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Ecological responses of macroalgae vegetation to seasonal variations and environmental changes in the Suez Canal District

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Abstract

The noticeable lack in macroalgae number and their vegetation composition in the Suez Canal district may refer to the importance of studying and following the temporal and spatial patterns that are in change in space and time. Therefore, we have to follow regular biodiversity monitoring to elucidate the changes to seaweed vegetation in the Suez Canal area that might occur as seasonal variations or anthropogenic impacts. The present study extended from summer 2020 to spring 2021 along the Suez Canal district, including eight sites at Port Said on the Mediterranean Sea, Timsah Lake in Ismailia and Suez Bay in the Red Sea. Distribution of seaweeds is usually affected by environmental factors as temperature, salinity, pH, and water chemistry. Most of the chemical parameters recorded very high concentrations (high significant) at the sites in the Suez Bay area during all seasons, excluding nitrogen and phosphorus, which were elevated recordings in the Port Said area. El-Timsah Lake area recorded an increase in salinity which was considered as a brackish stratification type. The taxonomic groups of the recorded species showed a total of 39 macroalgal taxa (20 Chlorophyta, 16 Rhodophyta and 3 Phaeophyta). Port Said area recorded the highest significant number of Chlorophyta and Rhodophyta communities. The relative abundance of macroalgal divisions was Chlorophyta, which formed the main coverage. *Enteromorpha-Ulva* community was characterized during all the study seasons. Multivariate analysis showed the great relation between seaweed distribution, physicochemical parameters and seasonal variations.

Keywords: El-Timsah Lake; Port-Said area; Seasonal variation; Seaweeds vegetation; Suez Bay area

1. Introduction

Macroalgae are the backbone of productive food webs that include commercially significant species and extend well beyond the shallow seas in which they exist [1, 2]. Seaweeds provide ecosystem products and services ranging from food to medicine to storms insurance, all of which are essential to human cultural and economic systems [3].

Seasonal variations are evident in the frequency and intensity of extreme temperatures and precipitation events on the local and regional scales. Flooding caused by increased human activity has a substantial impact on marine life's goods and services, particularly macroalgae's biotechnological potential [4]. Increased anthropogenic nutrient loading into shallow beaches has resulted from human activities such as agriculture, urbanization, and tourism, leading these delicate ecosystems to change into separate stages [5-7].

Changes in salinity, hydrogen ion concentration, temperature, and alkalinity are important selection variables in aquatic environments [8]. Chloride ion concentration and organic carbon concentration have a reversible effect on the development rate of some marine algae, according to [9].

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Suez Canal is an important international navigation canal for Egypt and the world, connecting the Mediterranean Sea at Port Said and the Red Sea at Suez, due to its unique geographic location. The Suez Canal is a vital shipping channel as well as a pathway for invasive alien creatures to migrate between the Red Sea and the Mediterranean Sea. Hundreds of foreign Indo-Pacific marine species have moved to the eastern Mediterranean Sea via the Suez Canal since its opening [10, 11]. This is known as ''Lessepsian migration'' [12].

The Suez Canal's northern flow, the region's high salinity, and rising temperatures as a result of global warming have all aided this process. Aside from natural factors, shipping and other industrial activities in the Suez Canal are altering the ecosystem and community structure, both directly and indirectly, resulting in a large drop of macroalgal species as part of a broader decline in biodiversity [7, 13]. Simultaneously, it is well established that the type of algal flora present can be influenced by the habitat, allowing for the dominance of certain species at the expense of others [14].

Many marine botany research and examinations on the marine flora of the Red Sea, the Mediterranean Sea, and the Suez Canal have been done at the Suez Canal University over the past thirty years. [15] Were the first to report the marine vegetation, describing four different sectors of the restored canal and listing 105 species? Since 1985, El-Manawy and El-Shoubaky, along with Farghaly, have focused on Macroalgae and published numerous scientific papers on their environmental and distributional patterns [15-18].

The purpose of this study is to investigate the effect of seasonal variations on seaweeds, including physical and chemical parameters in the Suez Canal district, particularly from the north Port Said on the Mediterranean Sea, the center (El-Timsah Lake), to the south Suez Bay on the Red Sea, with the significant degree of temporal and spatial differences in the distribution pattern, composition, and abundance of macroalgal species.

2. Material and methods

2.1. Study area

The study area included the Suez Canal district extending from Port Said, EL-Timsah Lake in Ismailia to Suez Bay. Each area was subdivided into different sites (Figure, 1). The latitude and longitude of each site were represented in Table (1). The studied sites were as following:

Table 1 Latitude and longitude of the studying area.

Area	Site	Latitude	Longitude
I (Port said)	I	31.26941" N	32.31513" E
	II	31.27929" N	32.25312" E
	III	31.28098" N	32.24129" E
	IV	31.24433" N	32.32522" E
II (Ismailia)	V	30.57083" N	32.27577" E
III (Suez)	VI	29.94338" N	32.56771" E
	VII	29.95242" N	32.50178" E
	VIII	29.88760" N	32.46694" E

2.1.1. Area 1 (Port Said)

The first area is in Port Said province, which is located in the northern portion of the Suez Canal from the Mediterranean Sea. This area was divided into four sites: site I: near the entrance of the Suez Canal (the hunting club), site II: before El-Gameel, site III: El-Gameel, and site IV: east corner of El-Tafriaa

2.1.2. Area 2 (Ismailia)

The second area is in Ismailia province, which is located in the center of the Suez Canal and include only one site: site V: El-Timsah Lake (El- Taawen region)

2.1.3. Area 3 (Suez)

The third area is in Suez province, which is located in the southern part of the Suez Canal on the Red Sea at Suez Bay. This area was divided into three sites: site VI: Suez Marine Science Institute, site VII: Suez Electric Power Station, and site VIII: El-Adabyia district.

