

Status of Seaweeds Community in the Mangrove Forest and Sandy Shore Ecosystems, Red Sea, Egypt

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ABSTRACT

The current study was organized to determine the abundance and distribution status of the seaweed community in two Red Sea locations in order to assist decision-makers in managing natural resources, particularly the macroalgal community. During summer, autumn of 2017, and winter, spring of 2018, seaweed species were collected seasonally by snorkeling in the intertidal zone at two sites: a mangrove forest 17 km south of Safaga City and Sandy shore at the National Institute of Oceanography and Fisheries, Hurghada branch. The community structure of the seaweed meadows at the two sites was described using the line transects method (LTM, 25m length) and the quadrat technique (1m²). The two sites were sampled for common macroalgae species in this study. Ten macroalgae species were identified in the mangrove site, including three Chlorophyta species (*Caulerpa racemosa*, *Halimeda opuntia* and *Halimeda macroloba*), five Phaeophyta species (*Padina boergesenii*, *Sargassum aquifolium*, *Hormophysa cuneiformis*, *Turbinaria turbinata* and *Cystoseira myrica*) and Rhodophyta with two species (*Digenea simplex* and *Actinotrichia fragilis*). Seven macroalgae species were identified at the NIOF site, including two Chlorophyta species (*Caulerpa racemosa* and *Halimeda macroloba*), four Phaeophyta species (*Padina boergesenii*, *Hormophysa cuneiformis*, *Sargassum aquifolium* and *Cystoseira myrica*), and one Rhodophyta species (*Digenea simplex*). In all seasons and locations, the brown seaweed *Cystoseira myrica* showed the highest biomass, averaging 1213 gm/m². Followed by the green sp., *Halimeda opuntia*, which recorded a fresh weight of 1083 gm/m². Finally, the current study shed highlights on the importance of nutrients, particularly phosphorus, in enhancing seaweed communities in two study sites.

1. INTRODUCTION

The Red Sea is a flooded valley that can be described as a young ocean, created by pulling apart of Africa and Arabia. It is a North-South elongation between 30°N and 12°E. Structurally, it is a part of the great rift-valley system forming one of the most marked features of the earth's crust (Bosworth *et al.*, 2020). This includes the Dead Sea, the Gulf of Aqaba, and the main basin of the Red Sea and extends southwards to include

some of the African great lakes (**Bosworth *et al.*, 2020**). The Red Sea is one of the world's closed seas, holding unique features specially in the northern part such as coral reefs (**Ghallab *et al.*, 2020**), seagrasses community (**Mahdy *et al.*, 2021a**), and dolphins (**Mahdy *et al.*, 2021b**).

Marine seaweeds (macroalgae) include the macroscopic, multicellular marine algae that commonly inhabit the coastal regions of the oceans where suitable substrata exist (**Santos *et al.*, 2015**). They are aquatic plants belonging to Thallophyta plant kingdom. Based on their pigmentation, Substrata can be classified into different taxonomic groups, viz. brown algae (Phaeophyceae), red algae (Rhodophyceae) and green algae (Chlorophyceae). Seaweeds can be found in the coastal zone during high and low tides, as well as in the sub-tidal zone up to a depth of 0.01% photosynthetic radiation (**Kim, 2012**).

Despite their benthic sessile function, macroalgae species have populations that are not uniform in space or time, but rather non-random and dynamically distributed along coastal rocky shores. These are the outcomes of complex ecological processes such as succession patterns, in which different species have different rates of recruitment, development and mortality (**Cervin *et al.*, 2005**). A diverse range of macroalgae species can be found in natural patches. These groups vary along a coastline in terms of the presence or absence (composition) of various organisms, both spatially and temporally. Different seaweed species, for example, have vertical distribution patterns that vary from the highest to the lowest tide levels, resulting in different zones of species or zonation patterns. This is due to the fact that various organisms have different adaptive responses to a range of physical (e.g., emersion or exposure to the atmosphere), chemical (e.g., salinity), and biotic (e.g., competition, grazing) factors that can impact where they reside on the shore (**Hurd *et al.*, 2014**). Macroalgae respond to a variety of environmental and physicochemical factors. Temperature, salinity, hydrodynamics, and wave exposure, as well as nutrients, carbon dioxide, and pH, all are important environmental factors that affect their survival, development, and reproduction (**Harley *et al.*, 2012**). These factors form latitudinal patterns of algal distribution (**Beratto-Ramos *et al.*, 2018**). The interactions of these parameters influence both the presence and the abundance of individual taxa. Nutrients are critical for seaweed growth; they are typically present in low concentrations in marine waters that are unaffected by anthropogenic inputs, which, in combination with grazing pressure (e.g., herbivorous fish), helps to maintain a healthy density of seaweeds (**Diaz-Pulido & McCook, 2008**). According to **Schaffelke *et al.* (2005)**, increasing nutrient levels boosts macroalgal growth and abundance. Sea urchins are universal herbivores that feed on attached algae in marine environments, ranging from shallow subtidal to depths of over 100 meters. They may primarily survive on detritus created in the shallow photic zone, catching these organic materials and thus regulating community structure in shallow algal habitats (**Whippo *et al.*, 2011**). **Jessen *et al.* (2012)** discovered that the increased nutrients had no effect on the composition of usable algae

classes in the central Red Sea; however, excluding larger herbivores increased the dry mass of non-coralline crusts and filamentous algae by 300 times. Herbivore exclusion combined with additional nutrient enrichment would increase the mass of these algae by 500 times.

Most of the mentioned previous studies on the seaweeds focused only on seaweeds as biota and neglected the relation with physicochemical parameters. Thus, the present study aimed to understand the relation between seaweeds and different marine parameters at different marine habitats (mangrove forest and sandy shore). Therefore, the objective of the current work was to comprehend the abundance and distribution status of the seaweeds community in the Red Sea in order to support the decision-maker to manage the natural resource, in particular the macroalgal community.

2. MATERIALS AND METHODS

2.1. Geomorphology of the study areas

A preliminary survey on the Egyptian Red Sea coast, using snorkeling led to the selection of two sites (Mangrove forest and NIOF site), which represent different hydrographic habitats along the coast of the Red sea (Fig. 1). The sampling sites could be described as follows:

2.1.1. Mangrove Site

Mangrove forest is located 17 km south of Safaga City and about 77 km to the south of Hurghada City. It lies between latitudes 26° 36' 59" N and longitudes 34° 00' 41" E. This site is distinguished by mangrove trees and shrubs of monospecific species *Avicenna marina* and an extended tidal zone (400m) formed from the raised quaternary terrace disrupted by sand patches overlaid by the mangrove trees near the coastline. This site is highly affected by some aspects, such as the land filling from the phosphate shipment, the effect of the shipyard, and many other human activities from Safaga harbor, fishing, and other coastal activities.

