



Full length article

Stability of macroalgal assemblage in the mangrove swamp as an indicator for the health and quality of the Red Sea waters

Sarah H. Rashedy^{a,*}, El sayed A.E. Hamed^a, Islam M. El-Manawy^b, Leonel Pereira^c^a National Institute of Oceanography and Fisheries (NIOF), Egypt^b Faculty of Science, Botany Department, Suez Canal University, Ismailia, Egypt^c Professor at Marine and Environmental Sciences Centre (MARE), Department of Life Sciences, University of Coimbra, 3000-456 Coimbra, Portugal

ARTICLE INFO

Article history:

Received 24 July 2022

Revised 18 January 2023

Accepted 26 January 2023

Available online 8 February 2023

Keywords:

Macroalgae

Mangrove

Red Sea

Community

Diversity

Health

And quality

ABSTRACT

Mangrove ecosystems support diverse macroalgal assemblages, which are primary producers. Community composition, percentage cover of macroalgae, and physicochemical parameters of seawater were studied at two mangrove areas in the Red Sea, Egypt, from November 2020 to October 2021. In addition, we sought to study changes in the relative densities of macroalgal species of the Red Sea in the two studied areas by using a comparison of our studying data (2020–2021) with previous studies carried out in the same locations in 1997–1998. In order to characterize the spatial variations in algal composition, three 20 m permanent line transects and three 1-m² quadrates were established at each site. Throughout the duration of the study, the physicochemical parameters varied significantly ($p < 0.05$) among the seasons and were slightly different between the two sites. Twenty-four species of macroalgae were collected and identified from the studied sites. Approximately 29.2% of these algae (7 species) belong to the Chlorophyta, 45.8% (11 species) to the Ochrophyta (class: Phaeophyceae), and 25% (6 species) to the Rhodophyta. Phaeophyceae species had the highest diversity and richness values at both sites. Comparing the composition of the community during the years 2020–2021 and 1997–1998 yielded no statistically significant differences ($p > 0.05$). Mangrove trees support a high macroalgae cover, resistant to most environmental circumstances. The macroalgal assemblages' stability in the two studied areas over the two decades shows the health and quality of the Red Sea waters.

© 2023 National Institute of Oceanography and Fisheries. Hosting by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Introduction

Mangroves are considered one of the most important marine ecosystems, dominating vegetation in tropical and subtropical protected coasts (Hoque et al., 2015). Mangroves provide habitats for terrestrial and marine organisms (Nagelkerken et al., 2008) and protect the coastal environment from natural disasters such as tsunamis and storms (Koch et al., 2009). Additionally, mangrove trees store and sequester a significant amount of carbon, which contributes to climate mitigation (Donato et al., 2011).

In intertidal regions, mangrove swamps support a variety of macroalgae on their roots, prop roots, branches, pneumatophores, and mud surfaces in intertidal regions (Zhang et al., 2014). Macroalgal flora of mangroves can be diverse, as observed in man-

groves around the world, including southern Brazil (60 species: Mendonça and Lana, 2021), China (31 species: Zhang et al., 2014), Caribbean Colombia (36 species: Salazar-Forero et al., 2021) and Western Australia (51 species: Huisman et al., 2015). Most studies on mangrove macroalgae have focused on epiphytic populations of pneumatophores and stilt roots, with the exception of a few studies on macroalgal turfs.

The macroalgae assemblages are important in mangrove ecosystems, where they serve as primary producers and provide another source of energy for carbon stock dynamics and nutrient recycling (Gao and Lin, 2018). Several invertebrate populations associated with macroalgae in mangrove areas have been reported to feed on macroalgae, and some may also have symbiotic relationships with algae (Omer et al., 2021). Recently, studies have demonstrated that mangrove swamps' macroalgae represent a metal pollution indicator in coastal areas (Billah et al., 2017). Physiological studies revealed that biotic and abiotic factors affect macroalgae's adaptation, distribution, and tolerance in mangrove areas. Ecological parameters such as water salinity, temperature, pH, and dissolved oxygen are regarded as the primary determinants

Peer review under responsibility of National Institute of Oceanography and Fisheries.

* Corresponding author.

E-mail addresses: sarahamdy.niof@gmail.com, sh.ibrahim@niof.sci.eg (S.H. Rashedy).

<https://doi.org/10.1016/j.ejar.2023.01.004>

1687-4285/© 2023 National Institute of Oceanography and Fisheries. Hosting by Elsevier B.V.

This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

of the algal abundance in the mangrove swamps (Fernandes and Alves, 2011).

In Egypt, mangroves are present in sheltered waters that are protected by intertidal sand spits, islands, or headlands. *Avicennia marina* is the dominant species and is found starting in the area north of Hurghada and continuing south. Several islands have dense thickets of mangroves, including Abu Minqar, Qiusoum, Safaga, El Qusair, and Wadi el Gemal (PERSGA/GEF, 2004). In Egypt, there is a paucity of studies on macroalgae associated with mangroves of the Red Sea; therefore, this study was designed to investigate the species composition and abundance of macroalgae in two different mangrove areas in relation to the seasonal variations of some ecological parameters. The study also aimed to report changes in the structure of macroalgal community and habitat aspects in the Red Sea mangroves swamp over 23 years, from 1998 to 2021.

Methods and materials

Study area

This study was performed in two mangrove areas of the Red Sea, Egypt (Fig. 1) during autumn (Nov. 2020), winter (Feb. 2021), spring (May 2021), and summer (Aug. 2021). The first location (Site 1): is 8 km south of Hurghada city on Abu Minqar Island at latitude $27^{\circ} 13' 01''$ N and longitude $33^{\circ} 52' 48''$ E. This island is shielded from the east and south by large and small Giftun islands and from the west by the coastline. Abu Minqar Island is divided into northern and southern sections. Additionally, two sections are separated by a channel that forms lagoons in some locations. Along both sides of the channel, a forest of mangroves is developing. The second site (Site 2) is located 17 km south of Safaga city at latitude $26^{\circ} 36' 55''$ N and longitude $34^{\circ} 00' 43''$ E. The area surrounding the mangroves is flattened plain with gentle sloping toward the sea. Mangrove plants form small patches over the old dead corals raised from the quaternary. Compared to Abu Minqar Island, this mangrove is less developed due to less protection from the sea and the land.

