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Ecological status assessment of eastern coastal waters of Qeshm Island (Persian Gulf, Iran) based on macroalgal assemblages.

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ABSTRACT

Aims: Monitoring variations in macroalgal assemblages is a crucial issue for the preservation and management program of coastal waters. This study was conducted to determine the seasonal and spatial distribution patterns, and composition of macroalgal communities along the eastern coasts of Qeshm Island, Iran.

Materials & methods: Seasonal sampling was conducted at three different sites of different tidal levels on the eastern coasts of Qeshm Island. Random samples of macroalgae were collected at three stations, seasonally. The species were identified and the dry weight of each species was used to calculate the macroalgae abundance. The Species richness and the Diversity indices were calculated to evaluate the distribution pattern and composition of the macroalgal community.

Findings: As a result, 51 species (4 Chlorophyta, 21 Phaeophyta, and 26 Rhodophyta) were identified. The seasonal and spatial dominant species were found to be *Padina* sp. and *Hypnea* sp., and a distribution pattern was seen to have increasing macroalgal biomass from the upper to lower intertidal level. The sampling sites shared more than 50% similarity of their macroalgal species, indicating a relatively homogeneous distribution. The highest (18.1±4.3 gr. drywt .m^{-2}) and lowest (8.27±2.1 gr. drywt .m^{-2}) mean of total seaweed biomass were recorded in winter and summer, respectively.

Conclusion: The assemblage composition of macroalgae significantly differs between hot and cold seasons, and there was no substantial compositional variation of seaweed communities along the tidal gradient. The macroalgal distribution was largely homogeneous with no significant difference among the research areas at sampling seasons.

Keywords: Biodiversity, Qeshm Island, Seaweeds, Tidal zone.

CITATION LINKS

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Introduction

Intertidal zones are the buffering regions of the sea that interact with the neighboring lands for the exchange of material and energy. In particular, these areas are inhabited by a large number of sea animals and marine microorganisms, many of which are not found in the other parts of the sea. Qeshm Island, the largest island with several rocky shores, is located in the northwestern part of Hormuz Strait in the Persian Gulf. This coastal zone of the Hormozgan Province is characterized by consolidated sediments favoring the development of rich algal flora (1). Coastal ecosystems involve the structure of the food network and material and energy cycles which are important factors to be considered. Macroalgae assemblages play an important role in the maintenance of the food chain and nutrient reserves for monitoring and management of marine ecosystems. In many coastal environments, macroalgae are widespread and recognized as important marine natural resources, providing the best habitats, shelter, and food sources for other marine organisms (2). Major macroalgae are classified into three groups; Chlorophyta, Rhodophyta, and Phaeophyta. However, their distribution varies from the lower intertidal to the shallow sub-tidal zone. Several factors such as rainfall, salinity, nutrients, and light intensity, can affect the abundance and distribution of these seaweeds. Consequently, fluctuation of structure and composition of macroalgal assemblages in time and space manners is anticipated in response to the varying conditions in the Persian Gulf (3-5). Therefore, changes in distribution, abundance, diversity, and species composition of assemblages in their communities need to be investigated for long-term success in the conservation and management of biodiversity in coastal waters (6, 7). Although the available knowledge can provide a baseline for complex ecological studies, the distribution, abundance, and diversity of the seaweed need to be updated for precise management of the macroalgal community in the intertidal zones. The dynamics of macroalgae assemblages in Persian Gulf coastal lines have been studied with variation in biomass and diversity of seaweed, whereas the species composition in different seasons and changes in their abundance, and diversity were neglected so far. The goal of this study was to determine seasonal variations of seaweed biomass and species diversity at three different sites along with the coastal areas of Qeshm Island, which is one of the most diverse and important habitats of aquatic communities with three objectives; (1) to update the few checklists provided by previous researchers in this area, (2) to identify the dominant species according to tidal gradient zonation and (3) to determine temporal changes in abundance and diversity of macroalgal assemblages.

Materials & Methods

The field study was conducted at three sites in Hormozgan Province, located on the eastern coastline of the Qeshm island in the Persian Gulf, including Iran Zamin (Station 1), Zeitun Park (Station 2), and Sinema Darya (Station 3)(Figure 1).

Sample collection

Three line transects were placed perpendicularly to the waterline randomly at each study site for three tidal levels that ran from high to low elevation (high tide, mid tides, and low tide). In June 2018 and February 2019, we determined total biomass, species diversity, and richness for 27 quadrates (50×50 cm) randomly placed along 3 transects (3 quadrates within each tidal level). All samples within each quadrate were bagged and labeled by location and transported to the laboratory immediately. A physicochemical water quality assessment was carried out on the temperature, turbidity, salinity, and pH of water (using

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Table 1) Results of physicochemical parameters (Mean±SD) during different seasons and stations of Qeshm Island, Iran.