2.1.2. NIOF Site

NIOF Site is located in front of the National Institute of Oceanography and Fisheries (NIOF), Hurghada branch, about 5km north of Hurghada City. It is located between latitudes 27° 17' 13" N and longitudes 33° 46' 21" E. It is characterized by the widely distributed reef flats, extending for about 5 km seaward and including many diving sites and many coastal lagoons with depth variation between 1.5m and 6m. The inshore zone of this site suffers from underground wastewater seepage.

2.2. Fieldwork

Seawater samples were collected from the intertidal zone during the four seasons (summer & autumn 2017; winter & spring 2018). In the field, each site was located by using a global positioning system (GPS).

2.3. Physicochemical variables measurement

Seawater samples were seasonally collected from the studied sites in previously acid-washed polyethylene bottles and were immediately transferred in to the laboratory in an icebox. The samples were filtered through a 0.45µm membrane. Samples were directly deep-frozen till carrying out chemical analysis. Air and water temperature (C°), Hydrogen ion concentration (pH value), salinity, and dissolved oxygen (DO) were determined in the

field by using the multiparameter instrument (YSI ProODO Instruments). Four nutrients, viz. dissolved inorganic nitrite (NO_2), dissolved nitrate (NO_3), dissolved ammonium (NH_4) and dissolved inorganic phosphate (PO_4) were spectrophotometrically determined according to the methods of APHA (2005).

2.4. Seaweeds collection

The line transect method (LT, 25m length) and quadrat technique (1m^2) of English *et al.* (1997) were used to describe the community structure of the seaweed meadows in the two study sites (Fig. 1). For the measurement of the seaweed coverage at each transects, the mean of the quadrates was calculated.

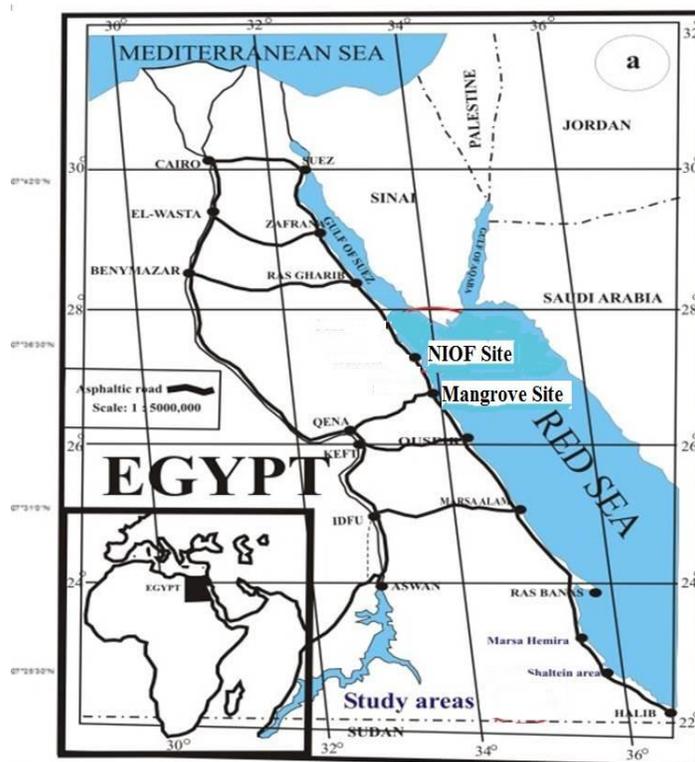


Fig. 1. Locations of the study areas; NIOF and mangrove sites, Red Sea coast, Egypt

3. RESULTS

3.1. Ecological factors at the two sites

3.1.1. Mangrove Site

The air temperature at this site ranged between 20.9°C in winter 2018 and 30.9°C in summer 2017, with a mean value of 25.8°C . Water temperature ranged between 20.8°C in winter 2018 and 27.5°C in autumn 2017, with a mean value of 24.6°C . The hydrogen ion concentration (pH) ranged between 8 in summer 2017 and 8.53 in winter 2018 and autumn 2017, with a mean value of 8.4. The dissolved oxygen ranged between 5.7 mg/l in summer and 7.1 mg/l in winter, with a mean value of 6.2 mg/l. The turbidity ranged between 7 NTU in both summer and autumn 2017 and 9 NTU in winter 2018, with a mean value of 7.6 NTU. The conductivity ranged between 62.8 ms/cm in summer and 64.4 ms/cm in spring 2018, with a mean value of 63.8 ms/cm. The salinity ranged

between 42.7‰ in winter and 43.3‰ in summer and spring, with a mean value of 43.0‰ (Table 1).

3.1.2. NIOF Site

The air temperature at the NIOF site ranged between 18.8°C in winter and 30.1°C in summer, with a mean value of 25.8°C. Water temperature ranged between 18.7°C in winter and 26.9 °C in summer, with a mean value of 23.7°C. The hydrogen ion concentration (pH) ranged between 8.1 in autumn and 8.5 in winter, with a mean value of 8.3. The dissolved oxygen ranged between 5.6 mg/l in autumn and 7.6 mg/l in winter, with a mean value of 6.6 mg/l. The turbidity ranged between 5 NTU in winter and 7 NTU in spring, with a mean value of 5.6 NTU. The conductivity ranged between 63.0 ms/cm in summer and 64.4 ms/cm in winter, with a mean value of 63.7 ms/cm. The salinity ranged between 41.6‰ in winter 2018 and 42.5‰ in summer, with a mean value of 42.1‰ (Table 1).

Table 1. Seasonal mean values and standard deviations of ecological factors at the two sites during investigation period

Season	Mangrove site						
	Temperature (°C)		pH	DO (mg/L)	Turbidity (NTU)	Conductivity (ms/cm)	Salinity (‰)
	Air	Water					
Summer 2017 Mean±SD	31.0±0.8	26.7±0.3	8.0±0.0	5.7±0.3	7.0±0.1	63.0±0.1	43.3±0.1
Autumn 2017 Mean±SD	27.0±0.2	27.5±0.1	8.3±0.2	6.1±0.1	7.0±0.1	64.0±0.1	43.1±0.1
Winter 2018 Mean±SD	21.0±0.2	20.8±0.1	8.5±0.1	7.1±0.2	9.0±0.0	64.0±0.1	42.7±0.3
Spring 2018 Mean±SD	24.4±0.4	23.5±0.4	8.5±0.4	5.4±0.2	7.2±0.9	64.4±0.2	43.3±0.2
Mean	25.8°C	24.6°C	8.4	6.2 mg/l	7.6 NTU	63.8 ms/cm	43.0‰
Season	NIOF site						
Summer 2017 Mean±SD	30.1±0.4	26.9±0.2	8.1±0.0	6.2±0.2	4.9±0.3	63.0±0.7	42.5±0.4
Autumn 2017 Mean±SD	28.3±0.7	26.7±0.5	8.1±0.0	7.2±0.4	5.8±0.3	63.3±0.2	42.1±0.1
Winter 2018 Mean±SD	18.8±0.3	18.7±0.3	8.5±0.2	7.6±0.4	5.0±0.8	64.3±0.4	41.6±0.5
Spring 2018 Mean±SD	26.0±0.3	22.6±0.6	8.3±0.3	5.6±0.3	7.0±0.6	64.2±0.1	42.3±0.3
Mean	25.8°C	23.7°C	8.3	6.6 mg/l	5.7 NTU	63.7 ms/cm	42.1‰

3.1.3. Statistical analysis

Statistical analysis of variance (MANOVA) indicated that dissolved oxygen, salinity, and turbidity were significantly different between the two sites ($p < 0.05$) as shown in Table (2). Using seasons as the independent variable and the ecological factors as dependent variables, a highly significant difference in all factors ($p < 0.01$) was observed (Table 2). The interaction between sites and seasons as independent factors and

ecological factors as dependent indicated that no significant differences were present in the studied ecological factors during the period of investigation, except for air temperature, dissolved oxygen, and turbidity, showing highly significant difference ($p < 0.03$) (Table 2).

