\&4}$ = 10 $\beta_{2\&4}$ = 19	
Gamma (γ) Diversity	γ = 26			
Turnover Rate (TR)	$TR_{1\&2}$ = 36.6% $TR_{2\&3}$ = 61.5% $TR_{3\&4}$ = 38.5% $TR_{4\&1}$ = 69.2% $TR_{1\&3}$ = 57.7% $TR_{2\&4}$ = 73.1%			
Sorenson's Similarity Index (SSI)	$SSI_{1\&2}$ = 85.2% $SSI_{2\&3}$ = 76.9% $SSI_{3\&4}$ = 85.7% $SSI_{4\&1}$ = 72.7% $SSI_{1\&3}$ = 78.1% $SSI_{2\&4}$ = 71.6%			

The tabulated number of beta species diversity recorded between stations varied form 9-19 unique species (Table 4&5). All the results of beta diversity in this investigation were unexpectedly low in comparison to the results found by Nogueira *et al.* (2010). Greater relative variation range (36.6 – 73.1%) of turnover rate was observed between stations. The minimum rate was measured between stations 1 and 2 which were closely near from each other while the maximum rate was found between stations 2 and 4 which were relatively far from each other (Table 4&5). Beta diversity values and turnover ratios were very high for stations1 and 4 as well as stations 2 and 4 (Table 4&5) indicating the uniqueness of many species occurring in the area. However, there was only a small difference between stations 1 and 2 as well as stations 3 and 4 indicating uniqueness lessness for stations closeness. The results showed that the beta diversity values as well as turnover ratios were significantly different ($P < 0.05$) among the sampling stations. Strong positive correlation ($r^2 = 0.8393$) between α- species diversity and β- diversity was observed (Figure 3). Same observations have been made by several authors such as Nabout *et al.* (2007). Similarly, β- diversity was strongly and positively correlated with turnover ratio.

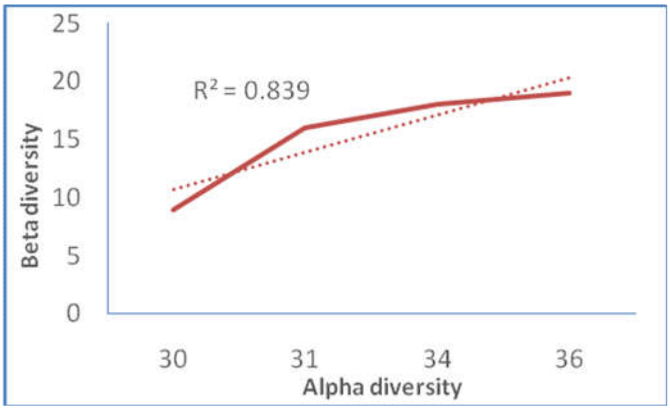

Figure 3. Correlation between alpha and beta diversity of benthic microalgal taxa of study area

Gamma diversity (γ-diversity) as defined by Hunter (2002) is a geographical-scale species diversity. Gamma diversity of Embikhah Khor was 26 taxa (Table 4). Gamma diversity found in this study was very low (26 taxa) comparing with γ-diversity (97 taxa) which found by Cardoso *et al.* (2012). γ-diversity is affected by alpha and beta diversity(Whittaker, 1972). Analysis of the station similarity of benthic microalgal community composition separated several clusters of stations at the different similarity level (Table 4&5). At lower levels of similarity (71-73%) several clusters of stations are evident, whereas at slightly higher levels of similarity (76-79%) several clusters break into individual stations. Some stations continue to be linked at higher levels of similarity (80-86%). It was observed from the results that higher similarities found between stations depend on interrelation between the stations locations. The highest similarity with Sorensen's Coefficients of 0.857 and 0.852 were found between stations 3 and 4 and stations 1 and 2 which were much closed to each other. The lowest similarity indices of 71.6% and 72.7% were observed between station 2 and 4 and stations 1 and 4 respectively which were located far away from each other.

Table 5. Benthic microalgal beta diversity, turnover rate and species similarity percentage between stations

Species diversity	Station	2	3	4
Beta Diversity	1	9	15	18
	2	-	16	19
	3	16	-	10
	4	19	10	-
Turnover Rate	1	36.6	57.7	69.2
	2	-	61.5	73.1
	3	61.5	-	38.5
	4	73.1	38.5	-
Sørenson's Similarity Index	1	85.2	78.1	72.7
	2	-	76.9	71.6
	3	76.9	-	85.7
	4	71.6	85.7	-

In this study, alpha diversity index has been applied as a tool of the potential harmful benthic microalgae. Table 6 is shown the harmful microalgal species summarized during this study. Harmful species made up slightly large proportion of the alpha diversity index contributing to 43.48 %. substances or organic pollution. Attached organisms have been utilized for the detection of pollution because the results obtained from microalgal analysis are more reliable than plankton analysis (Kelly *et al.,* 1995).