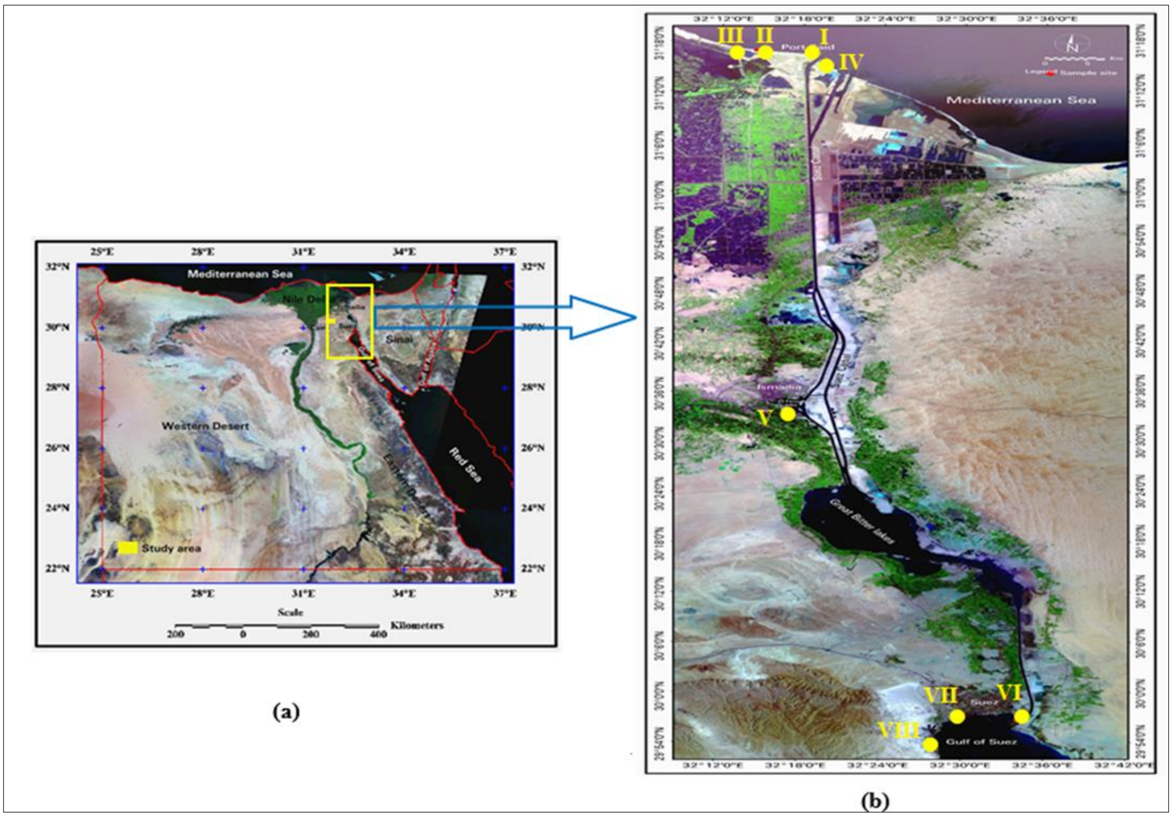

Figure 1 (a) A map of Egypt showing the Suez Canal district, and (b) The study area showing the selected sites location in Port Said, EL- Timsah Lake, and Suez Bay. (Site I: Near the entrance of the Suez Canal at the hunting club, Site II: Before El- Gameel, Site III: El-Gameel, Site IV: East Corner of El-Tafriaa, Site V: El-Timsah Lake, Site VI: Suez Marine Science Institute, Site VII: Suez Electric Power, and Site VIII: El-Adabyia district).

2.2. Environmental factors

The physicochemical parameters were measured seasonally through the period from summer 2020 to spring 2021 at the selected sites.

2.2.1. Physical parameters

Seasonally, the mean air and water temperatures were measured by using a thermometer (Glass Mercuric of 100 graduations). Salinity was determined in the field by using Hand Refractometer (ATAGO S/MILL Chem Lab. Scientific products Ltd). Hydrogen ion concentration (pH) (mol/l) was evaluated directly in the field by using digital pH-meter (DIGI-SENSE, Serial number 185031, OOLLE-PAMPER INSTRUMENT co, and CHICAGO, IL 606481). Electrical Conductivity (µmohs) was appraised in the field by using Conductivity meter (Conductance/ total dissolved solids, Models 72- 76- Engineered system, Designs #3 South Tatnall Street Wilmington, DE 198 Ø 1 (3 Ø 2) 571-1195).

2.2.2. Chemical analysis

The seawater samples were preserved in dark bottles and labeled with the date and the site of collection then preserved in freezer until measuring in Laboratory. The chemical parameters as cations (Ca^{+2}, Mg^{+2}, Na^{+} & K^{+}), anions (HCO^{-}, Cl^{-}, SO_4^{2-}, phosphorus, nitrite and nitrate were determined chemically according to Strickland and Parsons, 1972 [19].

2.3. Seaweeds vegetation

Seaweeds' sampling carried out seasonally during the study period along including the selected 8 sites. Seaweed species were collected and preserved in 4% formalin in seawater until transported to the laboratory. To assess the quantitative data of seaweeds, the percentage cover of abundance and distribution were performed using quadrate method of Russell and Fielding **(**1981) [20]**.** To each species inside the quadrate, the abundance was assessed using the following seven numerical scales: 0.1<1, 1=1-10, 2=10-15, 3=15-25, 4=25-50, 5=50-75 and 6=75-100. Seaweeds were identified using the taxonomic keys provided by [21-23]. Seaweed's collection was classified into six functional form groups (sheet, filamentous, coarsely branched, thick leathery, jointed calcareous and crustose) by the methods of Littler and Littler, 1984 [24].

2.4. Statistical analysis

Data of physico-chemical parameters and seaweed vegetation was statistically analyzed by using:

- One-way analysis of variance (ANOVA) was used for determination the significant differences between the different sites in relation to their physical and chemical parameters throughout the study period. Pearson's correlation analysis was performed with SPSS version 12.0 (SPSS, Inc., Chicago, IL).
- Cluster analysis was performed using the pc-ORD program, where it is a multidimensional analysis classify the data into partition or division of a set and then into subsets to clarify the similarity between sites.
- Multivariate Analysis of Canonical Correspondence Analysis (CCA), Detrended Correspondence Analysis (DCA) and Principal Component Analysis (PCA) Ordinations were performed using the CANOCO program version 5, to elucidate the relations between the macroalgae species and physicochemical parameters within sites, where the axes are constrained to optimize their relationship with a set of environmental variables. Arrows depict the direction (maximum change) of environmental variables in the ordination, while the length of the arrows shows their proportional influence.