Table 2: MANOVA for ecological factors: air and water temperature, hydrogen ion concentration, dissolved oxygen, turbidity, conductivity, salinity, and nutrients measured at the two sites during the four seasons

Source	Dependent variable	Type III Sum of Squares	df	Mean Square	F	Significant
Site	Air Temp	.002	1	.002	.008	.928
	Water Temp	.010	1	.010	.003	.957
	PH	.055	1	.055	1.303	.270
	DO	1.084	1	1.084	16.781	.001
	Cond	.069	1	.069	.723	.408
	Sali	5.199	1	5.199	60.144	.000
	Turb	21.470	1	21.470	87.042	.000
Season	Air Temp	365.28	3.00	121.76	613.908	.000
	Water Temp	289.59	3.00	96.53	27.272	.000
	PH	0.72	3.00	0.24	5.712	.007
	DO	9.36	3.00	3.12	48.299	.000
	Cond	7.21	3.00	2.40	25.088	.000
	Sali	1.90	3.00	0.63	7.328	.003
	Turb	5.15	3.00	1.72	6.961	.003
Season * Site	Air Temp	13.23	3.00	4.41	22.232	.000
	Water Temp	17.70	3.00	5.90	1.667	.214
	PH	0.09	3.00	0.03	.735	.546
	DO	1.47	3.00	0.49	7.611	.002
	Cond	0.59	3.00	0.20	2.049	.148
	Sali	0.12	3.00	0.04	.463	.712
	Turb	11.88	3.00	3.96	16.056	.000

3.2. Nutrients measurement

3.2.1. Nutrients at Mangrove Site

At the Mangrove Site, the dissolved ammonium ranged between 0.72 μM in summer and 0.37 μM in autumn, with a mean value of 0.50 μM (Table 3). The phosphate concentration ranged between 0.83 μM in winter and 0.14 μM in autumn, with a mean value of 0.39 μM . The nitrite measured during sampling ranged between 0.97 μM in winter 2018 and 0.22 μM in spring 2018, recording a mean value of 0.54 μM . The nitrate measured during sampling ranged between 3.7 μM in winter 2018 and 3.4 μM in spring 2018, and the mean value was 3.5 μM (Table 4).

3.2.2. Nutrients at NIOF Site

At the NIOF Site, the dissolved ammonium ranged between 1.07 μM in summer and 0.46 μM in autumn, with a mean value of 0.74 μM (Table 3). The phosphate concentration ranged between 0.46 μM in winter and 0.11 μM in summer, with a mean value of 0.23 μM . The nitrite measured during sampling ranged between 0.99 μM in summer and 0.40 μM in winter, with a mean value of 0.64 μM . The nitrate measured during sampling ranged between 4.40 μM in summer and 2.85 μM in winter and recorded a mean value of 3.7 μM as shown in Table (3).

Table 3. Seasonal means of the dissolved nutrients (μM) at two study sites during the four seasons of the study period

Season	Mangrove site			
	NH_4 (μM)	Po_4 (μM)	No_2 (μM)	No_3 (μM)
Summer 2017 Mean \pm SD	0.72 \pm 0.01	0.16 \pm 0.01	0.25 \pm 0.01	3.46 \pm 0.02
Autumn 2017 Mean \pm SD	0.37 \pm 0.02	0.14 \pm 0.00	0.71 \pm 0.03	3.54 \pm 0.02
Winter 2018 Mean \pm SD	0.41 \pm 0.00	0.83 \pm 0.01	0.97 \pm 0.02	3.70 \pm 0.02
Spring 2018 Mean \pm SD	0.50 \pm 0.07	0.44 \pm 0.00	0.22 \pm 0.01	3.39 \pm 0.09
Mean	0.50	0.39	0.54	3.5
Season	NIOF site			
Summer 2017 Mean \pm SD	1.07 \pm 0.02	0.11 \pm 0.02	0.99 \pm 0.04	4.40 \pm 0.10
Autumn 2017 Mean \pm SD	0.46 \pm 0.02	0.24 \pm 0.02	0.63 \pm 0.01	3.50 \pm 0.01
Winter 2018 Mean \pm SD	0.58 \pm 0.01	0.46 \pm 0.01	0.40 \pm 0.01	2.85 \pm 0.03
Spring 2018 Mean \pm SD	0.87 \pm 0.01	0.13 \pm 0.00	0.53 \pm 0.00	4.22 \pm 0.26
Mean	0.74	0.23	0.99	3.7

3.2.3. Statistical analysis

Statistical analysis of variance (MANOVA) indicated that highly significant differences of the studied nutrients were detected between the two sites during the period of investigation ($p < 0.01$) in sites, season and season*site (Table 4). Further statistical analysis (LSD) in Table (6) revealed significant differences in the nutrients among seasons at the two investigated sites. This leads to the following conclusions: The mean value of dissolved ammonium, nitrite, nitrate, and phosphate at the four seasons gave highly significant differences ($p < 0.01$) between each other.

Table 4. MANOVA for nutrients: Ammonia, Phosphate, Nitrite and Nitrate at two sites during four seasons

Source	Dependent variable	Type III Sum of Squares	Df	Mean Square	F	Signification
Site	Ammonium	0.360	1	.360	419.592	.000
	Phosphate	0.152	1	.152	701.558	.000
	Nitrite	0.060	1	.060	102.857	.000
	Nitrate	0.284	1	.284	68.670	.000
Season	Ammonium	0.82	3.00	0.27	317.126	.000
	Phosphate	0.94	3.00	0.31	1450.429	.000
	Nitrite	0.38	3.00	0.13	214.990	.000
	Nitrate	1.54	3.00	0.51	124.254	.000
Season * Site	Ammonium	0.08	3.00	0.03	32.434	.000
	Phosphate	0.22	3.00	0.07	333.763	.000
	Nitrite	1.40	3.00	0.47	798.990	.000
	Nitrate	3.17	3.00	1.06	255.681	.000

3.3. The distribution of seaweed community at the two sites

In the present study, the common macroalgae species at the two sites were collected. At the Mangrove Site, ten macroalgae species were recorded, three species of Chlorophyta (*Caulerpa racemosa*, *Halimeda opuntia* and *Halimeda macroloba*), five species of Phaeophyta (*Padina boergesenii*, *Sargassum aquifolium*, *Hormophysa cuneiformis*, *Turbinaria turbinata* and *Cystoseira myrica*), two species of Rhodophyta (*Digenea simplex* and *Actinotrichia fragilis*). At the NIOF Site, seven macroalgae species were recorded, two species of Chlorophyta (*Caulerpa racemosa* and *Halimeda macroloba*), four species of Phaeophyta (*Padina boergesenii*, *Hormophysa cuneiformis*, *Sargassum aquifolium* and *Cystoseira myrica*), in addition to one species of Rhodophyta (*Digenea simplex*) as presented in Fig. (2).