stations		season	Temp (°C)	Turbidity (FTU)	PH	Sal (ppt)
1	Iran Zamin	Summer	32.2 ± 0.17	6.5 ± 0.10	8.1± 0.5	43.8 ± 1.1
		Winter	25. 6 ± 0.5	6.1 ± 0.17	7.4 ± 0.5	42.1 ± 0.1
2	Zeitun Park	Summer	33.1 ± 0.13	11.03 ± 0.05	8.3 ± 0.5	43.5 ± 0.4
		Winter	25 ± 0.0	6.1 ± 0.20	7.8 ± 0.5	42.1 ± 0.1
3	Sinema Darya	Summer	32.1 ± 0.17	7.06 ± 0.05	8.2± 0.4	43.4 ± 0.5
		Winter	25.1 ± 0.4	6.03 ± 0.05	7.3 ± 0.5	42 ± 0.6

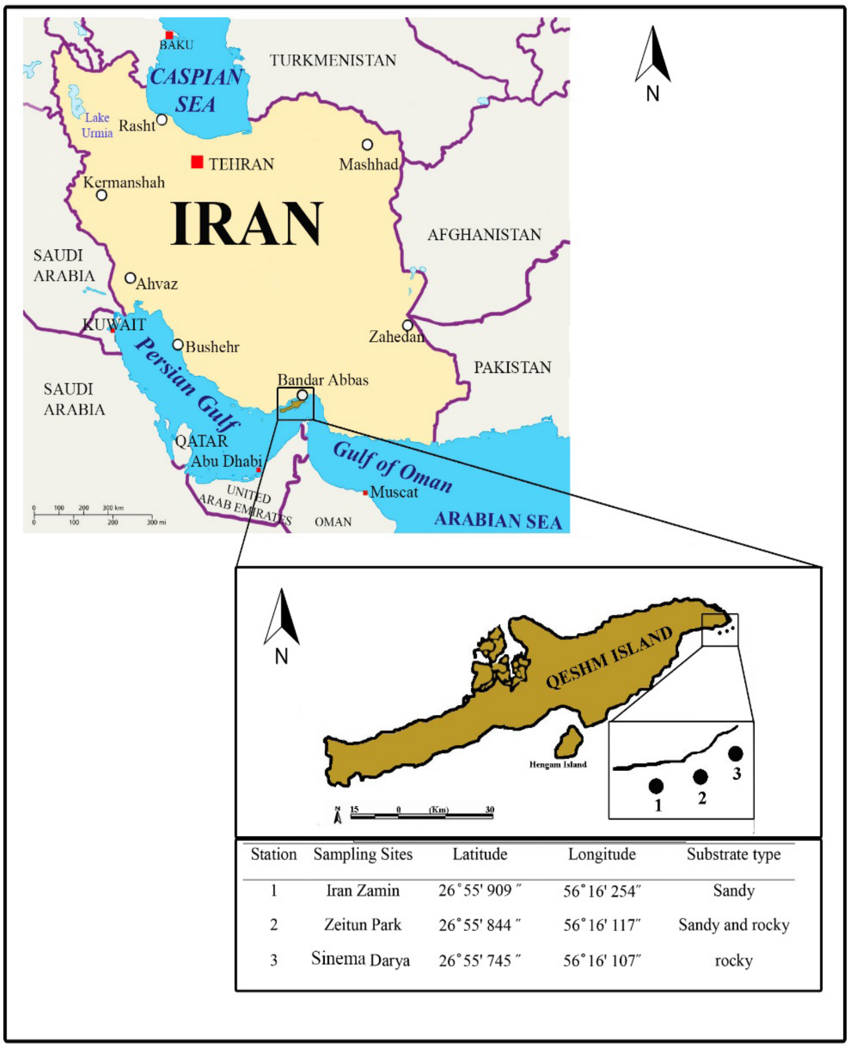

Figure 1) Map and Geographical Location of the Qeshm Island and sampling stations, the south of Iran. 1) Iran zamin (2) Zeitun Park, and 3) Sinema Darya stations.