Seawater analysis

At each site, water salinity, temperature, dissolved oxygen (DO), and pH value were measured from the mean of three readings by the Multi-parameter instrument (YSI ProODO Instrument). According to APHA (2005), the nutrient salts were determined spectrophotometrically in μM .

Community composition and cover percent of macroalgae

Spatial and temporal patterns

Three 20 m permanent line transects were set on each site, and at each transect, three 1-m² quadrates were randomly laid as replicates to characterize the spatial changes in algal composition. Macroalgal vegetation was described quantitatively by measuring the percentage cover of each species inside the quadrate. The size and number of quadrates were chosen based on trial monitoring and were similar to those used by El-Manawy (2008). During the above-mentioned time period, changes in macroalgal cover were analyzed. All work was accomplished through snorkeling.

The assessment of the succession of macroalgal species in two mangrove swamps was crosschecked with referencing data in two ways: using reported locations where macroalgae associated with mangroves studied in 1997 and 1998 (EL-Sharouny et al., 2001), visiting the same and identical locations between November 2020 and August 2021.

Taxonomical study

For the taxonomic study, specimens of all different species were seasonally collected from two different sites and kept in labeled plastic bags. A portion of these samples was fixed in a 4% formaldehyde seawater solution, and the other portion was spread on herbarium sheets. The algae were identified by morphological characteristics using identification manuals and keys to identification, according to Aleem, 1978; Coppejans and Beeckman, 1990; Sahoo, 2001. In addition, the accepted and valid names of the species of macroalgae were according to the taxonomic database site algaebase.com managed by Guiry and Guiry (2022).

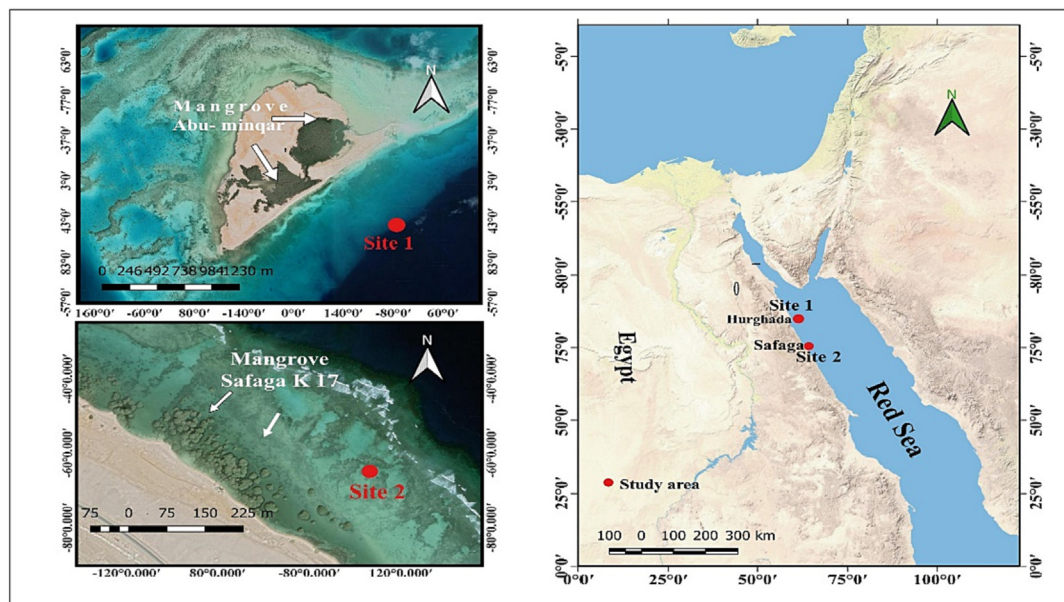


Fig. 1. Map of research area displaying the sites on the Red Sea coast, Egypt.

Statistical analyses

The Boxplots graph illustrates the spatial and temporal variability, and the statistical significance of these variations is illustrated by one-way ANOVA and Fisher's grouping test. Canonical Correspondence Analysis (CCA) and Pearson Correlation Coefficients were used to determine the correlation between the cover of the dominant species and environmental parameters. These statistical analyses were performed using Minitab® (Version 16) software. In addition, diversity indices, including Shannon–Wiener diversity index, species evenness, and species richness, were used to estimate the biodiversity through the study areas using the PRIMER program Version 5.2.

Results

Hydrographic parameters in the studied mangroves areas

Throughout the duration of the study, physicochemical parameters varied significantly ($p < 0.05$) among seasons (Fig. 2). The values of water temperature significantly fluctuated between 17.6 °C in mid-winter and 32.1 °C in mid-summer ($F = 145.5$, $P = 0.001$). The majority of temperature values are displayed in the box plot, and the length of the box indicates their variability. This is evident when comparing site 2 to the other site, where site 2 experienced more significant fluctuations than site 1. (Fig. 2 a). The measured pH range for site 1 was 7.53 to 8.63 and for site 2 it was 7.96 to 8.21. ANOVA and Fisher's grouping test demonstrated that there are no significant differences between sites, but there are highly significant differences between seasons ($F = 9.74$, $P = 0.001$) (Fig. 2 b).

Salinity was measured as 39.56–42.3 ppt for the seawater of mangrove Abu-Minqar, and 40.43–44.4 ppt for the other site (Fig. 2 c). ANOVA and Fisher's grouping test results demonstrated no significant difference among sites, indicating a substantial seasonal difference ($F = 23.4$, $P < 0.001$). Dissolved oxygen of seawater varied from 3.8 to 6.9 mg.l^{-1} for site 1, 4.8–7.3 mg.l^{-1} for site 2.

Box plot showed that winter had the highest median (7.1 mg.l^{-1}), followed by spring (5.9 mg.l^{-1}), autumn (5.5 mg.l^{-1}), and finally summer (5.1 mg.l^{-1}). Dissolved oxygen highly varied between seasons, as shown by ANOVA, indicating a significant distinction among seasons ($F = 18.62$, $P = 0.001$) (Fig. 2 d).