3. Results

3.1. Environmental factors

Seasonally, physical, and chemical parameters were recorded at the selected sites (Figure 2). Two-way analysis of variance showed the interaction between sites and seasons. The highest air temperature was recorded in Suez Bay area at site VII (37˚C) followed by sites VI and VII (34˚C) during the summer and the lowest air temperature was recorded at sites IV, VI, and VIII of 18˚C during the winter (highly significant p<0.001***). Water temperature values were registered the highest degree (30˚C) at site VII followed by sites III, VI and VIII (27˚C) during the summer, while site I recorded the lowest one (16˚C) in winter and spring (highly significant p<0.001***). The highest values of salinity recorded at site VII (48‰) during winter and the lowest one was 24‰ at sites II and III during autumn (highly significant p<0.001***). Electrical Conductivity values ranged between 25.8dsm^{-1} - 47.5dsm^{-1} at the site VII and II in autumn and spring respectively (highly significant p<0.001***). The Values of pH varied between 7.71mol/l at site I during spring and 8.46mol/l at site V during winter. Two-way analysis of variance assessed that difference in sites is non-significant (P>.05), while the differences in season and interaction between sites and seasons is highly significant (p<0.001***).

Chemical factors were determined seasonally as anions and cations contents. The content of calcium (Ca^{+2}) is ranged between 15 meg.l^{-1} at site V in summer and 35meg.l^{-1} at site VIII in the autumn (highly significant p<0.001***). The maximum content of magnesium (Mg^{+2}) ranged between 777.6 meg.l^{-1} at site V in summer, while the minimum content was 67.5 meg.l^{-1} at site III in autumn (highly significant p<0.001***). The greatest values of sodium (Na^{+}) content were present at site VIII in autumn 347meg.l^{-1} whereas the minimum values were 168 meg.l^{-1} at site II in autumn (highly significant p<0.001***). The content of potassium (K^{+}) at the selected sites ranged between maximum readings at site V (4 meg. l^{-1}) in summer to the minimum readings (0.1 meg. l^{-1}) at site III in summer (highly significant p<0.001***). Bicarbonate (HCO^{-}) readings showed that the maximum values were 12 meg. l^{-1} at site VII during spring, while the minimum values were at site II&VII (1.5 meg. l^{-}) in winter (highly significant p<0.001***). The content of chloride (Cl^{-}) revealed that site VI recorded the highest reading (385 meg. l^{-1}) in autumn, whereas the minimum reading was (225 meg. l^{-1}) at site III during autumn. ANOVA repeated measures assessed that the differences between sites were non-significant >0.05, between seasons is significant <0.05 and the differences at the interaction between sites and seasons were non-significant >0.05.

The maximum values of sulfate ($SO4^{2-}$) readings were recorded at site VII (190 meg. l^{-1}) during spring, while site II recorded the minimum value during autumn (highly significant p<0.001***). The levels of nitrate and nitrite (NO_2+ NO_3)

evaluated those sites III and IV recorded the highest reading during spring (33.8 μgl^{-1} and 30.4 μgl^{-1} respectively), whereas the lowest readings were recorded at sites VI (7.7 μgl^{-1}), VIII during spring (highly significant $p<0.001$***). Site III recorded the highest level (3.4 μgl^{-1}) of phosphorus (PO_4) in winter, while the lowest levels were recorded at sites I (0.1 μgl^{-1}) in spring (highly significant $p<0.001$***).