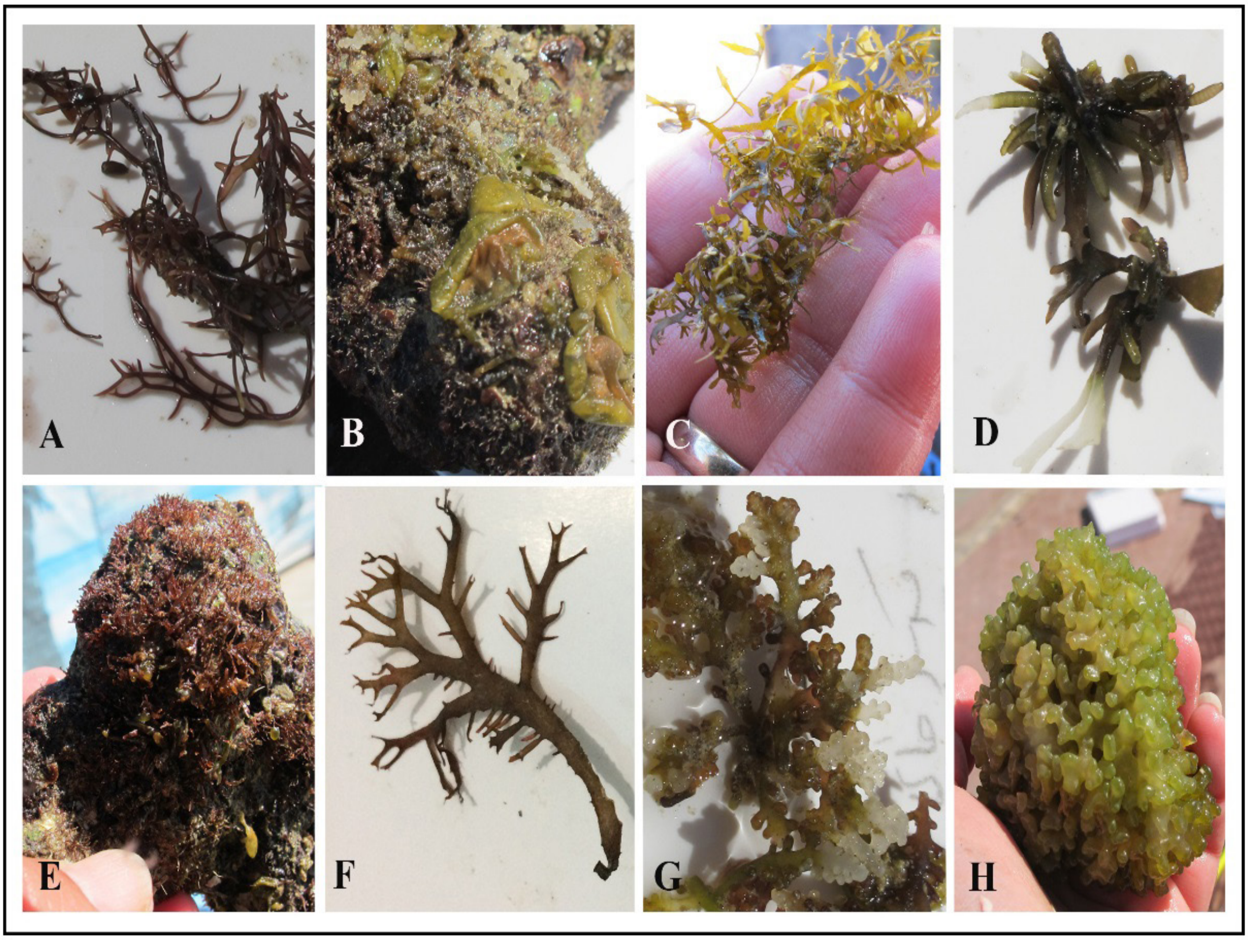

Figure 2) Some sampling macroalgae from the tidal zone of the eastern coasts of Qeshm Island, Iran. A: *Scinaia moniliformisa, B: Colpomenia sinuosa, C: Grateloupia somalensis, D: Champia kotschyana, E: Ahnfeltiopsis pygmaea, F: Gracilaria corticata, G: Laurencia papilosa*, H: *Lyengaria stellata*.

TDS-ECP150), during the sampling period. The species were observed and isolated under both a light microscope and a stereomicroscope, identified using standard identification keys (4, 8, 9), and the taxonomy was updated according to the online database Algae Base (www.algaebase.org). After identification, they were dried at 60 °C for ٢٤ hours and then weighed on a digital scale with the nearest 0.01 g.

Data analysis

To evaluate the distribution pattern and composition of macroalgal species in the intertidal regions, the Shannon diversity (H') was calculated for each season using Eq. (1) (10).

$$H' = \sum_{i=1}^{n} p_i \ln p_i \qquad \text{Eq. (1)}$$

where ∑is summation; Pi is the proportion of individuals found in the ith species; ln is the natural log.

Margalef's Species Richness Index (d) also was calculated for each station according to Eq. (2) (10).

$$d = \frac{S-1}{\ln N} \qquad \text{Eq. (2)}$$

where d is Margalef's richness index, S is the number of species; ln is the natural log, and N is the number of individuals in the sample.

All the quantitative findings are described as means ± standard deviations of collected data. All mentioned indices were calculated by using PAST software 3.12 (Paleontological