3.4.1. Site 1

The algal fresh weight at this site ranged between 873 gm/m² in spring 2018 and 593 gm/m² in summer 2017, with a mean value of 712 gm/m². While, the dry weight ranged between 218 gm/m² in spring 2018 and 81 gm/m² in winter 2018, with a mean value of 164 gm/m² (Table 5).

3.4.2. Site 2

The fresh weight of algal samples at this site ranged between 893 gm/m² in spring 2018 and 286 gm/m² in summer 2017, with a mean value of 620 gm/m². The dry weight ranged between 150 gm/m² in spring 2018 and 50 gm/m² in summer 2017, with a mean value of 109 gm/m² (Table 5).



Fig. 2. Common seaweed species collected from the two sites showing; **A)** *Caulerpa racemose*; **B)** *Halimeda opuntia*; **C)** *Hormophysa cuneiformis*; **D)** *Cystoseira myrica*; **E)** *Digenea simplex*; **F)** *Actinotrichia fragilis*; **G)** *Sargassum aquifolium* and **H)** *Padina boergesenii*

3.4.3. Statistical analysis

Statistical analysis of variance (MANOVA) indicated that significant differences of the studied fresh weight and dry weight were observed between the two sites during the period of investigation ($p < 0.05$) (Table 6). In the case of season and season*site, only fresh weight showed a significant difference ($p < 0.05$) (Table 6).

Table 5. Seasonal means of fresh and dry weights at the two sites during four seasons

Season	Mangrove Site	
	F.W	D.W
Summer 2017 Mean \pm SD	593.33 \pm 45.09	166 \pm 14.73
Autumn 2017 Mean \pm SD	733.33 \pm 72.86	193 \pm 76.54
Winter 2018 Mean \pm SD	650.00 \pm 87.89	82 \pm 12.58
Spring 2018 Mean \pm SD	873.33 \pm 55.08	218 \pm 108.29
Mean	712	164
Season	NIOF Site	
Summer 2017 Mean \pm SD	288.67 \pm 66.58	50.33 \pm 14.64
Autumn 2017 Mean \pm SD	750.00 \pm 136.11	98.33 \pm 72.06
Winter 2018 Mean \pm SD	550.00 \pm 170.59	140.00 \pm 119.06
Spring 2018 Mean \pm SD	893.33 \pm 117.30	150.00 \pm 25.98
Mean	620	109

Table 6. MANOVA for fresh and dry weight at two sites during four seasons

Source	Dependent variable	Type III Sum of Squares	Df	Mean Square	F	Sig.
Site	Fresh weight	51337.50	1.00	51337.50	4.894	.04
	Dry Weight	18205.04	1.00	18205.04	4.314	.05
Season	Fresh weight	650345.83	3.00	216781.94	20.666	.000
	Dry Weight	22817.46	3.00	7605.82	1.802	.18
Season * Site	Fresh weight	105745.83	3.00	35248.61	3.360	.04
	Dry Weight	27440.79	3.00	9146.93	2.168	.013

3.5. The biomass of common seaweeds species at the two sites

In the current study, the two sites were different in seaweeds' fresh weight biomass. The total biomass at the Mangrove Site was higher compared to that at the NIOF Site during the survey time except for autumn 2017 and spring 2018 (Table 7). The brown species, *Cystoseira myrica*, showed the highest biomass in all seasons and sites and accounted about 1213 gm/m², with a biomass average of 294 gm/m² of fresh weight at the Mangrove Site in winter 2018. While, the lowest biomass average of 65 gm/m² of fresh wt. was recorded in winter 2018 at the NIOF site (Table 7).

The green sp., *Halimeda opuntia* was the followed biomass, with 1083 gm/m² of fresh wt. The highest seaweed fresh weight biomass was 412 gm/m² at the Mangrove Site in the spring season, while the lowest average biomass was 82 gm/m² at the NIOF site in summer (Table 7).

Table 7. Seasonal change and percentage biomass of seaweeds at the study sites

Taxa	Season	Summer 2017				Autumn 2017				Winter 2018				Spring 2018			
	Site	Mangrove		NIOF		Mangrove		NIOF		Mangrove		NIOF		Mangrove		NIOF	
	Units	g/m ²	%	g/m ²	%	g/m ²	%	g/m ²	%								
Chlorophyta	<i>Halimeda opuntia</i> (Linnaeus) Lamouroux	-	-	82	28.4	380	55.1	-	-	-	-	209	38	412	47	0	-
	<i>Caulerpa racemosa</i> var. <i>gracilis</i> (Zanardini)	-	-	57	19.7	-	-	15	2	104	16	-	-	-	-	137	13.2
	<i>Caulerpa strularoides</i> (S.G.Gmelin)	-	-	-	-	-	-	-	-	-	-	-	-	5	1	134	12.9
	<i>Halimeda macroloba</i> (Decaisne.)	240	40.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Phaeophyta	<i>Padina boergesenii</i> (Alender and Kraft)	67	11.2	34	11.6	-	-	74	9.8	-	-	134	24	37	4	284	27.4
	<i>Cystoseira myrica</i> C.Agardh (S.G.Gmelin)	80	13.4	-	-	212	31	80	10.6	294	45	65	12	215	25	267	25.7
	<i>Hormophysa cuneiformis</i> (Gmelin) Silva	-	-	57	19.7	59	8.5	65	8.6	254	39	-	-	-	-	-	-
	<i>Sargassum aquifolium</i> ((Turner) C. Agardh)	97	16.2	59	20.4	-	-	517	68.8	-	-	-	-	-	-	-	-
Rhodophyt	<i>Actinotrichia fragilis</i> (Forsskal) Børgesen.)	-	0	-	-	-	-	-	-	-	-	-	-	97	11	15	1.4
	<i>Digenea simplex</i> (Wulfen) C. Agardh)	114	19.1	-	0	39	5.6	-	-	144	26	-	-	107	12	200	19.3
Mean		119.6	16.7	57.8	16.7	20	25	150	20	217.3	33.3	138	25	145.5	16.7	148.1	17.35
Total		598	100	289	100	100	100	751	100	652	100	552	100	873	100	1037	100

4. DISCUSSION

4.1. Ecological parameters

Macroalgae interact with their physical surroundings and communicate with other marine species. This dynamic physicochemical climate is constantly changing and includes all external abiotic factors affecting the organism (Hurd *et al.*, 2014). In this analysis, the pattern of variations in physico-chemical parameters was assessed for the surveyed sites over four seasons. In the current study, two sites were surveyed in Safaga (Mangrove Site) and Hurghada (NIOF Site).