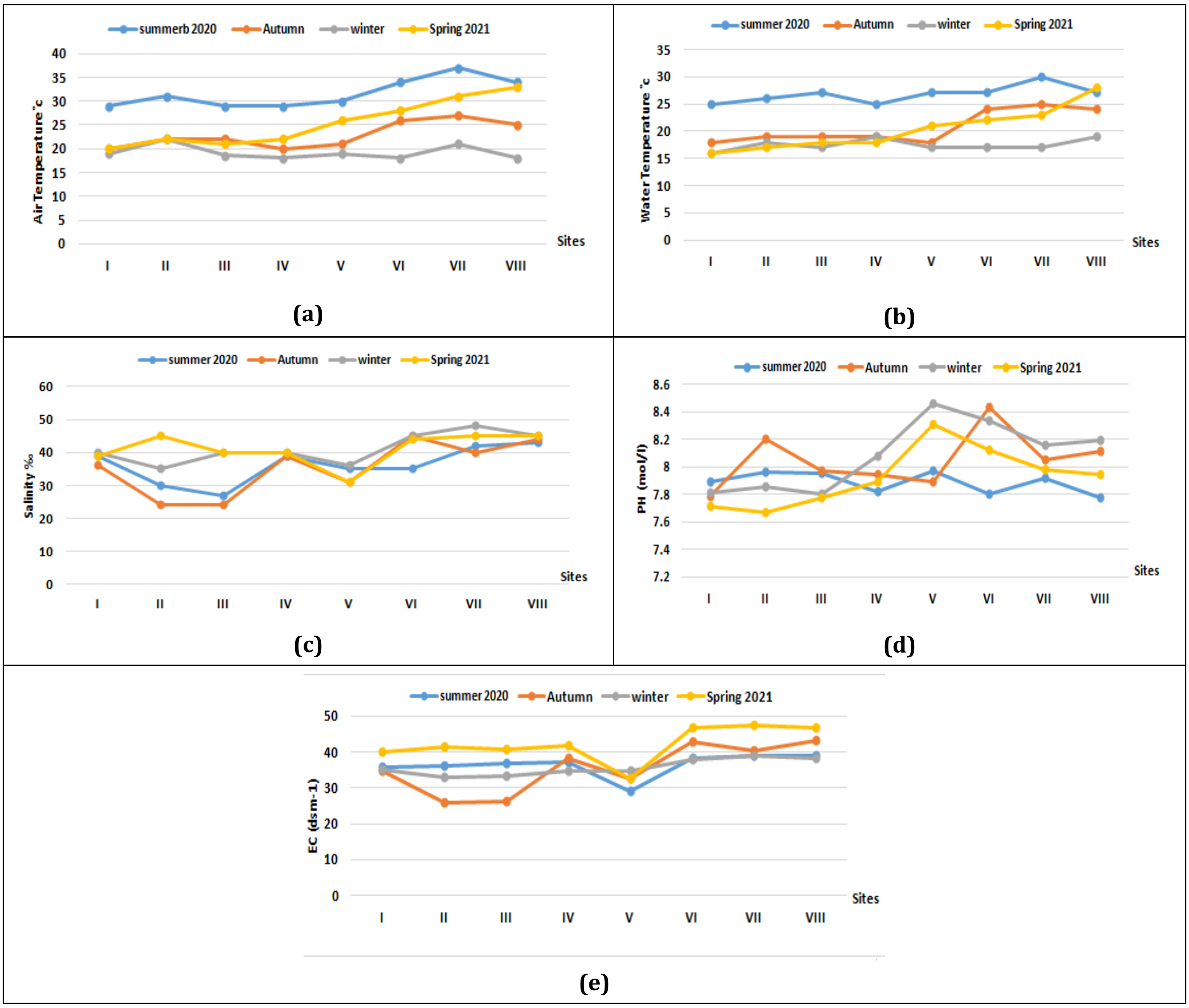

Figure 2 Air temperature, Water temperatures, Salinity, pH, and Electrical Conductivity changes at the selected sites from summer 2020 to spring 2021.

3.2. Seaweeds vegetation

The taxonomic groups of the recorded species showed that a total of 39 macroalgal taxa were identified at the selected sites through the study period. The percentage cover of seaweed divisions was estimated in Figure (3). Chlorophyta was the most dominant division (51%), followed by Rhodophyta (41%), then finally Phaeophyta (8%). The differences between divisions were highly significant as revealed by Chi-squared test (<0.001***). Total number of seaweed species at the selected sites was calculated (Figure, 4). Site II recorded the highest significant No. of species, followed by site I, then site III. However, Site VII recorded the lowest number of species.

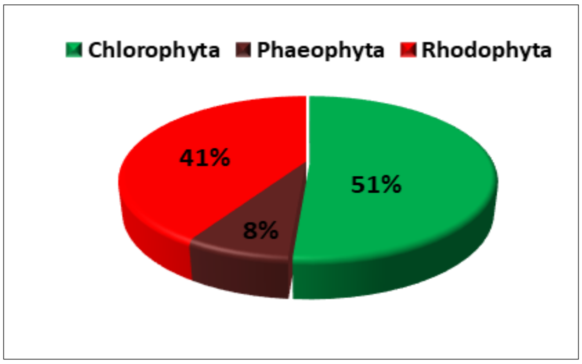

Figure 3 Percentage cover of seaweed divisions at the selected sites from summer 2020 to spring 2021.

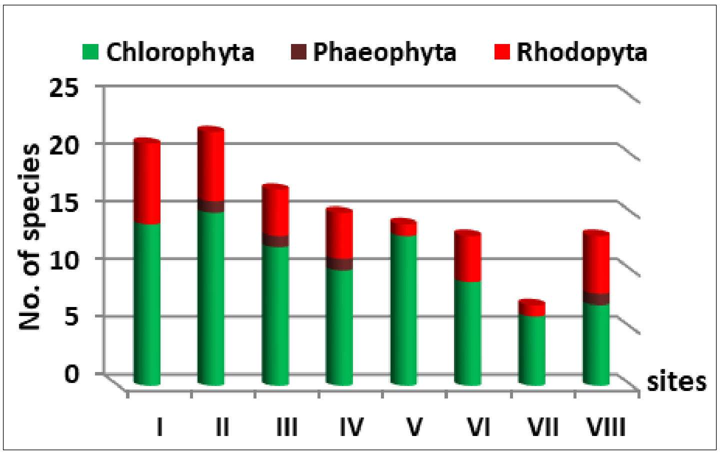

Figure 4 Total number of seaweed species at the different divisions in the selected sites from summer 2020 to spring 2021.

The presence and absence of seaweeds species were analyzed statistically by chi-square. *Enteromorpha intestinalis, Polysiphonia variegate* and *Porphyra umbilicalis* showed highly significant difference between seasons ($p \leq 0.05$). *Enteromorpha intestinalis, Ulva fasciata, Ulva lactuca, Ulva rigida, Petalonia fascia* and *Grateloupia filicina* exhibit highly significant difference between sites ($p<0.001^{**}$). The highest number of seaweeds species were presented at autumn season followed by winter, while the summer had the lowest number of seaweeds species as shown in table 2.

Multivariate analysis using PCA, CCA and DCA showed the relation between physicochemical parameters with seaweeds distribution. The PCA revealed that *Cladophora crinalis, Cladophora patentirmaea, Cladophora prolifera, Enteromorpha compressa, Enteromorpha tubulosa, Ulva fasciata, Ulva flexuosa, Ulva rigida* and *Grateloupia filiciana* found at high position along the gradients with dissolved organic nitrogen, nitrite, nitrate and total phosphorus along the studied period from summer 2020 to spring 2021. *Ulva sp.* gives its maximum growth rate in enriched seawater by P and N. In other areas total phosphorus and total nitrogen represented a limiting growth and productivity factors of some marine macroalgae. PCA also revealed that most seaweed were in a close relation with water temperature, Salinity and EC like *Ulva lactuca, Enteromorpha intestinalis, Enteromorpha prolifera, Hypnea cornuta and Ceramium gracillium* (Figure 5).