Ammonium concentrations ranged from 3.5 to 8.5 μM for site 1 and from 2.19 to 3.85 μM for site 2. Site 1 exhibited the highest median value, 6.65 μM (Fig. 2). ANOVA and Fisher's grouping test results demonstrated a highly significant difference among sites ($F = 29.7$, $P = 0.001$). The temporal medians were 6.1, 5.6, 4.2, and 3.3 μM during winter, summer, autumn, and spring, respectively. As depicted by box plots, ANOVA results revealed a highly significant variance among seasons ($F = 46.5$, $P = 0.001$). Dissolved nitrate values varied between 1.21 μM mid-winter and 0.23 μM mid-autumn (Fig. 2 e). The levels of dissolved phosphate significantly varied from one season to another ($F = 5.96$, $P = 0.004$) and between the two sites ($F = 8.2$, $P = 0.009$). It was measured from 0.09 to 0.89 μM for site 1 and 0.04–0.25 μM for site 2 (Fig. 2 f). The temporal medians were 0.48, 0.31, 0.10, and 0.08 μM in the middle of the winter, fall, spring, and summer, respectively. As confirmed by ANOVA, reactive silicate varied among sites, revealing highly significant differences ($F = 17.7$, $P = 0.001$). However, there are no significant differences between seasons (Fig. 2 f).

Community composition and percentage cover (%) of macroalgal species at two studied mangrove areas during 2020–2021.

Twenty-four species of macroalgae were collected and identified from the studied sites. About 29.2% of these algae (7 species) belong to phylum Chlorophyta, 45.8% (11 species) to phylum Ochrophyta (class: Phaeophyceae), and 25% (6 species) to phylum Rhodophyta, as shown in Table 1. Ochrophyta (class: Phaeophyceae) contained a greater number of genera than Chlorophyta and Rhodophyta phyla. It had nine genera, eight of which were represented by only one species, and *Sargassum* is the only genus with three taxa, namely *S. acinacifolia*, *S. aquifolium*, and *S. Subrepandum*.

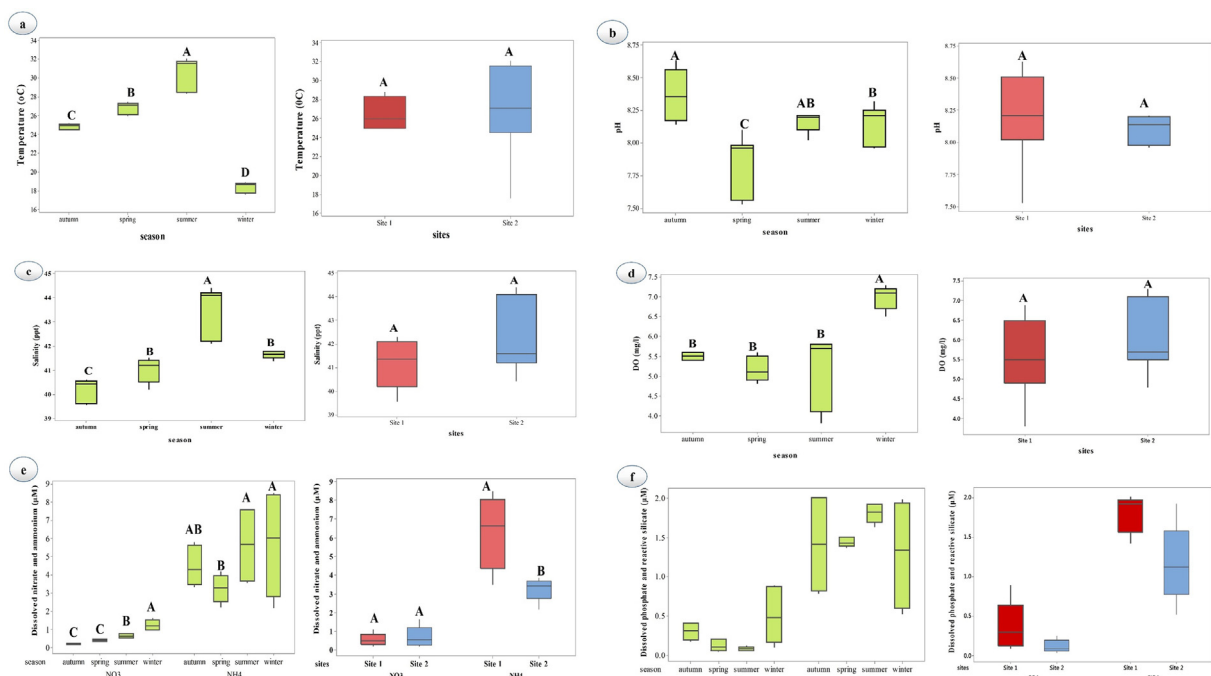


Fig. 2. The Seasonal variations of the ecological factors in two mangrove areas during 2020–2021. Different letters (A, B, C & D) show a significant similarity ($p \leq 0.05$).

Table 1
Phylum/class, species names and temporal variations of their percentage cover (%) at two sites (1 and 2) during different seasons.