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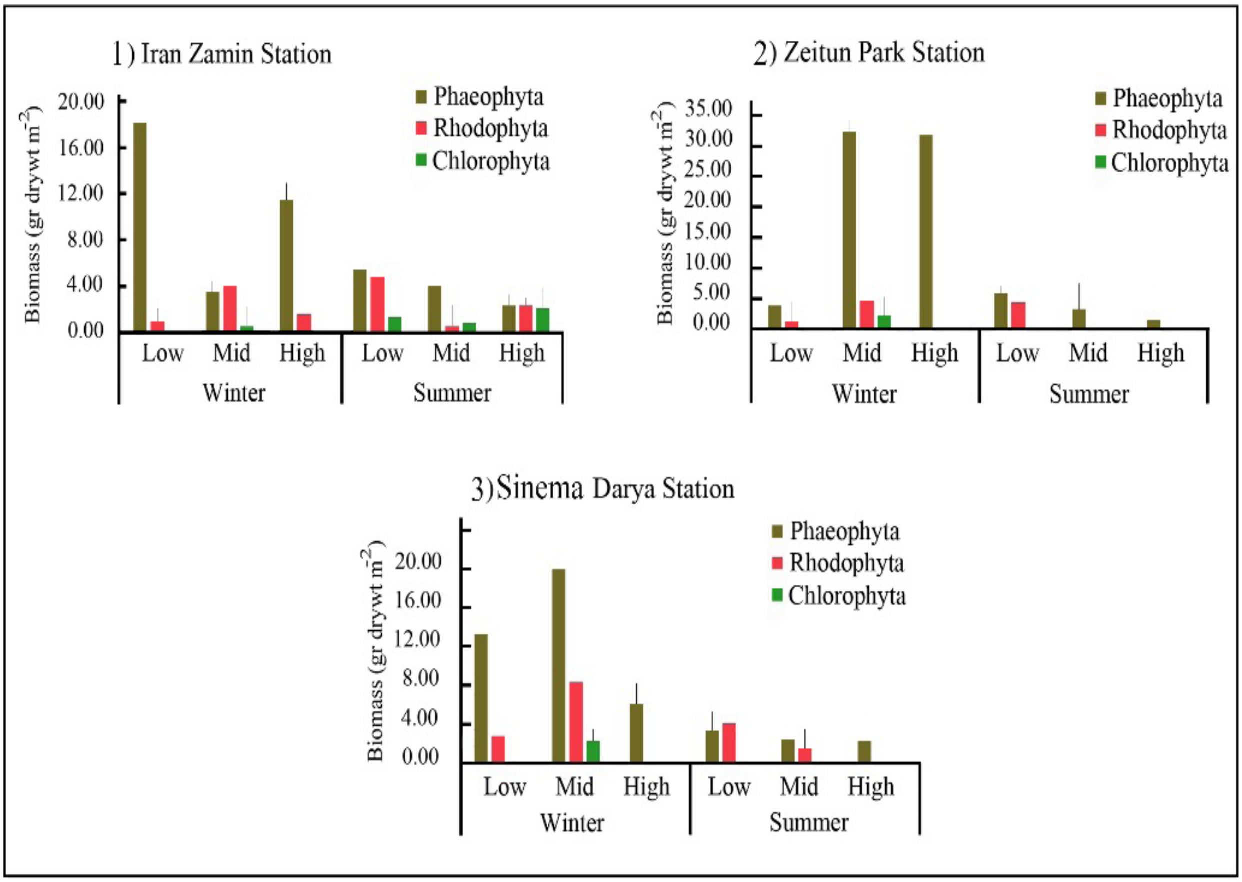

Figure 3) Seasonal and temporal scale variation in the mean biomass of macroalgae during the sampling in 1) Iran Zamin, 2) Zeitun park, and 3) Sinema Darya stations, eastern coasts of Qeshm Island, Iran. Low: Low intertidal zone, Mid: Mid intertidal zone, High: High intertidal zone.

Statistics). ANOVA tests were employed to compare the abundance and diversity of macroalgae communities between seasons ($P<0.05$) and study sites, pairwise comparisons were conducted with the HSD Tukey post hoc test using SPSS 22.

Cluster analyses based on the Bray-Curtis similarity matrix were used to visualize spatial and temporal patterns in assemblages' macroalgae structure based on macroalgae biomass in two seasons.

Findings

During the sampling, the temperature varied between 25.1±0.4 and 32.2 ± 0.17°C and salinity ranged from 42.0±0.06 to 43.8±1.1 ppt. during the winter and summer, respectively (Table 1).

A total of 51 macroalgae taxa (4 Chlorophyta, 21 Phaeophyta, and 26 Rhodophyta) belonging to 14 families were identified across the three intertidal levels at the three study sites in two seasons (Figure 2, and Table 2).

It was found that the most common group was the Dictyotaceae (Phaeophyta) with seven species in the area, followed by Rhodomelaceae and Cystocloniaceae with five and three species (Rhodophyta), respectively. Among the Chlorophyta, Ulvophyceae was the most abundant family in the area. The total biomass of macroalgae communities is shown in Figure 3.

In general, in all study stations, the highest mean biomass of macroalgae was observed among Phaeophyta (brown algae) in winter (Figure 3 a, b, and c) and, the greatest value of mean biomass among Phaeophyta, was found in the mid and high intertidal zones during the winter (Figure 4).

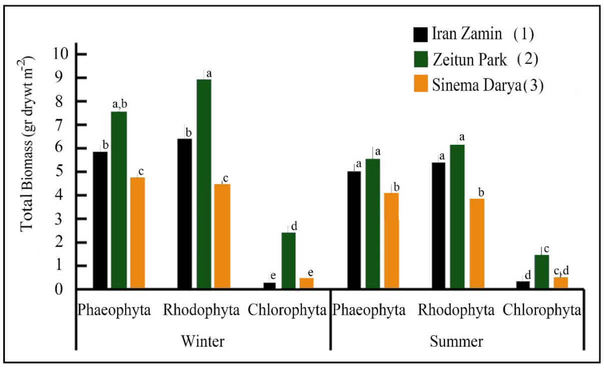

Figure 4) Total biomass (g.dry wt.m^{-2}) of macroalgae at different sampling sites of Qeshm Island, Iran.

Interestingly, although the mean biomass of macroalgae in groups of Phaeophyta and Rhodophyta at stations 1 and 2 was higher than at station 3 (Figure 4), in both seasons, the species richness (Figure 5) and diversity index (Figure 6) at station 3 were equal or higher than other stations.