4.1.1. Physico-chemical parameters

The most important abiotic factor that influences the distribution and abundance of marine vegetation either directly or indirectly is water temperature. During the investigation period, the distribution of the documented algal species were detected at the study seashores (summer 2017 to spring 2018). This can be expressed by Van Hoff's rule which states that, a rise in temperature to 10°C within the tolerable limits can increase the rate of biological processes by three times. The impact of water temperature on algal vegetation was observed during the current study, and it was manifested in the periodicity

of individual organisms. Thus, the standing crop of the major algal groups are recorded in the algal communities. This could point to a seasonal pattern that corresponds to temperature shifts. This is also consistent with **Garzke *et al.* (2019)** and **Hala *et al.* (2021)**, who discovered that water temperature influences species distribution. Algal species biomass was low in winter 2018, and a gradual rise was detected through the summer and early spring (**Pawlita-Posmyk *et al.*, 2018**).

The variations in water temperature in the present study were strictly linked to seasonal changes, with a minimum variation in winter 2018 at the NIOF Site and a maximum in autumn 2017 at the Mangrove Site, with no significant difference between the sites. This may be related to the similar areas where the two study sites are situated. The most important abiotic factor that directly or indirectly affects the distribution and abundance of marine biota, especially flora, is water temperature (**Ibraheem *et al.*, 2014**). Due to several factors, such as latitude, sun altitude, water depth, wind, season, waves, and heat gain or loss in shallow waters close to the land, it is subject to large variations. Similar results have been reported in the studies of **Abdelmongy and El-Moselhy (2015)** and **Fahmy *et al.* (2016)** in the months of summer. The NIOF Site is a coastal lagoon, while the Mangrove Site represents a coastal habitat and the surface water temperature in these sites may be influenced by the intensity of solar radiation, evaporation, and cooling and mixes up with subsides and flows from adjoining littoral waters (**Kumar *et al.*, 2017**).

In the current study, turbidity varied significantly among seasons; the maximum average of turbidity was 9 NTU in winter 2018 at the Mangrove Site, while the minimum average was recorded in summer at 4.87 NTU at the NIOF Site. The turbidity of seawater is one of the significant environmental factors with an important impact on marine organisms. Even one meter below the water surface, turbid water prevents light from penetrating. This decreases the level of macrophyte photosynthesis in the deeper layers (**Hurd *et al.*, 2014**). Water turbidity, by stirring up the bottom, is governed by wave action, tides, wind agitation and rainfall. Thus, fine sand and mud particles or settled particles are re-suspended in shallow areas, such as the case in the current study area. It fluctuated between sites as well. The more prominent variations in the Mangrove Site could be attributed to the turbid nature of the coastal waters triggering by land runoff (**Kumar *et al.*, 2017**). In the same manner, the two sites were very shallow, with high sedimentation rates and high turbid environments.

In the current study, the pH value was different in terms of seasons and locations. It was discovered on the alkaline side at the Mangrove Site, recording a maximum value in winter 2018 and spring and a minimum value in summer. Generally, **Hajjalizadeh *et al.* (2020)** and **Singh (2020)** postulated that, the seasonal variation could be attributed to factors, such as CO₂ removal by photosynthesis through bicarbonate degradation, low primary productivity, reduction of salinity and temperature, in addition to organic matter decomposition. Hydrogen ion concentration is one of the major environmental variables for metabolism, physiology, chemical processes, aquatic organism growth and survival (**Neina, 2019**).

In terms of salinity, it is worthnoting that marine algae can tolerate a wide range of salinities. Remarkably, no major variations were found in salinity between the locations under survey. This may explain the presence or absence of species that grow there. This result is consistent with the finding of **Alves *et al.* (2021)** who assessed that,

salinity is a dominant factor affecting both the local distribution and growth of algae. The salinity in the studied area varied between 44 ‰ in summer at the Mangrove Site and 42 ‰ at the NIOF Site in winter 2018. The highest salinity values were observed during the summer season in the study period, and this could be related to higher temperatures, leading to increased seawater evaporation rates (Ibraheem *et al.*, 2014). In the current study, the salinity was higher than the mean values recorded by Abdelmongy and El-Moselhy (2015) compared to the previous studies but similar to the results recorded in the study of Fahmy *et al.* (2016).

The amount of dissolved oxygen in water is determined with respect to the temperature and the salinity of water (Saravanakumar *et al.*, 2008). It also depends on how much organic matter is present in the aquatic system. When organic matter decomposes in large quantities, it absorbs too much dissolved oxygen in water (Shakweer, 2003). In the current study, the general distribution of DO revealed high values and the presence of well-oxygenated waters. It ranged from 5.4 mg/l in spring to 7.1 mg/l at the Mangrove Site in winter 2018. For a general trend, the lowest concentrations of DO were detected during summer and spring. This result agrees with the fact that dissolved oxygen declines with increasing temperature and salinity (Calliari *et al.*, 2005). The highest DO value during winter 2018 could be due to the swelling effect of higher wind velocity and the mix of fresh water through rainfall (Neina, 2019).

2.2. Nutrients

Nutrients are one of the most important factors affecting the growth, reproduction, and metabolic activities of marine organisms in the estuarine and coastal ecosystem. The distribution of nutrients is influenced by tidal conditions, freshwater drift from land sources and seasons (Vengadesh *et al.*, 2010; Abdelmongy & El-Moselhy, 2015). They are present in small concentrations in marine waters, despite their importance for seaweed development (Jevne *et al.*, 2020). In the current study, nitrite was highly variable between sites and seasons. During winter 2018 at the mangrove site when water mixing was at its peak, the highest nitrite concentration was 1.0 μM . Increased phytoplankton excretion, ammonia oxidation, nitrate reduction, and nitrogen recycling can all contribute to nitrite accumulation in the water column. In addition, it may be attributed to the bacterial decomposition of planktonic detritus in the water (Rashedy, 2015). Nitrate is the most stable and common inorganic nitrogen form in seawater. It is naturally produced as part of the nitrogen cycle when bacteria convert toxic ammonia wastes to nitrite, which is then converted to nitrate (Abdelmongy & El-Moselhy, 2015). During this study, dissolved nitrate was highly significantly varied among sites and seasons. The higher nitrate value of 4.4 μM was recorded in summer at the NIOF Site. Qutob *et al.* (2002) reported that, expanding the winter mixing increased nitrate enrichment from deeper water into the euphotic zone, while the lowest value was recorded in winter (2.85 μM). As evidenced by the high phytoplankton population, this could be due to its use by phytoplankton (Rashedy, 2015). Additionally, this phenomenon may be related to the dominance of neritic water, which only contains a small amount of nitrate (Govindasamy *et al.*, 2000). In seawater, nitrate is the most stable and main inorganic form of nitrogen that is naturally formed as part of the nitrogen cycle when a bacterium breaks down toxic ammonia wastes into nitrite, then nitrate (Abdelmongy and El-Moselhy, 2015).