Phylum/Class, Species names	Nov. 20		Feb. 21		May 21		Aug. 21	
	1	2	1	2	1	2	1	2
Chlorophyta								
<i>Boergesenia forbesii</i> (Harvey) Feldmann	0	5	0	9	0	1	0	3
<i>Caulerpa racemosa</i> var. <i>gracilis</i> (Zanardini) Weber-van Bosse	5	0	8	0	2	0	3	0
<i>Caulerpa serrulata</i> (Forsskal) J.Agarth	0	3	0	2	0	2	0	1
<i>Dictyosphaeria cavernosa</i> (Forsskal) Børgesen	9	2	7	1	5	1	15	1
<i>Valonia aegagropila</i> C.Agarth	0	2	0	1	0	2	0	1
<i>Valonia ventricosa</i> J.Agarth	2	0	1	0	0	0	1	0
<i>Halimeda opuntia</i> (Linnaeus) Lamouroux	8	25	12	15	7	22	6	20
Ochrophyta (class Phaeophyceae)								
<i>Colpomenia sinuosa</i> Derbes et Solier	1	1	1	1	0	0	0	0
<i>Dictyota ciliolata</i> Sonder ex Kützing	1	10	2	7	0	15	1	19
<i>Hydroclathrus clathratus</i> (C.Agarth) Howe	0	1	1	1	0	0	1	0
<i>Padina boergesenii</i> Alender & Kraft	2	10	2	15	10	30	5	12
<i>Polycladia myrica</i> (S.G.Gmelin) Draima, Ballesteros, F.Rousseau & T.Thibaut	65	36	60	32	65	23	50	26
<i>Sirophysalis trinodis</i> (Forsskal) Kützing	25	5	10	8	3	3	17	0
<i>Hormophysa cuneiformis</i> (Gmelin) Silva	40	28	33	20	21	5	32	32
<i>Sargassum acinacifolium</i> Setechell & Gardner	0	8	0	6	0	3	0	2
<i>Sargassum aquifolium</i> (Turner) C.Agarth	8	26	2	15	0	8	6	23
<i>Sargassum subrepandum</i> (Forsskal) C.Agarth	0	0	0	0	0	0	0	0
<i>Turbinaria triquetra</i> (J.Agarth) Kützing	4	5	1	2	0	1	7	3
Rhodophyta								
<i>Digenea simplex</i> (Wulfen) C.Agarth	0	15	0	13	0	19	0	10
<i>Jania rubens</i> (Linnaeus) J.V.Lamouroux	1	3	1	7	1	2	3	2
<i>Laurencia obtusa</i> (Hudson) J.V.Lamouroux	1	0	2	0	0	0	3	0
<i>Palisada perforata</i> (Bory) K.W.Nam	25	0	35	0	17	0	20	0
<i>Acanthophora spicifera</i> (M.Vahl) Børgesen	15	0	20	0	7	0	8	0
<i>Hypnea valentiae</i> (Turner) Montagne	6	0	10	0	3	0	4	0

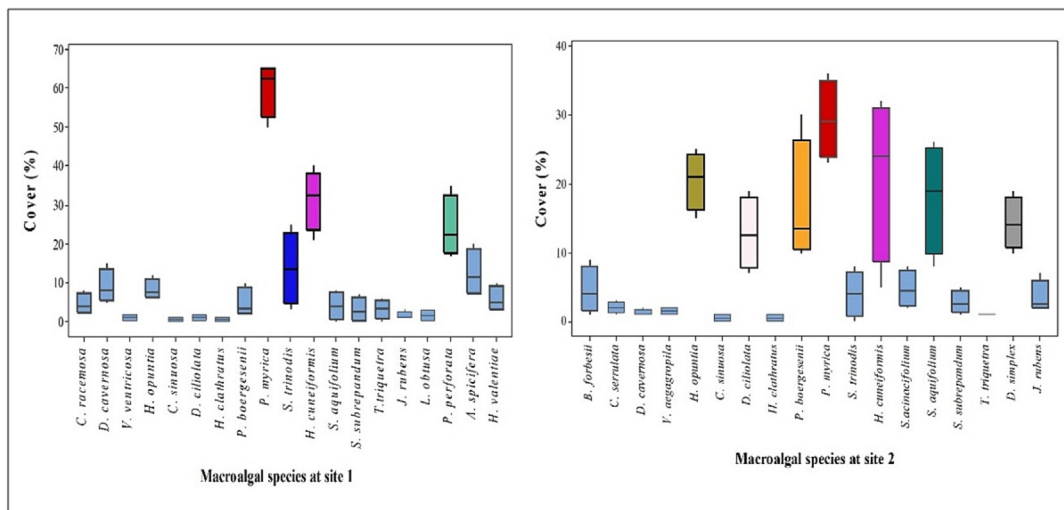


Fig. 3. Boxplots showing the variability of cover (%) of macroalgal species at two studied mangrove areas.

For spatial patterns, box plots (Fig. 3) for macroalgal species coverage at site 1 showed that *Polycladia myrica* had the highest median (63%) followed by *Hormophysa cuneiformis* (33%), *Palisada perforata* (23%) and then *Sirophysalis trinodis* (14%). The length of the box plot for any species indicated the annual variability of that species, with the variability of the previous species' cover at site 1 being greater than that of other species at site 1. In contrast, box plots for macroalgal species coverage at site 2 showed that *Polycladia myrica* also had the highest median (29%) but less than site 1, followed by *Hormophysa cuneiformis* (24%), *Halimeda opuntia* (21%), *Sargassum aquifolium* (19%) *Padina boergesenii* and *Digenea simplex* (14%), then *Dictyota ciliolata* (13%). In terms of temporal dynamics, ANOVA revealed an insignificant difference ($P > 0.05$) in species coverage between seasons at each site.

The succession of macroalgal species associated with mangroves over time

In order to track the colonization and succession of macroalgal species over two decades at two mangrove-studied areas, it is most efficient to compare the list provided by EL-Sharouny et al., 2001 with the current list since they studied the same areas. Table 2 displays the relative density of algal species at the two study sites during the years 2020–2021 and 1997–1998. By comparing the dominant species between 2020 and 2021 and 1997–1998, we found that the species with the highest percentage cover and relative density in this study are the same species listed in 1997–1998 with high relative density. The species that had the highest relative density at site 1 during 1997–1998 were *Polycladia myrica* (22.70),

Table 2
Relative densities of macroalgal species at two mangroves areas during the period of 2020–2021 and 1997–1998.