Table 2 The presence and absence of seaweeds species (Chi-Square) analysis at the studied sites from summer 2020 to spring 2021

Species (N %)	Summer 2020	Autumn 2020	Winter 2021	Spring 2021	Chi-Square	
					Season	Site
Chlorophyta						
Bryopsis plumosa C. Agardh	0	0	6	0	ns	ns
Chaetomorpha atennina (Bory) Kutzing	0	0	0	3	Ns	ns
Ch. linum (Mull.) Kutzing	0	0	0	3	Ns	ns
Ch. idica Kutzing	0	0	0	3	Ns	ns
Cladophora albida (Huds.) Kutzing	9	9	0	3	Ns	ns
C. crinalis Harv.	3	6	0	0	Ns	ns
C. crystallina (Roth) Kutzing	3	0	0	0	Ns	ns
C. patentirmaea Montagne	6	0	3	0	Ns	ns
C. prolifera (Roth) Kutz.	13	9	6	16	Ns	ns
C. rupestris Kutzing	9	9	16	0	Ns	ns
Enteromorpha clathrate (Roth) Grevile	0	0	9	3	Ns	ns
E. compressa (Linn.) Kutzing	0	9	13	9	Ns	ns
E. intestinalis (Linn.) J. Agardh	3	13	9	22	*	ns
E. linza (Linn.) J. Agardh	0	6	3	6	Ns	**
E. prolifera Agardh	16	16	16	0	Ns	ns
E. tubulosa (K¨utzing) K¨utzing	16	6	3	9	Ns	ns
Ulva fasciata Delile	13	9	9	9	Ns	**
U. flexuosa Wulfen	19	16	13	22	Ns	ns
U. lactuca Lamour.	3	16	16	9	Ns	**
U. rigida C. Agardh	16	16	9	13	Ns	**
Phaeophyta						
Dictyota dichotoma (Hudson) J.V.Lamouroux	0	0	3	0	ns	ns
Pilayella littoralis (Linn.) Kjellman	0	6	0	0	Ns	ns
Petalonia fascia (O.F.Mull.) Kuntze	0	3	3	0	Ns	**
Rhodophyta						
Antithamnion sp.	0	0	6	0	ns	ns
Ceramium gracillimum (Harv.) Mazoyer	0	0	3	6	Ns	ns
C. strictum Kutzing	0	3	0	0	Ns	ns
Chondrus crispus Stackhouse	0	0	0	3	Ns	ns
Galaxaura tenera Kjellman	0	3	0	0	Ns	ns
Gelidium crinale (Tumer) Lamouroux	0	3	0	0	Ns	ns
Gelidiella acerosa (Forsk.) Feldm. Et Hamel	0	6	0	3	Ns	ns
Gracilaria arcuate Zanardini	3	0	0	0	Ns	ns

Grateloupia lanceolata (Okamura) Kawaguchi	6	3	3	3	Ns	ns
G. filiciana (Wulf.) Ag.	0	3	3	0	Ns	**
Gelidiopsis variablis (Grev. ex J.Agardh)	0	0	6	0	Ns	ns
Hypnea cornuta (Kutz.) J. Ag.	6	3	3	3	Ns	ns
Nitophyllum punctatum (Stack) Gerville	0	3	0	0	Ns	ns
Polysiphonia variegate (Agar.) Zanardini	0	0	0	9	*	ns
Porphyra umbilicalis Kutzing	0	6	13	0	*	ns
Rhodymenia erythrea Zanardini	0	3	0	0	Ns	ns

Where ns: non-significant; * Significant ≤ 0.05; ** Significant ≤ 0.01

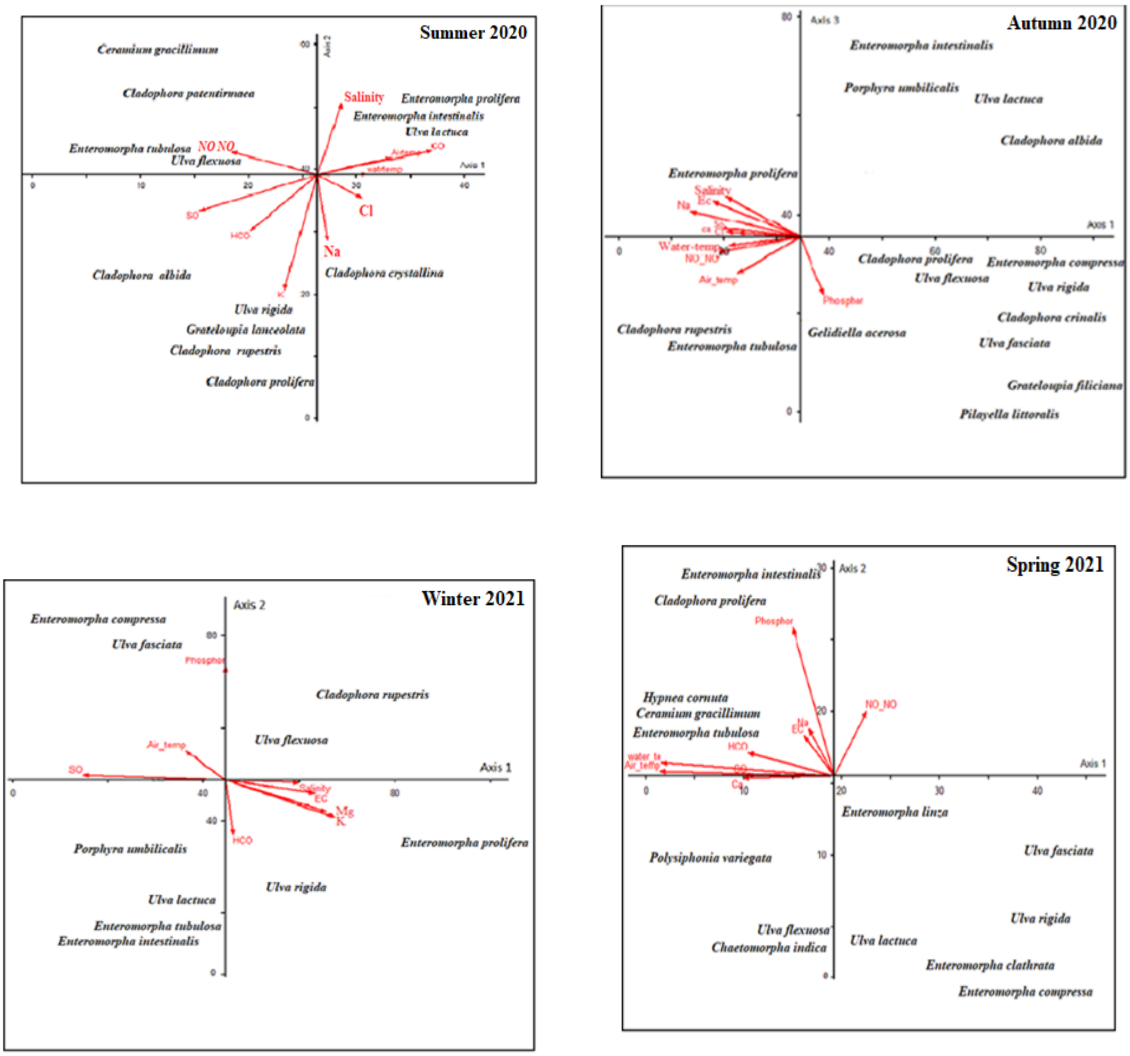

Figure 5 Principal Component Analysis (PCA) diagram for macroalgal species (points) with physicochemical parameters (arrows) in Summer2020, Autumn, Winter 2021 and Spring at the selected sites, where Air temperature (Air_temp), Water temperature (water_temp), Electrical conductivity (EC), Calcium (Ca), Magnesium (Mg), Sodium (Na), Potassium (K), Bicarbonate (HCO), Chloride (Cl), Sulfate (SO) and Nitrate and Nitrite (NO_NO).