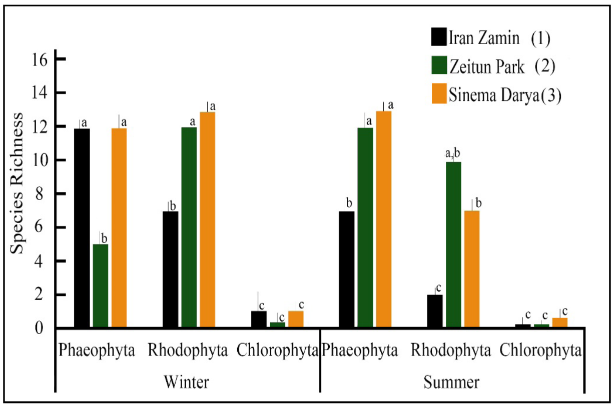

Figure 5) Macroalgae Species Richness (according to Margalef's Species Richness Index) at each station by seasons at the eastern coasts of Qeshm Island, Iran.

the highest amount of Chlorophyta biomass was recorded for station 2 in both seasons (Figure 4), which was significantly higher than the biomass of this group of algae in stations 1 and 3 ($P<0.05$). The diversity index value of Chlorophyta also in station 2 was equal to the other two stations (Figure 6), and even in winter, it was more than station 1 significantly ($P<0.05$); However, the lowest species richness index in this group of algae (Chlorophyta) was recorded in station 2, compared to the other two stations (Figure 5).

Phaeophyta (Brown Algae)

Some species such as *Tinocladia crassa*, *Dictyota cervicornis, Padina distormatic,* and *Colpomenia sinuosa* were observed only at "Iran Zamin" (Station 1) in both winter and summer, while *Dictyota indica, Padina boergesenii, Lyengaria stellata* and *Turbinaria ornate* were observed only in Zeitun Park (Station 2) in both seasons. Interestingly, *Padina dubia*, *Padina gymnospora, Padina pavonica, Padina tetrastomatica*, *Stoechospermum marginatum,* and *Rosenvingea intricate* were identified in all stations of the intertidal zone in both seasons (Table 2). The low intertidal zone showed the higher biomass of Phaeophyta, and the high intertidal zones revealed the lower value of brown macroalgae biomass In summer (Figure4). The highest value of total biomass (g. dry wt. m^{-2}) of Phaeophyta was recorded at station 2 (7.62±0.4) in summer, and the lowest value was recorded at station 3 (4.31±0.46) in the winter. In general, the total biomass of Phaeophyta was higher in winter than in summer.

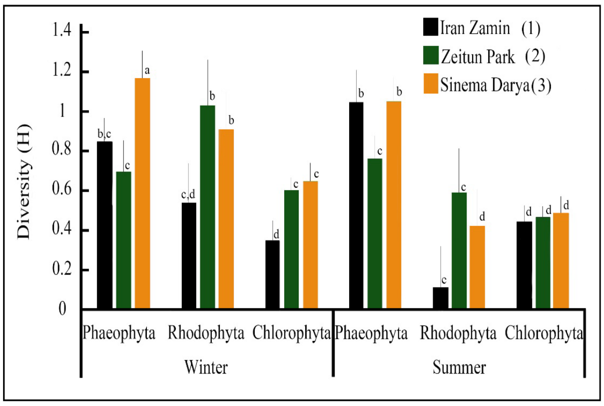

Figure 6) Diversity Index (H') of macroalgae at each station by seasons on the eastern coasts of Qeshm Island, Iran.

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Table 2) Seasonal distribution of macroalgae at the studied area of the eastern coasts of Qeshm Island, Iran; 1) Iran Zamin,(2) Zeitun Park and 3) Sinema Darya stations.

Macroalgae species	Season/Stations					
	Winter			Summer		
Rhodophyta	1	2	3	1	2	3
Acanthophora spicifera			+	+		
Chondria curnata		+			+	
Laurencia glandulifera	+	+			+	
Laurencia paniculata		+	+		+	
Laurencia papilosa	+	+	+	+	+	+
Laurencia snyderiae		+				
Laurencia undulate		+			+	+
Leveillea jungermannioides		+			+	
Jania adhaerens	+			+		
Grateloupia somalensis	+	+	+	+	+	+
Gelidiella acerosa	+					+
Solieria robusta		+		+		
Chondrus ocellatus		+			+	
Hypnea boergesenii	+	+	+	+	+	+
Hypnea cervicornis	+	+	+	+	+	+
Hypnea ecklonii	+	+	+	+	+	+
Hypnea pannosa	+	+	+	+	+	+
Ahnfeltiopsis pygmaea						+
Gracilaria arcuata	+			+		+
Gracilaria corticata			+	+		
Gracilaria gracilis		+	+	+		
Scinaia moniliformisa		+		+		
Helminthocladia australis			+			+
Champia compressa		+			+	+
Champia kotschyanab		+				
Champia zonata		+	+		+	+
Phaeophyta						
Tinocladia crassa	+			+		
Dictyota dichotoma					+	
Dictyota cervicornis	+					
Dictyota friabilis					+	
Dictyota indica		+			+	
Padina boergesenii					+	
Padina distormatic	+			+		
Padina dubia	+	+	+	+	+	+
Padina glabra					+	
Padina gymnospora	+	+	+	+	+	+
Padina pavonica	+	+	+	+	+	+
Padina tetrastomatica	+	+	+	+	+	+
Stoechospermum marginatum	+	+	+	+	+	+
Cystoesira myrica		+	+		+	
Sargassum ngustifolium	+				+	+
Sargassum assimile			+			+
Sargassum glaucescens	+			+		+
Turbinaria ornate		+			+	
Colpomenia sinuosa	+			+		
Lyengaria stellate		+			+	
Rosenvingea intricate		+	+	+	+	+
Chlorophyta						
Chladophora rugulosa	+					
Chladophoropsis membranacea		+	+	+		+
Rhizoclonium riparium		+				
Valoniopsis pachynema	+			+		+