Species	Relative densities			
	Site 1	Site 2	Site 1	Site 2
	2020–2021 Our study		1997–1998 According to EL-Sharouny et al, 2001	
Chlorophyta				
<i>Boergesenia forbesii</i>	0	2.83	0	0
<i>Caulerpa racemosa</i> var. <i>gracilis</i>	2.36	0	0.20	0
<i>Caulerpa serrulata</i>	0	1.26	0	0.50
<i>Dictyosphaeria cavernosa</i>	4.72	0.79	0	0
<i>Valonia aegagropila</i>	0	0.94	0	0
<i>Valonia ventricosa</i>	0.52	0.00	2.70	0.70
<i>Halimeda opuntia</i>	4.33	12.89	21.25	1.50
Ochrophyta, Phaeophyceae				
<i>Colpomenia sinuosa</i>	0.26	0.31	0	0
<i>Dictyota ciliolata</i>	0.52	8.02	0	0
<i>Hydroclathrus clathratus</i>	0.26	0.31	5.30	5.60
<i>Padina boergesenii</i>	2.49	10.53	3.60	11.80
<i>Polycladia myrica</i>	31.50	18.40	22.70	10.10
<i>Sirophysalis trinodis</i>	7.22	2.52	8.30	6.20
<i>Hormophysa cuneiformis</i>	16.54	13.36	5.30	5.10
<i>Sargassum acinacifolium</i>	0	2.99	0	0
<i>Sargassum aquifolium</i>	2.10	11.32	5.50	6.60
<i>Sargassum polycystum</i>	1.57	1.73	4.20	5.00
<i>Sargassum subrepandum</i>	1.71	0.63	0.20	0.30
Rhodophyta				
<i>Digenea simplex</i>	0.5	8.96	13.90	15.80
<i>Jania rubens</i>	0.79	2.20	0.20	0.20
<i>Palisada perforata</i>	12.73	0	9.50	3.10
<i>Laurencia obtusa</i>	0.79	0	6.50	6.70
<i>Acanthophora spicifera</i>	6.56	0	0	0
<i>Hypnea valentiae</i>	3.02	0	0.60	0.20

Halimeda opuntia (21.25), *Digenea simplex* (13.9), *Palisada perforata* (9.50), and *Sirophysalis trinodis* (8.30). In contrast, the species that were listed at site 2 were *Digenea simplex* (15.80), *Padina boergesenii* (11.80), *Polycladia myrica* (10.10), *Sargassum aquifolium* (6.60), and *Sirophysalis trinodis* (6.20). However, some species recorded in the present study were not found during 1997–1998, such as *Dictyosphaeria cavernosa*, *Valonia aegagropila*, *Colpomenia sinuosa*, *Dictyota ciliolata*, and *Acanthophora spicifera*. Some species recorded during 1997–1998 were not also found in the present study, such as *Enteromorpha intestinalis*, *Ulva lactuca*, and *Codium repens*. Applying ANOVA and Fisher's grouping test, no significant difference could be noted at the two sites between the two periods of time ($p > 0.05$) in the relative density for macroalgal species at the two sites, as presented in Fig. 4.

Species-environment correlations

The results of canonical correspondence analysis (CCA) (Fig. 5 A) and correlation matrices (Fig. 5 B) indicated that an abundance of the dominant species of macroalgae at each site was mainly related to the physicochemical parameters. At site 1, the abundance of *H. cuneiformis* was correlated significantly with pH ($r = 0.984$) and reactive silicate ($r = 0.932$). On the other hand, the abundance of *P. boergesenii* was correlated negatively and significantly with pH ($r = -0.943$), dissolved ammonium ($r = -0.674$), dissolved phosphate ($r = -0.65$), and reactive silicate ($r = -0.961$). The abundance of *P. myrica* was significantly negatively correlated with salinity ($r = -0.884$) and dissolved ammonium ($r = -0.666$). The water temperature has a negative influence on the abundance of *S. trinodis* and *P. perforata*, while dissolved oxygen, dissolved ammonium, dissolved nitrate, dissolved phosphate, and reactive silicate have positive effects on the abundance of *S. trinodis* and *P. perforata*.

For site 2, water temperature and pH positively influence the presence of *H. cuneiformis*, *S. aquifolium*, and *H. opuntia*, while

they negatively affect the abundance of *P. boergesenii*, *P. myrica*, and *S. trinodis*. The abundance of *S. trinodis* was significantly negatively correlated with salinity ($r = -0.679$). Alternatively, dissolved oxygen has a positive impact on the abundance of *S. trinodis*, and it has a negative effect on the abundance of *H. cuneiformis* and *H. opuntia*. Dissolved salts such as nitrate, nitrite, phosphate, ammonium, and reactive silicate have significant influences on the abundance of *P. myrica*, *S. aquifolium*, and *S. trinodis*. In addition, they have negative effects on the abundance of *H. opuntia*, *H. cuneiformis*, and *P. boergesenii*.

Discussion

Macroalgae interact with other marine organisms, and all interact with their physicochemical environment. In this study, the trend of variations in physico-chemical parameters was evaluated for the surveyed sites during four seasons. Remarkably, water temperature is an essential abiotic influence that directly or indirectly affects the distribution of marine plants (Ibraheem et al., 2014). In this investigation, the surface water temperature at two sites may be affected by evaporation, cooling, the intensity of solar radiation, and mixing up with the tides from adjacent neritic waters, as reported by Kumar et al. (2017).

The pH is another essential environmental factor for aquatic plants' metabolism, physiology, chemical processes, growth, and survival (Fernández et al., 2019). In this study, the seasonal variation could result from several factors, such as the reduction of carbon dioxide by photosynthesis, lower primary productivity, variations in temperature and salinity, and degradation of organic matter, as reported by Bragadeeswaran et al. (2007). Due to the high temperatures, high evaporation, and absence of river inflow, the salinity of the Red Sea is high. In this study, the salinity of surface water of mangrove regions is slightly higher than that of the open sea, as measured by Nassar et al. (2014). The general distribu-