Ammonium is formed when bacteria decompose nitrogen-containing natural organic matter, and it can be used directly as a nutrient by a variety of algal species and

aquatic plants (**Hurd *et al.*, 2014**). The amount of dissolved ammonium in water differed significantly among sites and seasons in the current sample. The maximum values were recorded in summer at the NIOF Site, while the minimum values occurred in autumn 2017 at the Mangrove Site. On the other hand, the NIOF Site showed the highest value, which may be attributed to ammonia mineralization from dead seagrass and organic matter oxidation from dead plants and animals associated with vegetation (**Vasudevan *et al.*, 2012**).

Phosphorus, which is mostly available as the inorganic ions PO_4^{3-} or H_2PO_4^- , is not the most important nutrient for macroalgal development (**Hurd *et al.*, 2014**). Carbonate sediments near coral reefs in shallow waters serve as phosphate sinks, decreasing the amount of phosphorus available to seaweed (**Jevne *et al.*, 2020**). In this study, dissolved inorganic phosphate of seawater fluctuated among the investigated sites and seasons. The Mangrove Site recorded the highest value of phosphate, compared to other sites, while the lowest values occurred at the site of the NIOF. On the other hand, the highest concentrations of phosphate occurred in winter 2018. This could be related to the light limitation of phytoplankton growth. Moreover, the dinoflagellates and blue-green algae showed their maximum flourishing during those seasons (**Ohtake *et al.*, 2020**).

4.3. Seaweed distribution at the two sites

In the current study, common macroalgae species at the two sites were collected. In the Mangrove Site, ten macroalgae species were recorded, compared to seven species of macroalgae at the NIOF Site. The distribution of macroalgae in the Red Sea was different according to habitat and physicochemical parameters. In the present study, low macroalgae species were recorded compared to other work in the same areas. However, **El-Manawy *et al.* (2019)** recorded 36 seaweed species from three sites in the Red Sea. The result of the present study matches with several Red Sea works and some of the surrounding studied habitats, such as the Shalateen-Halaib sector (**El-Manawy & Gaballa, 2000**), Zabargad Island (**El-Manawy, 2001**), the Al-Shoaiba region of Saudi Arabia, the Red Sea (**El-Shoubaky & Kaiser, 2014**), and along the Suez Canal (**Farghaly & El-Shoubaky, 2015**). Approximately, 32 species of seaweed were observed in Hurgada reef on the Egyptian Red Sea coast (**El-Manawy, 2008**), and 19 species on the Umluj northwest coast of the Red Sea near Saudi Arabia (**Ibraheem *et al.*, 2014**). In the current study, the NIOF Site possesses ten macroalgae species and the Mangrove Site owns seven species. In addition, previous studies confirmed that these species were dominant at various Red Sea sites (**El-Manawy *et al.*, 2000**; **El-Manawy & Gaballa, 2000**; **El-Manawy, 2001**; **El-Shoubaky & Kaiser, 2014**; **Ibraheem *et al.*, 2014**; **Kamal, 2014**).

4.4. Seaweed species biomass and abundance

In the current study, the seaweed species, *Cystoseira myrica* and *Halimeda opuntia*, recorded the highest biomass in all seasons and sites. This may be due to the highest level of nutrients measured in the current study. This finding coincides with that of **Yaakob *et al.* (2021)** who found that, the nutrient concentration increases algal biomass. The current study concurs with the results of **Kamal (2014)** and **El-Manawy *et al.* (2019)**. The previous authors found that the highest seaweed cover was *Polycladia myrica*, *Sargassum aquifolium* and *Padina boergesenii*.

4.5. Relation between Macroalgae and nutrients

In the current study, the seaweed species differed regarding the two sites; the Mangrove Site recorded the highest fresh weight of algal biomass in all seasons except in autumn 2017. Similarly, the NIOF Site showed the highest value in the autumn 2017, but with no exceptions. This is related to the increase of phosphorus and dissolved ammonia in NIOF compared to the Mangrove Site. Nitrate and phosphate levels, as predicted, had a significant impact on algal development. **Pietilainen and Niinioja (2001)** found that nitrate levels had no significant impact on algal development, which contradicted with the present findings. Their research, however, took place at different sites and in various seasons. Both nitrogen and phosphates increase algal biomass (**Fried et al., 2003**). Notably, phosphorus is essential for microalgae development, particularly in terms of generating and converting metabolic energy (**Sun & Wang, 2009**). Phosphorus is a nutrient required for the formation of cells, nucleotides and nucleic acids (**Siedliska et al., 2021**). **Ren et al. (2017)** found that phosphate levels had no major impact on algal development, contradicting those findings. However, phosphate was not included as a component in their research. Rather, they looked at the impact of a variety of herbicides on algal growth in the presence of high or low phosphate concentrations. The herbicide's effects on algal growth were not affected by phosphate levels. In comparison, the researchers in the current study addressed the impact of phosphate levels on algal growth.

5. REFERENCES

- Abdelmongy, A.S. and El-Moselhy, K.M. (2015).** Seasonal Variations of the Physical and Chemical Properties of Seawater at the Northern Red Sea, Egypt. *Open Journal of ocean and coastal sciences*, 2(1): 7–15.
- Alves, J. de P.; Bessa Junior, A. P. and Henry-Silva, G. G. (2021).** Salinity tolerance of macroalgae *Gracilaria birdiae*. *Ciencia Rural*, 51(1): 1–7. <https://doi.org/10.1590/0103-8478cr20190958>.
- APHA, (2005).** Standard methods for the examination of water and waste water, 21st Edn, American Public Health Association, Washington. 25 pp.
- Beratto-Ramos, A.; Castillo-Felices, R.d.P.; Troncoso-Leon; Agurto-Muñoz, A. and Agurto-Muñoz, C. (2018).** Selection criteria for high-value biomass: seasonal and morphological variation of polyphenolic content and antioxidant capacity in two brown macroalgae. *J Appl Phycol*, 31(1) 653–664. <https://doi.org/10.1007/s10811-018-1528-9>.
- Bosworth, W.; Khalil, S. M.; Ligi, M.; Stockli, D. F. and McClay, K. R. (2020).** Geology of Egypt: The Northern Red Sea. Springer, Cham. (343–374). https://doi.org/10.1007/978-3-030-15265-9_9.
- Calliari, D.; Gómez, M.; and Gómez, N. (2005).** Biomass and composition of the phytoplankton in the Río de la Plata: Large-scale distribution and relationship with environmental variables during a spring cruise. *Continental Shelf Research*, 25(2): 197–210. <https://doi.org/10.1016/j.csr.2004.09.009>.