In winter, the highest diversity index of Phaeophyta was calculated for station 3, followed by stations 1 and 2, respectively; but in summer, there was no significant difference between stations 1 and 3 ($P<0.05$) in terms of diversity index (Figure 6).

Rhodophyta (Red Algae)

Among 26 identified species of Rhodophyta, only six species *Laurencia papilosac, Grateloupia somalensis, Hypnea boergesenii, Hypnea cervicornis, Hypnea ecklonii,* and *Hypnea pannosa* were found in all three stations at both seasons (Table 2). Some species such as *Chondria curnata, Leveillea jungermannioides,* and *Chondrus ocellatus were* only observed at station 2, in both seasons. *Laurencia snyderiae* was recorded only in winter at station 2, while *Ahnfeltiopsis pygmaea* was found only in summer at station 3.

The highest total biomass (g. dry wt. m^{-2}) of Rhodophyta was recorded at station 2 (8.54±1.04) and followed by station 1 (6.18±1.13) and station 3 (4.42±0.91), in winter; But in summer, station 2 and 1 showed the higher amount of biomass of Rhodophyta (6.18±1.2 and 5.56±1.18, respectively) and no significant difference was found between these two stations (p<0.05) (Figure 4). Station 3 was the richest station of Rhodophyta according to the greatest number of identified species in both seasons; while, station 1 showed the minimum richness of Rhodophyta during both summer and winter (Figure 5). Compared to summer, every station has shown greater richness and diversity of red algae in winter (Figures 5 and 6).

Chlorophyta (Green Algae)

Among the four species of green macroalgae identified in the studied area, *Chladophora rugulosa* was only observed in Station 1, and *Rhizoclonium riparium* was only recorded in Station 2, both in winter (Table 2). In general, the highest mean total biomass of Chlorophyta (3.18±2.40 g. dry wt. m^{-2}) was observed in station 1 at a high intertidal zone during summer (Figure 3a). The highest richness of Chlorophyta assemblage was recorded in winter at both station 1 and station 3 (Figure 5), and there was no significant difference between the two stations (P<0.05). In winter, the value of the diversity index (H') of Chlorophyta was higher than in summer, particularly at stations 2 and 3 (Figure 6); however, Chlorophyta showed less diversity in comparison to Phaeophyta and Rhodophyta in both summer and winter (Figure 6). Overall, Chlorophyta total biomass and species richness were significantly (P<0.05) lower than Phaeophyta and Rhodophyta in both seasons, as well as its diversity indices. According to Cluster analysis based on data matrix in winter and summer, the frequency distribution of Rhodophyta and Phaeophyta assemblages at all sampling stations in winter showed up to 60% similarity, while it showed less than 50% similarity for the two mentioned assemblages in summer (Figure 7).

In both seasons, the abundance distribution of Chlorophyta (green algae) showed no similarity to either red (Rhodophyta) or brown (Phaeophyta) macroalgae. The cluster analysis also indicated that green algae were not strongly clustered by season in winter compared to summer; they formed two groups based on similarities in their assemblage structure (Figure 7).

A non-metric multidimensional scaling plot based on Bray-Curtis similarities showed relative differences in macroalgal assemblage's biomasses in winter and confirmed the results of cluster analysis (Figure 8).

Discussion

The present results revealed higher biomass of Phaeophyta and Rhodophyta in winter (Figure 3). This is to be expected due to the location of the study area in the tropics and extreme heat in summer and vice versa, the desired temperature balance in winter(11). In line with the present study, other studies on macroalgae assemblages on the southern coasts of Qeshm Island (1, 12) confirmed that there are relatively diverse and rich macroalgal communities on the eastern coast of Qeshm, however, they demonstrated greater diversity of seaweeds than the present study. A list of macroalgae identified species has been reported by Sohrabipour and Rabiee (1999) in Hormozgan province including 75 species of Rhodophyta, 36 species of Chlorophyta, and 33 species of Phaeophyta macroalgae(12). Further, Sohrabipour et al. (2004) contributed a checklist of macroalgae in Bandar Lengeh in which 59 species of red, 29 species of green, and 31 species of brown macroalgae were presented (13). Considering the number of species observed in the present study (4 species of Chlorophyta, 21 species of Phaeophyta, and 26 species of Rhodophyta) (Table 2), and in comparison with the results provided by other researchers in the area around Qeshm Island, we found

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that the eastern coast of Qeshm Island has a considerable variety of different macroalgae, but the diversity of seaweeds is less than other coasts of this island. Since most of the recreational-tourist centers and public parks are located on the east coast of the island (studying area), and the effects of human intervention in this part of the island are more than in other parts, the most predictable reason for reducing the diversity and abundance of seaweeds in the eastern costs, could be due to pollution and stressful conditions caused by human recreational activities in this area (15). The existence of numerous recreational diving centers, especially in stations 1 and 2, and the frequent traffic of boats for transferring the tourists and diving equipment in the tidal zone of these two stations, can be one of the main reasons for the low diversity and species richness of macroalgae compared to other reports of different coasts of Persian Gulf (1, 13). The negative impact of human recreational activities on the diversity and abundance of algae in the coastal area has already been reported on other coasts by researchers (13, 15).