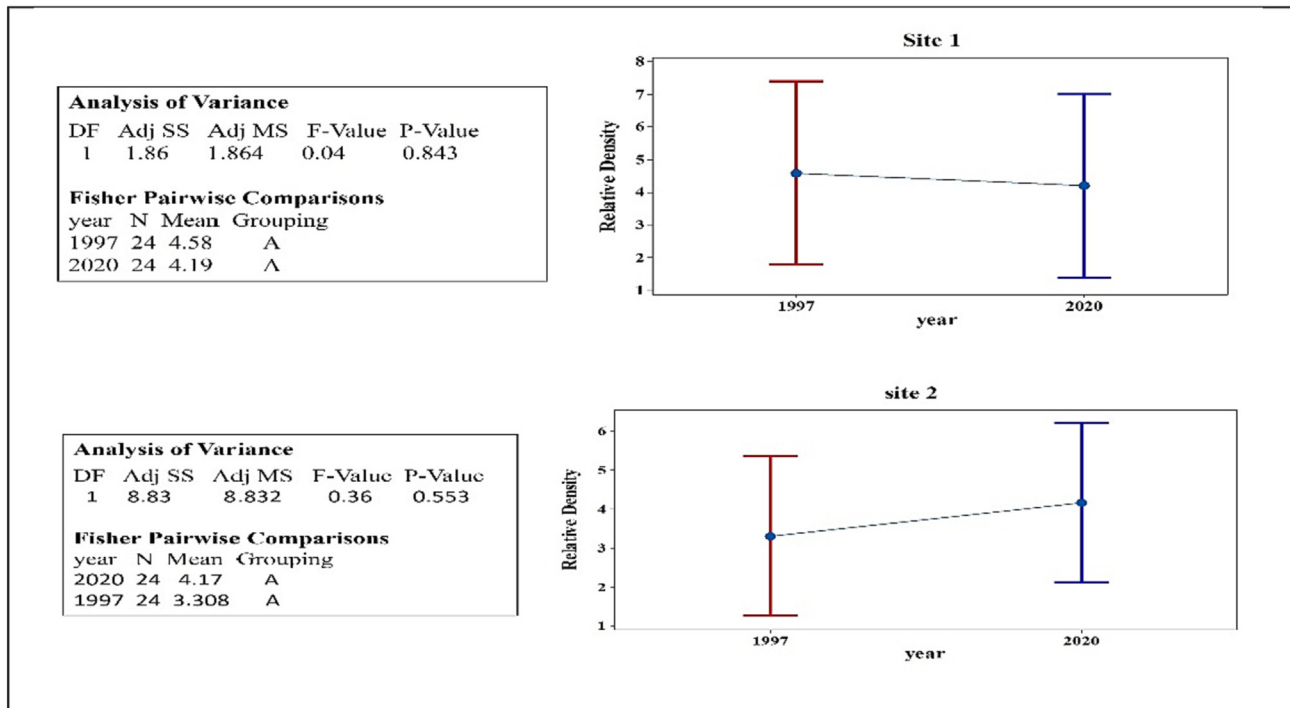


Fig. 4. Interval Plot of Relative Density versus year at the two studied sites.

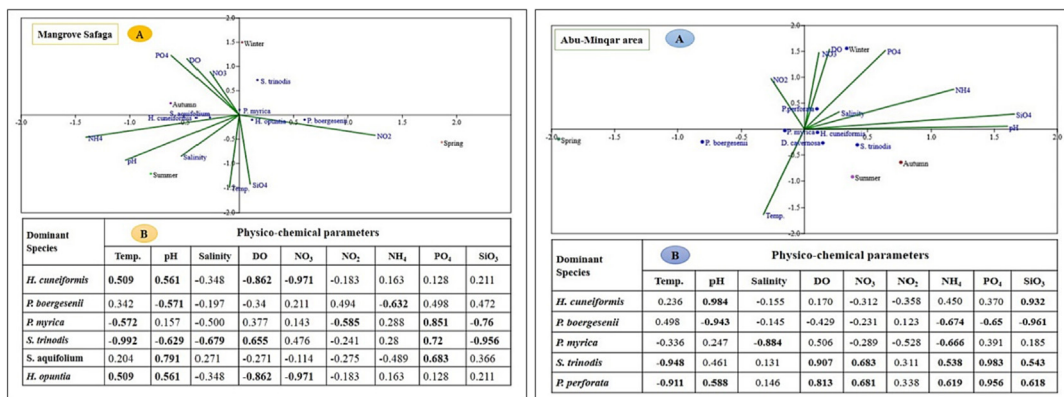


Fig. 5. The correlations between the cover of the dominant species and environmental parameters at Abu-Minqar area. A. The canonical correspondence analysis (CCA) results. B. Pearson correlation. Bolded correlation coefficients are significant at a p-level ≤ 0.05.

tion of dissolved oxygen revealed high values and the presence of well-oxygenated waters in the studied areas. The DO in mangrove regions are lower than that of the open sea due to the high content of organic matter in mangrove regions.

Nutrients are one of the vital factors in estuarine and coastal areas, which affect the growth, metabolic activities, and reproduction of marine algae. Although they are essential for macroalgal growth, they exist in low concentrations of marine waters (Nassar et al., 2014). The most important nutrient that was measured during this study was dissolved ammonium. It significantly varied between seasons and sites. The highest median was recorded at site 1 because of the mineralization of ammonia from dead seagrass and oxidation of the organic matter from dead plants and animals associated with mangrove trees at this site (Vasudevan et al., 2012). Phosphorus is not the main limiting nutrient for macroalgal growth and is mainly available as the inorganic ions PO₄³⁻ or H₂PO₄⁻ (Hurd et al., 2014). In this study, dissolved inorganic phosphate of seawater fluctuated among the investigated

sites and seasons. There was a slight increase in the phosphate level of Abu-Minqar Island compared with those of the mangrove Safaga region, which may be the result of the decomposition of dead organisms and a relatively dense *Avicennia marina* on the island.

The recorded macroalgal species in the *A. marina* assemblage from the two sites have already been reported from different areas of the Red Sea (El-Manawy, 2008; Issa, Hifney, Abdel-Gawad, & Gomaa, 2014; Ansari, 2016). However, the macroalgal species number (24) listed from mangrove systems of the Red Sea in this investigation is comparatively less than those stated from the open seashore. On the contrary, this number is comparatively greater than those detected in mangrove systems in other worldwide coastal areas (Melville and Pulkownik, 2007; Nwankwo and Adesalu, 2012; Billah et al., 2016). The percentage of species coverage varied significantly between the two studied areas in terms of spatial variation. The difference in species diversity between the two sites may be due to the density of mangrove trees at site 1 ver-

site 2. According to Kaleem et al., 2015, this may be due to the mangrove trees' shading, which prevents light diffusion and ultimately supports the homogenous distributions of macroalgae in site 1 compared to site 2. At each site, there is no significant difference between seasons in the percentage of species coverage. This finding agrees with other articles that studied macroalgae associated with mangroves that grow during the year, and seasonal impacts on their abundance were not observed (Perez-Estrada et al., 2012). This result can be attributed to the correlation between these species and hard substrata than hydrological parameters, including nutrients. In addition, these macroalgae are perennial and have the potential to store nutrients during nutrient limitations. (Billah et al., 2016).