Dendrogram produced by the Cluster analysis of the selected sites (Figure, 6A) also showed similarities and differences in the ecologically studied sites using both physico-chemical factors and species abundance or presence and absence to more or less the same classification direction. Dendrogram scheme resulting from the use of physical and chemical properties was clear, sharp and had a higher degree of difference than Dendrogram scheme obtained by using the presence and absence of species, which illustrating the ability of some groups of algae to live in different environmental conditions. This was evident in our results, showed that the ability of some types of seaweed to exist in different environments with different degrees and measurements of physical and chemical factors such as *Enteromorpha intestinalis, Cladophora albida, Cladophora prolifera, Ulva flexuosa* and *Ulva lactuca*.

Dendrogram produced by the Cluster analysis of the selected sites (Figure, 6B) contributed that the identification of site II as a separate site with a significant difference when compared to the other sites. Site II was identified as a separate group with considerable dissimilarity when compared to the major other group, which included IV and I with separation from VI, VII, and VIII, with VI and VIII grouped together in a small subgroup. This is attributed to the fact that the sites contain the highest nitrogen, which explains why they contain the largest number of seaweeds. The lowest rates of salinity, electrical conductivity, sodium, potassium and sulfate were also recorded.

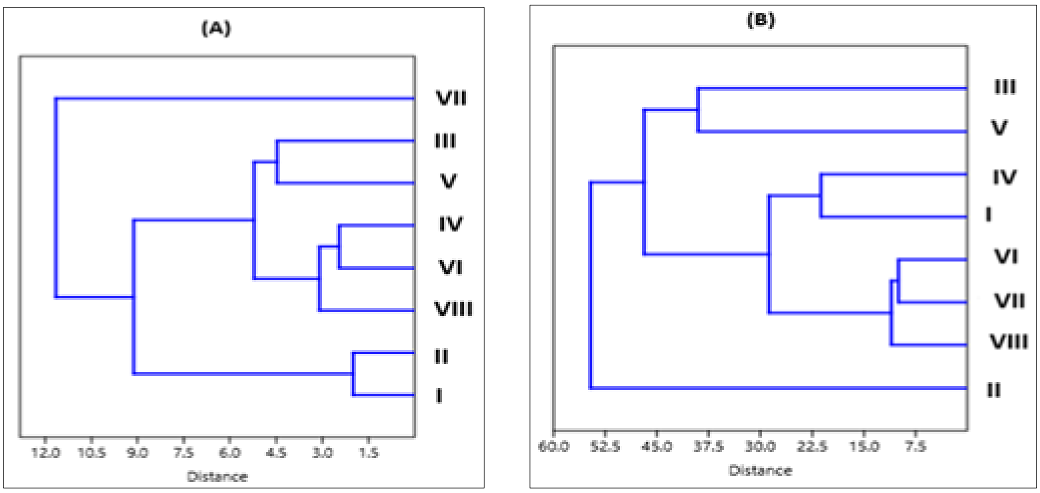

Figure 6 Dendrogram produced by the Cluster analysis of the selected, where A: by using the species abundance and B: by using the Physico-chemical parameters.

Dendrogram produced by the cluster analysis of the most abundant species at the selected sites in the study area (Figure, 7) was indicated that both *Grateloupia lanceolata* and *Hypnea cornuta* were separated with high dissimilarity factor from the other species, while the most common species *Enteromorpha intestinalis* and *Ulva lactuca* were related in one sub-group. In the other sub-group, *Ulva flexuosa, Ulva rigida, Cladophora Prolifera, Ulva fasciata and Enteromorpha tubulosa***.** *Ulva fasciata* and *Enteromorpha tubulosa* were gathered in minor subgroup with low dissimilarity factor.

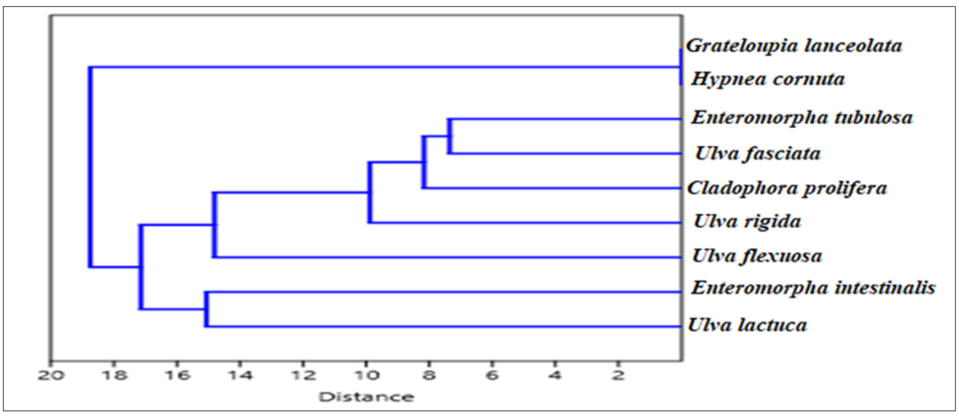

Figure 7 Dendrogram produced by the cluster analysis of the most abundant species at the selected sites in the study area.