In the present study, the Rhodophyta and Phaeophyta revealed the highest biomass (Figure 4) and species richness (Figure 5), which is in agreement with the previous report on macroalgae flora of the Persian Gulf, Iran (1, 13, 15), and other coasts of the worlds (7, 17, 18). This might be attributed

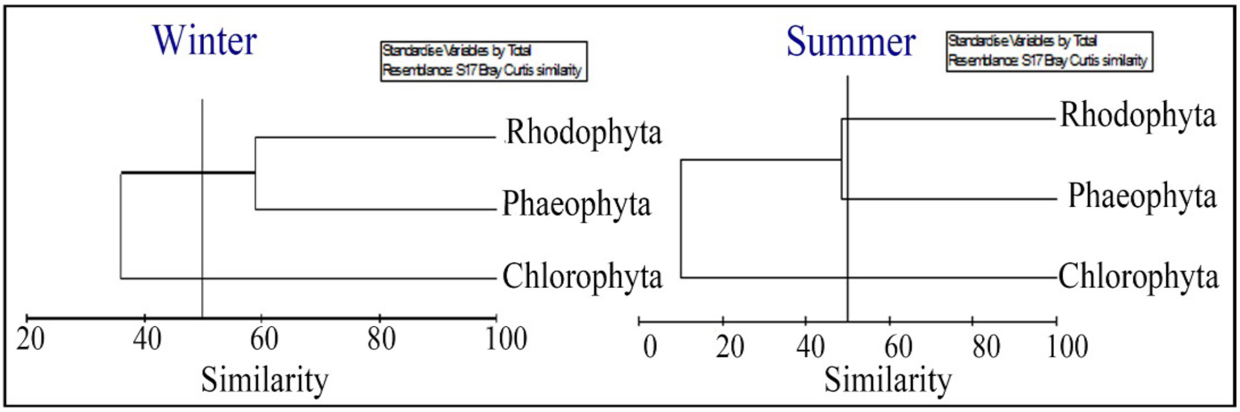

Figure 7) Cluster analysis of seasonal variation for macroalgae biomass data using Bray-Curtis similarity index.

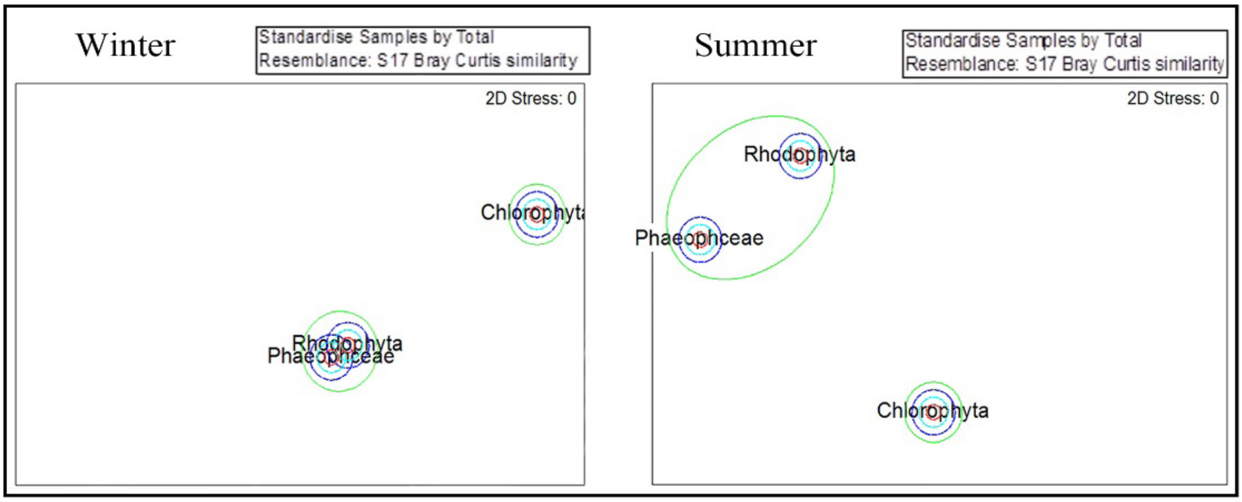

Figure 8) Non-metric Multidimensional Scaling (n-MDS), with Bray Curtis index as similarity measure, based on macroalgae biomass data in winter and summer.