Comparing the dominant species during the years 2020–2021 and 1997–1998, we discovered that the species with the highest percentage cover and relative density in this study are the same species that were identified as having a high relative density during 1997–1998. It is plausible that the hyper-salinity of water may have prevented a greater number of species from migrating to mangrove areas. The salinity was measured as 42.7 ppt in 1997 and 44.4 ppt in 2021. However, euryhaline species such as *Ulva*, *Enteromorpha*, and *Cladophora* were found from 1997 to 1998 and were not recorded during this study. This could be a result of the nutrient-depleted ecosystem in the studied mangrove regions, which receives little nutrient input from the soil, agriculture, and pollution on land (Nassar et al., 2014). Generally, Kepel et al. (2019) suggested that the differences in the biodiversity of macroalgae compared to other research outcomes are because of the differences in sampling situations, as well as fluctuations in the environmental factors such as anthropogenic impacts, transparency of waters, substratum, and seasonal variations.

In the present study, the correlations between the cover of the dominant algae and environmental parameters are significant. Most of these algae are influenced by temperature, salinity, pH, dissolved oxygen, and nutrient availability. Several factors, including salinity, water turbidity, availability of light, tide level, wave motion, and shading, have already been analyzed as controlling the existence or deficiency of macroalgal species in mangrove environments (Billah et al., 2016; Isa et al., 2017).

Conclusion

The mangrove of Abu-Minqar Island and south Safaga is dominated by the *Avicennia marina*, which grows under intense conditions of high temperature and salinity. This ecosystem depends on the nutrient that accumulates from the mangrove trees and supports a high cover of macroalgae that resist extreme environmental conditions. Our results showed that twenty-four species of macroalgae were collected and identified from the studied sites. Comparing the composition of the macroalgal community during the years 2020–2021 and 1997–1998 yielded no statistically significant differences which indicate the stability of the macroalgal community associated with the mangrove in the two studied areas over the 23 years.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

- Aleem, A. A. (1978). A preliminary list of algae from Sierra Leone. *Bot. Mar.*, 21, 397–399.
- APHA (2005). *Standard methods for the examination of water and wastewater*. 21st Eds. Washington DC, USA: American Public Health Association.
- Ansari, A. A. (2016). Seasonal dynamics in the relative density of aquatic flora along some coastal areas of the Red Sea, Tabuk, Saudi Arabia, Egypt. *J. Aquat. Res.*, 42, 273–280.
- Billah, M. M., Mustafa Kamal, A. H., Idris, M. H., & Ismail, J. B. (2016). Seasonal variation in the occurrence and abundance of mangrove macroalgae in a Malaysian estuary. *Algologie*, 37(2), 109–120.
- Billah, M. M., Mustafa Kamal, A. H., Idris, M. H., & Ismail, J. (2017). Mangrove Macroalgae as Biomonitor of Heavy Metal Contamination in a Tropical Estuary, Malaysia. *Water Air Soil Pollut.*, 228, 347. <https://doi.org/10.1007/s11270-017-3500-8>.
- Bragadeswaran, S., Rajasegar, M., Srinivasan, M., & Kanagarajan, U. (2007). Sediment texture and nutrients of Arasalar estuary, Karaikkal, southeast coast of India. *J. Environ. Biol.*, 28, 237–240.
- Coppejans, E., & Beeckman, T. (1990). Caulerpa (Chlorophyta, Caulerpales) from the Kenyan coast. *Nova Hed.*, 50, 111–125.
- Donato, D., Kauffman, J., Murdiyarto, D., Kurnianto, S., Stidham, M., & Kanninen, M. (2011). Mangroves among the most carbon-rich forests in the tropics. *Nature Geosci.*, 4, 293–297. <https://doi.org/10.1038/ngeo1123>.
- El-Manawy, I. M. (2008). The spatial variability of macroalgal communities and their functional groupings on the fringing reefs of Ghardaqah. *Egy. J. of Phycol.*, 9, 55–69.
- EL-Sharouny, H. M., EL-Tayeb, M. A., & Ismail, M. S. (2001). Macroalgae associated with mangroves at Hurgada and Safaga of the Egyptian Red Sea coast. *Journal of king. Abdul Aziz University. Marine science*, 12(241–251).
- Fernandes, M. E. B., & Alves, E. F. S. (2011). Occurrence and distribution of macroalgae (Rhodophyta) associated with mangroves on the Ajuruteua Peninsula, Braganca, Para, Brazil. *UAKARI*, 7(2), 35–42.
- Fernández, P. A., Leal, P. P., & Henríquez, L. A. (2019). Co-culture in marine farms: macroalgae can act as chemical refuge for shell-forming molluscs under an ocean acidification scenario. *Phycologia*, 58(5), 542–551. <https://doi.org/10.1080/00318884.2019.1628576>.
- Gao, Y., & Lin, G. (2018). Algal diversity and their importance in ecological processes in typical mangrove ecosystems. *Journal of Biodiv. Sci.*, 26(11), 1223–1235.
- Guiry, M.D., Guiry, G.M. Algaebase: Listing the World's Algae. Available online: <https://www.algaebase.org/> (accessed on 27 January 2022).
- Hoque, M. M., Abu Hena, M. K., Ahmed, O. H., Hoque, A. T., & Billah, M. M. (2015). Litterfall production in a tropical mangrove of Sarawak, Malaysia. *Journal of Zoology and ecology*, 25, 157–165.
- Huisman, J. M., Kendrick, A. J., & Rule, M. J. (2015). Mangrove-associated macroalgae and cyanobacteria in Shark Bay, Western Australia. *Journal of the Royal Society of Western Australia*, 98(1), 45–68.
- Hurd, C. L., Harrison, P. J., Biscoff, K., & Lobban, C. S. (2014). *Seaweed Ecology and Physiology*. United Kingdom: Cambridge University Press.
- Ibraheem, B. M., Alharbi, R. M., Abdel-Raouf, N., & Al-Enazi, N. M. (2014). Contributions to the study of the marine algae inhabiting Umluj Seashore, Red Sea. *Beni - Suef University journal of Basic and Applied sciences*, 3, 278–285.
- Isa, H. M., Kamal, A. M., Idris, M. H., Rosli, Z., & Ismail, J. (2017). Biomass and Habitat Characteristics of Epiphytic Macroalgae in the Sibuti Mangroves, Sarawak, Malaysia. *Tropical Life Sciences Research*, 28(1), 1–21. <https://doi.org/10.21315/tlsr2017.28.1.1>.
- Issa, A. A., Hifney, A. F., Abdel-Gawad, K. M., & Gomaa, M. (2014). Spatio temporal and environmental factors influencing macroalgal β diversity in the Red Sea, Egypt. *Botanica Marina*, 57(2), 99–110. <https://doi.org/10.1515/bot-2013-0107>.
- Kaleem, S., Abu Hena, M. K., Zamri, R., Khalid, R. H., & Hoque, M. M. (2015). Composition and diversity of plants in Sibuti Mangrove forest, Sarawak, Malaysia. *Forest Science and Technology*, 12(2), 70–76. <https://doi.org/10.1080/21580103.2015.1057619>.
- Kepel, R. C., Lumings, Lawrence J. L., Tombokan, John L., Mantiri & Desy, M. H. (2019). Biodiversity and community structure of seaweeds in Minahasa Peninsula, North Sulawesi, Indonesia. *Aquaculture, Aquarium, Conservation and Legislation. International Journal of the Bioflux Society*, 12(3), 880–892.
- Koch, E. W., Barbier, E. B., Silliman, B. R., Reed, D. J., Perillo, G. M., Hacker, S. D., Graneck, E. F., Primavera, J. H., Muthiga, N., Polasky, S., Halpern, B. S., Kennedy, C. J., Kappel, C. V., & Wolanski, E. (2009). Non-linearity in ecosystem services: temporal and spatial variability in coastal protection. *Frontiers in Ecology and the Environment*, 7, 29–37. <https://doi.org/10.1890/080126>.
- Kumar, S. D., Santhanam, P., Ananth, S., Kaviyaranan, M., Dhanalakshmi, B., Park, M. S., & Kim, M. (2017). Seasonal variation of physico-chemical parameters and phytoplankton diversity in the Muthukuda mangrove environment, southeast coast of India. *J. Mar. Biol. Ass. India*, 59(2), 20–33.
- Melville, F., & Pulkownika, A. (2007). Seasonal and spatial variation in the distribution of mangrove macroalgae in the Clyde River, Australia. *Estuarine coastal and shelf science*, 71, 683–690.
- Mendonça, I. R. W., & Lana, P. C. (2021). Richness and biomass distribution of the mangrove macroalgal association in a subtropical estuary. *Ocean and Coastal Research*, 69. <https://doi.org/10.1590/2675-2824069.21006irwm>.