Table 6. Harmful species and their alpha species diversity at four sampling stations during this study. (Present = P; Absent = A)

Taxon	Stations			
	1	2	3	4
Chaetoceros sp	A	P	P	P
Navicula distans	P	P	P	P
Navicula gracilis	P	P	P	P
Navicula punctata	P	P	P	P
Navicula rectangulata	P	P	P	P
Nitzschia closterium	P	P	P	P
Nitzschia marina	P	P	P	P
Nitzschia sicula	P	P	P	P
Diatom α- diversity	7	8	8	8
Ceratium furca	A	A	P	P
Ceratium longipes	A	A	P	A
Peridinium cinctum	A	A	A	P
Peridinium gatunense	P	P	P	P
Peridinium orientale	P	P	A	A
Gonyaulax schilleri	A	P	P	A
Gonyaulax sp	P	P	A	A
Dinoflagellate α- diversity	3	4	4	3
Anabaena sp	P	P	A	A
Oscillatoria sp1	P	P	A	A
Oscillatoria sp2	P	P	P	P
Trichodesmium sp	P	P	P	P
Tolypothrix sp	A	A	A	P
Blue green algae α- diversity	4	4	2	3
Total α- diversity	14	16	14	14

Amongst twenty harmful microalgae, 7 Naviculaceae and Nitzschiaceae species recorded the highestα- species diversity. The most numerous benthic diatoms at sampling stations were: *Navicula distans*, *Navicula gracilis*, *Navicula punctata, Navicula rectangulata*, *Nitzschia closterium,Nitzschia marina* and *Nitzschia sicula*. Although Peridiniaceaerecorded the highest α- species diversity off all harmful dinoflagellate, but species of this family did not find at all stations except *Peridinium gatunense*. Amongst all Cyanophyta, *Oscillatoria* with 2 species recorded the highest α- species diversity, and only *Oscillatoria sp2* was the dominant species at all stations. Stations 4 (control station) recorded less numbers of toxic Cyanophyta and Dinophyta species. However, toxic species such as*Peridiniumorientale*, *Gonyaulaxsp*,*Anabaena sp* and *Oscillatoria sp1* were absent at this station (Table 6). This to indicate that control station was not affected by toxic substances or organic pollution.

CONCLUSION

The present study was the first observation of benthic microalgae on artificial substrate in Embikhah Khor which is considered the unique area of mangrove habitats in Mukalla coastal zone. The results are just considered as preliminary information on occurrence and distribution of benthic microalgae as well as community composition and species diversity in study area during the period of study. Based on the results, it can be concluded that benthic microalgae of Embikhah Khor comprises mainly of diatoms followed by dinoflagellates then blue green and green microalgae. The primary productivity is contributed by the dominant benthic microalgal growth on the glass slide substrate. Diatoms were the dominant benthic microalgae in waters of Mukalla coast, indicating the relatively pristine nature of the water. The contribution of the dominant diatoms to the total number of species was the maximum during the period of study. Despite non-diatom species numbers were low, but they provided information concerning the general nature of the microalgal diversity and part of community composition. Alpha, beta and gamma diversity indices were used in this study as good fundamental descriptive variables of ecology and conservation biology have to be carried out once again in other several coastal areas along Yemen coast. The presence of dinoflagellates, blue green and green microalgae indicated the occurrence of organic pollution resulting from land discharge and run off. The harmful benthic microalgae presence indicates the need of a regular monitoring system. Although, the results expand our current knowledge on the community composition and species diversity of benthic microalgae in coastal area but it is impossible to suggest a suitable time of harmful microalgal blooming, due to the lack of a regular seasonal rhythm. Since there are no much monitoring studies had been done on coastal areas and it has no received increased attention from the scientific researchers and authority, the authors recommend full attention and an extensive monitoring should be carried out to collect historical data information regarding the seasonal and annual changes in benthic microalgae assemblages, nutrients and other water quality parameters, and the interacting variables that influence the coastal areas benthic microalgal community compositions.

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