Functional form groups (sheet, coarsely, branched, thick leathery, filamentous, and jointed calcareous) were observed and fluctuated seasonally at the study sites from summer 2020 to spring 2021 (Table 3). Chlorophyta had the highest number of representatives followed by Rhodophyta then Phaeophyta. Mainly, general pattern of the macroalgae vegetation at all sites was belonging to the sheet and filamentous groups. The highest percentage of filamentous group was recorded 33.3%, followed by the sheet group (27.6%). Coarsely branched group and jointed calcareous had the same percentage (16.6%). The thick leathery group has the smallest percentage (5.5%). The green algae *Ulva*, *Enteromorpha* and the red algae *Nitophyllum*, *Porphyra* and *Grateloupia* were represented the sheet group. The filamentous group was characterized by species as *Chaetomorpha*, *Cladophora*, *Ceramium*, *Polysiphonia*, *Gelidiella* and *Pilayella.* Coarsely branched group was distinguished by *Dictyota*, *Gigartina* and *Hypnea*, while thick leathery group was corresponded to *Gracilaria*. *Bryopsis*, *Galaxura* and *Griffthesia* were represented as jointed calcareous. No species was recorded in crustose group.

Table 3 Functional-form groups for macroalgae on the studied areas.

Functional form Group	External morphology	Taxa examined
Sheet	Thin tubular and sheet like (foliose)	*Ulva, Enteromorpha,Porphyra, Grateloupia, Nitophyllum*
Filamentous	Delicately branched (filamentous)	*Chaetomorpha,Cladophora, Ceramium, Polysiphonia, Geladiella*, *Pilayella*
Coarsely branched	Coarsely branched	*Dictyota, Gigartina, Hypnea*
Thick leathery	Thick bladders and branches	*Gracilaria sp*.
Jointed calcareous	Articulated	*Bryopsis, Galaxura, Griffthesia*
Crustose	Epilithic, Prostrate, encrusting,	----

4. Discussion

Distribution, Physiological performance, and biodiversity of seaweeds are primarily affected by anthropogenic interferences or various environmental factors such as temperature, salinity and nutrients, carbon dioxide and pH [25]. The Suez Canal district including Port-Said, El-Timsah Lake and Suez Bay exposed to environmental variables and man-made modifications during the last decades. The macroalgae vegetation inhabiting in the previous areas have been influenced by these alterations. The modifications included the consequences disturbances imposed by the increasing movement of ships navigation, rapid increase in the construction of tourist resorts and villages along the coast with increasing its related touristic activities interrupt macroalgae [26].

Physico-chemical parameters in the study areas including the selected sites were measured seasonally from summer 2020 to spring 2021. Seawater temperature is rather homogeneous and changes gradually with seasons. Surface water temperature fluctuated from 16 ∘ C in winter to 30 ∘ C in summer. Increasing of temperature at site VII in Suez Bay area can be attributed to this site next to the effluent discharge of Suez electric power station.

Port- Said area mainly sites II and III on the Mediterranean Sea registered the lowest values of salinity (14‰) in autumn. There was an unusual recording in this area, and this may be attributed to overflow from anthropogenic activities as new coffee constructions on the sea. Madkour and El-Shoubaky (2007) [27] was also assessed that salinity was measured as 14 ‰ in Port Said. The elevated salinity in Suez Bay area (48‰) than the other areas corresponded to their connection with the Red Sea. Our study showed that El-Timsah Lake area recorded increasing in salinity (31-36‰) than the earlier authors [28, 29]. This may be attributed to closure of the Nile channel recently. The salinity of El-Timsah Lake is of a brackish stratification type due to the freshwater inflow of Ismailia Canal reaching the lake. Decreases in salinity were noted as early as 1871 following Suez Canal construction and following enlargement of the channel from the Nile and other construction projects increased the inflow of fresh water to the lake [30]. Generally, macroalgae show decreased photosynthesis [31] or growth [32] with increasing pH levels. During the study period, the pH has a tendency towards the alkaline state during spring in Port Said area. This agreed with Madkour and El-Shoubaky (2007)[27]. In our study pH recorded increasing in alkalinity in El-Timsah-Lake during winter than that recorded by El-Shoubaky, 2015 [28].

Suez Bay area showed rising of Ca^{+2}, Na^{+}, K^{+}, HCO^{-}, Cl-, and SO_4^{2-} values compared to the other areas and this may be attributed to the high pollution of seawater which receive huge number of pollutants as a result of the activity of the condensed petroleum industrialization, discharged run-off from fertilizer and glass factories in addition the organic wastes from city sewage in this area [33]. Port Said area showed the greatest values of nitrogen and phosphorus than the other studied areas. The obvious increase in the nitrogen and phosphorus level may attribute to the raise of human wastes in the sea.

Seasonal variations of macroalgae in the study areas showed that a total of 39 macroalgal taxa were recorded during the period from summer 2020 to spring 2021. Chlorophyta was the most dominant division (51%), followed by Rhodophyta (41%) and finally Phaeophyta (8%). In view of the relative abundance of macroalgal divisions in the present study, Chlorophyta formed the main coverage during the study seasons in the studied areas. The noticeable lack in seaweeds species number and their vegetation composition than the previous studies may refer to the importance of studying and following the temporal and spatial patterns with anthropogenic activities for the nature, strategy and geography of the studied areas along the Suez Canal [15-18].

Enteromorpha-Ulva community was characterized throughout all the study seasons; beside *Cladophora* community occupied a lower limit of vegetation in summer and autumn. The green algae *Bryopsis - Ulva* community appeared only in Suez Bay in winter. These agree with Madkour and El-Shoubaky (2007) [27], El-Manawy and Shafik (2008) [34], and El Shoubaky (2015) [28]. *Grateloupia - Porphyra* community was showed in the littoral zone during all seasons and particularly autumn and winter in Port-Said area. The appearance of the previous community may attribute to associate Port-Said with the Mediterranean Sea.

In our study, Port Said area recorded the highest significant number of Chlorophyta and Rhodophyta communities. On the other hand, the southern area representing Suez Bay characterized by the lowest number of Chlorophyta, while El Timsah Lake area showed sharp decreasing in Rhodophyta. *Cladophora albida, Cladophora Prolifera, Ulva flexuosa, Enteromorpha intestinalis,* and *Ulva lactuca* are the most abundant species at all sites and seasons from summer 2020 to spring 2021. According to Chang and Tseng (2010) [7], Chlorophyta are more resistant to water pollution than Rhodophyta and Phaeophyta. This clarifies increase in Chlorophyta species number regarding to Rhodophyta and Phaeophyta in our study. In this regard, El-Manawy and Shafik (2008) [34] revealed that in polluted ecosystems, Chlorophyta growth accelerates dramatically. According to the typetaxon, *Enteromorpha flexuosa* recently recognized *Ulva flexuosa* as established in Shabaka (2018) [35].