to the lower sensitivity of Rhodophyta and Phaeophyta to water turbidity and their ability to live at greater depths in comparison to Chlorophyta, which are less exposed to disturbance of the surface water (14). This higher tolerance also might be in result of the great variety of life forms and more efficient reproductive strategies in Rhodophyta, such as producing spores that allow them to resist seasonal variation of environmental parameters (19). In contrast, seasonal variations in species diversity of seaweeds showed the maximum distribution of Phaeophyta (brown algae) in comparison to Rhodophyta and Chlorophyta along the studied area in summer (Figure 6). Dadolahi et al (2012) also reported the same seasonal variation of seaweeds on the northern coasts of the Persian Gulf (Bushehr Province). As reported by other researchers (7, 9, 20), we also believe that the distribution patterns of macroalgae are strongly related to the fluctuation of many ecological parameters such as water transparency and exposure (21). Biotic factors also play important role in case of composition and diversity of macroalgal communities, which among these, competition with other macroalgae for space, and herbivores grazing on macroalgae can be mentioned (22, 23). However, the mean total biomass of green macroalgae (Chlorophyta) was dramatically lower than those of red (Rhodophyta) and brown (Phaeophyta) algae in both seasons (Figure 4). This probably demonstrates that some favorable environmental conditions such as long tidal area, type of substratum, and less exposure to wind and wave actions are suitably available for the growth of Rhodophyta and Phaeophyta seaweeds, while Chlorophyta is more sensitive to the fluctuation of these parameters in the tidal zone. Chlorophyta habit at a lower depth of the tidal zone than the other two groups, which is related to their photosynthetic pigments (24); Therefore, they are more exposed to fluctuations in environmental parameters and face more environmental stress (23); This can also be considered as a reason explaining why Chlorophyta biomass is less than Rhodophyta and Phaeophyta. nowadays, numerous secondary metabolites have been identified as bioactive compounds in Rhodophyta and Phaeophyta, which are often produced in response to environmental stressors and it's proved that they protect the cells of these algae against stressful conditions (25-27). previous research has shown that the diversity and abundance of these metabolites in Chlorophyta is considerably less than in Rhodophyta and Phaeophyta (28, 29), and this could be also one of the reasons explain that why green seaweeds are more sensitive to environmental stressors in comparison to brown or red macroalgae.

In the present study, there were significant differences in macroalgal biomass, between station 3 and two other stations in both seasons (Figure 4), which might be belonging to the rocky substrate of this station, which is not as favorable as the sandy substrate of other stations for seaweed growth. The effect of substrate type on abundance and diversity of macroalgae assemblages was proved by other researchers as well (30, 31). The values of the diversity index (H') in the present study were notably lower than those reported by Dadolahi et al. (2012), on the northern coasts of the Persian Gulf in Bushehr province. It is postulated that human activities (urbanization and substratum) have remarkably impacted the macroalgal community on the eastern coast of Qeshm Island, resulting in large-scale changes in the abundance and distribution of species (32, 33). In line with previous reports (7, 9, 20), the highest abundance of macroalgae was observed at lower intertidal levels. The lower intertidal zone is mostly submerged underwater most of the time and is only exposed during low tide. It is generally accepted that the upward distribution of organisms is mainly limited by the desiccation of the intertidal zones at a local scale (34, 35). However, red and brown algae displayed more homogeneity among three intertidal levels and seasons (Table 2 and Figure 7).

It should be noted that the absence of some macroalgae in greater depth of the studied area may be attributed to withstanding desiccation, wave action, and limitation of continuous photosynthesis in intense turbidity. It is reasonable to assume that this may have happened on the eastern coasts of Qeshm Island due to the increasing number of marine tourism centers and diving stations that make it unable for the seaweeds to grow in some parts of this area. Temperature and desiccation tolerance especially in tropical regions are the main factors that can affect the seasonal distribution of algal communities (13). It is realized that the Persian Gulf is subjected to wide climate fluctuations, with surface water temperatures generally ranging from 12 °C in winter to more than 40 °C in the summer and salinity from 28 to near 60 ppt (36). Therefore, the relatively unstable temperature regime and the unsteady shallow water status of the Persian Gulf particularly in the tidal zone probably result in Seasonal changes in the algal flora. Our findings also showed that winter is the most suitable season for macroalgal growth and development along the eastern coasts of Qeshm Island. This result agreed well with previous work in the literature in which it was anticipated that due to more thorough mixing of the seawater during winter, the highest biomass of macroalgae was achieved in the Persian Gulf (37). Furthermore, the current finding showed that *Padina spp*. in Phaeophyta was the dominant species of the macroalgal; community at the studied sites (Table 2). These species were mostly identified in the intertidal zones in both summer and winter in the Persian Gulf, while they seemed to appear throughout the year in other tropical areas in the world (38). Among red algae (Rhodophyta), the *Hypnea* species was found to be dominant in the intertidal zones in both seasons. On the other hand, *Chladophoropsis membranacea* was observed to be more available in both seasons, compared to the other identified Chlorophyta species.

Conclusion

The present study revealed remarkable stability and consistency of the macroalgal communities existing in the eastern Qeshm Island area as well as in the other parts of the Persian Gulf, particularly in various locations of the same island. Moreover, the assemblage composition of macroalgae significantly differs between hot and cold seasons. We observed no substantial compositional variation of seaweed communities along the tidal gradient, while the highest macroalgal biomass was observed in the low tidal zones. It was evidenced by our investigation that brown and red seaweeds were the most abundantly distributed macroalgal species in the studied areas. However, further investigations are required to establish assertive correlations between the seaweed community and distribution in these locations.

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