- Cervin, G.; Aberg, P. and Jenkins, S.R.** (2005). Small-scale disturbance in a stable canopy dominated community: implications for macroalgal recruitment and growth. *Marine Ecology Progress Series*, 305: 31–40.
- Chung, I.K., Beardalla, J.; Mehta, S.; Sahoo, D. and Stojkovic, S.** (2007). Using marine algae for carbon sequestration: a critical appraisal. The United Nations Framework Convention on Climate Change, UNFCCC, and the Fourteenth Conference of the Parties, COP-14, Side event of seaweed coastal CO₂ removal belt in Korea & algal paper and biofuel, 1–12 December 2008, Ponzan, Poland.
- Diaz-Pulido, G. and McCook, L.J.** (2008). Effects of nutrient enhancement of the fecundity of a coral reef macroalgae. *Journal of Experimental Marine Biology and Ecology*, 317:13–24.
- Dubertret, L.** (1970): Review of structural geology of the Red Sea and surrounding areas. *Philos. Trans. R. Soc. Lond. A.*, 267: 9–20.
- El-Manawy, I. M.; Hamdy A. A.; El-Deek, M. S. and Mohammed, A. A.** (2000). Seasonal variations in iodine content of some seaweeds from the great Bitter Lake, Egypt. *Bull. Fac. Sci., Assiut Univ.*, 29: 199–209.
- El-Manawy, I.M.** (2001). Floristic composition and zonation of seaweeds on Zabargad coral reef (Red Sea, Egypt). *Taekolmia*, 21 (1): 115–134.
- El-Manawy, I.M.** (2008). The spatial variability of macroalgal communities and their functional groupings on the fringing reefs of Ghardaqah, Egypt. *Egyptian J of Phycology*, 9: 55–69.
- El-Manawy, I.M. and Gaballa, A.F.A.** (2000). Distribution and diversity of seaweeds on coral reefs at Shalateen–Halaib sector (Red Sea, Egypt). *Proc. 1st Int. Conf. Biol. Sci. Tanta Univ.*, 1: 45–60.
- El-Manawy, I.M.; Nassar, M.Z.; Fahmy, N.M. and Rashedy, S.H.** (2019). Evaluation of proximate composition, antioxidant and antimicrobial activities of some seaweeds from the Red Sea coast, Egypt. *Egypt. Aqu. Sci. & Fish Res.*, 23(1): 317 – 329.
- El-Shoubaky, G.A. and Kaiser, M.A.** (2014). Monitoring Spatial and Temporal Seaweeds Variation Using Remote Sensing Data in Al-Shoaiba Coast, Red Sea. *British Journal of Environment & Climate Change*, 4(4): 409–422.
- English, S.; Wilkinson, C. and Baker, V.** (1997). *Survey Manual for Tropical Marine Resources*. Australian Institute of Marine Science, Townsville. Australia. pp. 34–49.
- Fahmy, M.A; Abdel Fattah L.M.; Abdel-Halim, A.M.; Aly-Eldeen1 M.A.; Abo-El-Khair E.M.; Ahdy H.H.; Hemeilly A.; El-Soud, A. and Sheridan, M.** (2016). Evaluation of the Quality for the Egyptian Red Sea Coastal Waters during 2011-2013. *Journal of Environmental Protection*, 7: 1810–1834.
- Farghaly, M.S. and El-Shoubaky, G.A.** (2015). Synopsis of Biodiversity and Distribution of Macrophytes along the Suez Canal in Time and Space. *International Conference on Plant, Marine and Environmental Sciences (PMES-2015) Jan. 1-2, Kuala Lumpur (Malaysia)*.

- Fouda, M. (1993).** The Red Sea habitat diversity. In M. Kassas (ed.). Habitat Diversity: Egypt. Publication of the National biodiversity Unit, No. I. 256-302.
- Fried, S.; Mackie, B. and Nothwehr, E. (2003).** Nitrate and phosphate levels positively affect the growth of algae species found in Perry Pond. *Tillers*, 4: 21–24.
- Garzke, J.; Connor, S.J.; Sommer, U. and O’connor, M.I. (2019).** Trophic interactions modify the temperature dependence of community biomass and ecosystem function. *PLoS Biology*, 17(6) e2006806. <https://doi.org/10.1371/journal.pbio.2006806>.
- Ghallab, A.; Mahdy, A.; Madkour, H. and Osman, A. (2020).** Distribution and Diversity of Living Natural Resources from the Most Northern Red Sea Islands, Egypt: I- Hard and Soft Corals. *Egypt. Aqu. Sci. & Fish Res.*, 24(5): 125-145.
- Hajjalizadeh, P.; Safaie, M.; Naderloo, R.; Shojaei, M. G.; Gammal, J.; Villnäs, A. and Norkko, A. (2020).** Species Composition and Functional Traits of Macrofauna in Different Mangrove Habitats in the Persian Gulf. *Frontiers in Marine Science*, 7, 809. <https://doi.org/10.3389/fmars.2020.575480>.
- Hala, S. Doma; Moghazy, R. M. and Mahmoud, R. H. (2021).** Environmental factors controlling algal species succession in High Rate Algal Pond. *Egyptian Journal of Chemistry*, 64(2): 729–738. <https://doi.org/10.21608/EJCHEM.2020.38324.2788>.
- Harley, C.D.G.; Anderson, K.M.; Demes, K.W.; Jorve, J.P.; Kordas, R.L.; Coyle, T.A. and Graham, M.H. (2012).** Effects of Climate Change on Global Seaweed Communities. *Journal of Phycology*, 48(5): 1064–1078.
- Hurd, C.L.; Harrison P.J.; Biscoff, K. and Lobban, C.S. (2014).** *Seaweed Ecology and Physiology*. Cambridge University Press, United Kingdom.
- Ibraheem, B.M.; Alharbi, R.M; Abdel-Raouf, N. and 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.
- Jessen, C.; Roder, C.; Lizcano, J.V.; Voolstra, C.R. and Wild, C. (2012).** Top-down and bottom-up effects on Red Sea coral reef algae; Proceeding of the 12th International coral reef symposium, cairns, Australia, 9–13.
- Jevne, L. S.; Forbord, S. and Olsen, Y. (2020).** The Effect of Nutrient Availability and Light Conditions on the Growth and Intracellular Nitrogen Components of Land-Based Cultivated *Saccharina latissima* (Phaeophyta). *Frontiers in Marine Science*, 7, 914. <https://doi.org/10.3389/fmars.2020.557460>.
- Kamal, H. (2014).** Seaweed as health status indicator for Ghardaqah coral reef. Master science thesis. Environmental science department, faculty of science, Suez Canal University.
- Kim, Se-Kwon (2012).** *Handbook of Marine Macroalgae: Biotechnology and Applied Phycology*. Hoboken, NJ: John Wiley & Sons. 30 PP.
- Kumar, S. D.; Santhanam, P.; Ananth S.; Kaviyarasan, M.; Dhanalakshmi, B.; Park, M.S. and 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):19–33.