- Nagelkerken, S. J. M., Blaber, S., Bouillon, P., Green, M., Haywood, L. G., Kirton, J.-O., Meynecke, J., Pawlik, H. M., & Penrose, A. (2008). The habitat function of mangroves for terrestrial and marine fauna: A review. *Aquatic Botany*, 89(2), 155–185.
- Nassar, M. Z., Mohamed, H. R., Khiray, H. K., & Rashedy, S. H. (2014). Seasonal fluctuations of phytoplankton community and physico-chemical parameters of the north western part of the Red Sea, Egypt. *Egyptian Journal of Aquatic Research*, 40(4), 395–403. <https://doi.org/10.1016/j.ejar.2014.11.002>.
- Nwankwo, D. I., & Adesalu, T. A. (2012). Checklist of Mangrove Macroalgae from Southwest, Nigeria. *Journal of American Science*, 8(4), 689–691.
- Omer, M. Y., Abd El-Wakeil, K. F., Hussein, H. N., & Rashedy, S. H. (2021). Invertebrate Assemblages Associated with Seaweeds at Different locations in the Red Sea, Egypt. *Egyptian Journal of Aquatic Biology & Fisheries*, 25(1), 407–421.
- Perez-Estrada, C. J., Leon-Tejera, H., & Serviere-Zaragoza, E. (2012). Cyanobacteria and macroalgae from an arid environment mangrove on the east coast of the Baja California Peninsula. *Botanica Marina*, 55(2), 187–196. <https://doi.org/10.1515/bot-2012-0501>.
- PERSGA/GEF. (2004). Status of Mangroves in the Red Sea and Gulf of Aden. PERSGA Technical Series No. 11. PERSGA, Jeddah.
- Sahoo, D. (2001). *Seaweeds of Indian coast* (p. 283). A.P.H Publishing Corporation: New Delhi.
- Salazar-Forero, C., Gavio, B., & Wynne, M. (2021). Macroalgae associated with aerial roots of *Rhizophora mangle* in Islas del Rosario, Colombia, Southwestern Caribbean. *Caldasia*, 43(1), 94–104. <https://doi.org/10.15446/caldasia.v43n1.85228>.
- Vasudevan, S., Kumar, S., Kathiresan, M., Jayalakshmi, T., Kaviyaran, M., Rameshkumar, A., Nandakumar, R., & Santhanam, P. (2012). Short term investigation on vertical distribution of physico-chemical and phytoplankton biomass in Pambanar estuary, Southeast coast of India. *Indian J. Nat. Sci.*, 3, 1182–1190.
- Zhang, Y., Li, Y., Shi, F., Sun, X., & Lin, G. (2014). Seasonal and spatial variation in species diversity, abundance, and element accumulation capacities of macroalgae in mangrove forests of Zhanjiang, China. *Acta Oceanologica Sinica*, 33(8), 73–82.