- Mahdy, A.; Ghallab, A.; Madkour, H. and Osman, A.** (2021a). Status of Seagrass community in Northern Protected Islands, Hurghada, Red Sea, *Aquatic Science and Fish Resources.*, 2: 1–8. DOI: 10.21608/asfr.2021.55440.1011.
- Mahdy, A.; Ghallab, A.; Madkour, H. and Osman, A.** (2021b). Status of Indo-Pacific Bottlenose Dolphin, *Tursiops aduncus* (Family Delphinidae: Order Cetacea) in the Northern Protected Islands, Hurghada, Red Sea, Egypt. *Egypt. Aqu. Sci. & Fish Res.*, 25(1): 681–697.
- Neina, D.** (2019). The Role of Soil pH in Plant Nutrition and Soil Remediation. In *Applied and Environmental Soil Science*. Applied and Environmental Soil Science, ID 5794869, 9 pp. <https://doi.org/10.1155/2019/5794869>.
- Ohtake, M.; Natori, N.; Sugai, Y.; Tsuchiya, K.; Aketo, T.; Nishihara, G. N. and Toda, T.** (2020). Growth and nutrient uptake characteristics of *Sargassum macrocarpum* cultivated with phosphorus-replete wastewater. *Aquatic Botany*, 163, 103208. <https://doi.org/10.1016/j.aquabot.2020.103208>.
- Pawlita-Posmyk, M.; Wzorek, M. and Placzek, M.** (2018). The influence of temperature on algal biomass growth for biogas production. In: *MATEC Web of Conferences*, 240, ID 04008. 1–7. <https://doi.org/10.1051/mateconf/201824004008>.
- Pietilainen, O. P. and Niinioja, R.** (2001). Nitrogen and phosphorus as algal growth limiting factors in a boreal lake. *International Association of Theoretical and Limnology*, 27: 2944–2947.
- Qutob, D.; Kemmerling, B.; Brunner, F.; Kűfner, I.; Engelhardt, S.; Gust, A. A.; Lubracki, B.; Seitz, H.U.; Stahl, D.; Rauhut, T.; Glawischnig, E.; Schween, G.; Lacombe, B.; Watanabe, N.; Lam, E.; Schlichting, R.; Scheel, D.; Nau, K.; Dodt, G. and Nürnbergger, T.** (2006). Phytotoxicity and innate immune responses induced by Nep1-like proteins. *Plant Cell*, 18(12): 3721–3744. <https://doi.org/10.1105/tpc.106.044180>.
- Rashedy, S.H.** (2015). Ecophysiological studies on the phytoplankton along the north western area of the Red Sea, Egypt. Master thesis in Botany (Phycology). Botany department, South Valley University. 206 pp.
- Ren, L.; Wang, P.; Wang, C.; Chen, J.; Hou, J. and Qian, J.** (2017). Algal growth and utilization of phosphorus studied by combined mono-culture and co-culture experiments. *Environmental Pollution*, 220: 274–285. <https://doi.org/10.1016/j.envpol.2016.09.061>.
- Santos, S.A.O.; Vilela, C.; Freire, C. S. R.; Abreu, M. H.; Rocha, S. M. and Silvestre, A. J. D.** (2015). Chlorophyta and Rhodophyta macroalgae: A source of health promoting phytochemicals. *Food Chemistry*, 183: 122–128. doi: 10.1016/j.foodchem.2015.03.006. Epub 2015 Mar 11.

- Saravanakumar, A.; Rajkumar, M.; Sesh Serebiah, J. and Thivakaran, G.A.** (2008). Seasonal variations in physico-chemical characteristics of water, sediment and soil texture in arid zone mangroves of Kachchh-Gujarat. *J. Environ. Biol.*, 29: 725–732.
- Schaffelke, B.; Mellors, J. and Duke, N.C.** (2005). Water quality in the Great Barrier Reef region: responses of mangrove, seagrass and macroalgal communities. *Marine pollution Bulletin*, 51:279–296.
- Shakweer, L.** (2003). Ecological and fishery investigations of Nozha Hydrome near Alexandria 2000- 2001. 1. Chemistry of Nozha Hydrome water under the conditions of fertilizers applications. *Bulletin National Institute of Oceanography and Fishers*. 29: 387–425.
- Siedliska, A.; Baranowski, P.; Pastuszka-Woźniak, J.; Zubik, M. and Krzyszcak, J.** (2021). Identification of plant leaf phosphorus content at different growth stages based on hyperspectral reflectance. *BMC Plant Biology*, 21(1), 1–17. <https://doi.org/10.1186/s12870-020-02807-4>.
- Singh, J. K.** (2020). Structural characteristics of mangrove forest in different coastal habitats of Gulf of Khambhat arid region of Gujarat, west coast of India. *Heliyon*, 6(8). <https://doi.org/10.1016/j.heliyon.2020.e04685>.
- Sun, Y. and Wang, C.** (2009). The optimal growth conditions for the biomass production of *Isochrysis galbana* and the effects that phosphorus, Zn^{2+} , CO_2 and light intensity have on the biochemical composition of *Isochrysis galbana* and the activity of extracellular CA. *Biotechnol. Bioprocess Eng.*, 14: 225–231.
- Vasudevan, S.; Dinesh Kumar, S.; Kathiresan, M.; Jayalakshmi, T.; Kaviyarasan, M.; Rameshkumar, A.; Nandakumar, R. and 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.
- Vengadeshperumal, N.; Damotharan, P.; Rajkumar, M.; Perumal, P.; Vijalakshmi, S. and Balasubramanian, T.** (2010). Laboratory culture and biochemical characterization of the calanoid copepod, *Acartia southwelli* Sewell, 1914 and *Acartia centrura* Giesbretch, 1889. *Adv. Biol. Res.*, 4: 97–107.
- Whippo, R.; Low, A. and Britton-Simmons, K.** (2011). Effects of the Red Sea Urchin on benthic invertebrate communities, a link of spatial subsidies; in: Pollock N W, ed. *Diving for science. Proceedings of the American Academy of underwater science 30th symposium*, Dauphin Island, AL, AAUS.
- Yaakob, M. A.; Mohamed, R. M. S. R.; Al-Gheethi, A.; Aswathnarayana Gokare, R. and Ambati, R. R.** (2021). Influence of Nitrogen and Phosphorus on Microalgal Growth, Biomass, Lipid, and Fatty Acid Production: An Overview. In *Cells*, 10(2). NLM (Medline). <https://doi.org/10.3390/cells10020393>.