Cladophora crinalis, Enteromorpha compressa, Ulva fasciata, Grateloupia lanceolata and *Porphyra umbilicalis* characterized the northern part of the Suez Canal (Port Said area) as Mediterranean Sea species. Verlaque *et al.* (2015) [36] stated that *Ulva fasciata* introduced to the Mediterranean Sea, firstly found in the Venice Lagoon in 1960, then now well-established on the northern shores of the Mediterranean Sea [37]. Shabaka (2018) [35] and Madkour & El-Shoubaky (2007) [27] mentioned that *Grateloupia filicina* has been recorded in Port-Said. *Grateloupia lanceolata* recently appeared in Port-Said in our study. The brown alga *Pilayella littoralis* only distinguished in autumn in this area. It was considered a cold-water species that distributed in the Arctic, Antarctic and the sub-Antarctic islands, Atlantic Ocean and Pacific Ocean. The green algae *Ulva lactuca, Ulva rigida, Chaetomorpha atennina, Chaetomorpha linum* and *Chaetomorpha indica* discriminated El-Timsah Lake area in central point of Suez Canal to make up the algal bloom during spring season. This relatively agreed with El Shoubaky (2015) [28], who revealed that the massive macroalgal mats, composed mainly of *Enteromorpha clathrata* and *Ulva lactuca* to form the principal predominant green mats in spring season. *Chaetomorpha atennina, Chaetomorpha linum* and *Chaetomorpha indica* appeared only in El-Timsah Lake area. *Polysiphonia variegata* was recorded as abundant red species in this studied area. This may be attributed to increase the salinity in El-Timsah Lake during the study period than the previous years.

In the northern part of Red Sea, *Bryopsis plumosa, Dictyota dichotoma, Antithamnion sp., Ceramium gracillium* and *Gelidiopsis variablis* distinguished the southern part in Suez Bay area during winter season as Red Sea species. *Hypnea cornuta* appeared in Port-Said during summer and autumn then showed at Suez Bay in winter and spring. This may be attributed to differentiation of the temperature between north and south of the study areas. The brown alga *Dictyota dichotoma* characterized to the south part of the studied areas during winter season.

The dominant green algae *Ulva Flexuosa* and *Ulva lactuca* registered during Suez Bay area especially in site VII (Suez Electric Power Station). This may be attributed to the effluent of industrial and sewage drainages. El-Manawy and Shafik (2008) [34] mentioned that only *Ulva* and *Enteromorpha* dominated seaweeds vegetation in Suez, beside a considerable demonstration of low species number, they attributed that to receive large number of pollutants as the condensed petroleum industrialization, discharged effluent from fertilizer and glass factories beside the organic wastes from city sewage. Aleem (1984) [21] also mentioned that, the flourishing growth of *Ulva* spp. was related to the areas exposed to human activities, making a pure community [18].

According to Principal component Analysis PCA, this was showed the obvious relationship between physcio-chemical parameters and macroalgal species that increased with the length of arrows. The PCA revealed that *Cladophora crinalis, Cladophora patentirmaea, Cladophora prolifera, Enteromorpha compressa, Enteromorpha tubulosa, Ulva fasciata, Ulva flexuosa, Ulva rigida* and *Grateloupia filiciana* found at high position along the gradients with nitrogen, nitrite, nitrate and total phosphorus along the study period from summer 2020 to spring 2021. Therefore, the previous species recorded high abundance in Port-Said area. These results are supported by authors as [38, 39]. John and ShriDevi (2013) [40] also stated that *Ulva* gives its maximum growth rate in enriched seawater. Douglas *et al.,* 2014 [41] reported that the green alga *Ulva*, that often known as algal turf, was characterized by an enhanced growth in the polluted areas making a pure community with a dark green color and showed a higher relative abundance [40, 42]. Additionally, most seaweeds in the PCA joint plot were in a close relation with water temperature, Salinity and EC like *Ulva lactuca, Enteromorpha intestinalis Enteromorpha prolifera, Hypnea cornuta* and *Ceramium gracillimum.*

Dendrogram produced by the Cluster analysis of the selected sites results from using physicochemical parameters was obvious, sharp and with high dissimilarity than using species presence and absence, which reflects the ability of some algal groups to coexist in different environmental conditions. Dendrogram analysis classified site II (port Said) in separate group with high dissimilarity compared with the major other group contain IV and I (port Said) with separation from VI, VII and VIII (Suez Bay), where VI & VIII were gathered in minor subgroup. This is agreed with Mofeed and Deyab, 2015 [33], who reported that, seaweeds in natural systems have the ability to resist and to recover from disturbance, but it is largely dependent on life composition in the aquatic environment.

Functional form groups of the macroalgal vegetation varied seasonally in the studied areas. Most of the macroalgae belong to the sheet and filamentous groups as *Ulva* spp., *Enteromorpha* spp., *Nitophyllum, Porphyra, Grateloupia Chaetomorpha, Cladophora, Ceramium, Polysiphonia, Geladiella* and *Pilayella*. Higher temperatures may enhance turf algae as opposed to fleshy algae. Seaweeds with filamentous thalli and the coarsely branched group are generally more productive and grow in temporally more unstable habitats than thicker and calcareous seaweeds, which are conspicuous in more constant environments [24]. Those authors suggested a functional-form concept to highlight the importance of morphology, which has resulted in ecological classifications of seaweeds based on thallus morphology, longevity and life history [43]. Functional traits are those features (morphological, physiological, phenological, etc.) that determine how species respond to environmental factors, interact with other species and/or influence ecosystem properties [44].

5. Conclusion

Seaweeds species' patterns are varied in space and time with anthropogenic activities because of the nature, strategy and geography of the studied area along the Suez Canal. The Suez Canal district as well as Port-Said, El-Timsah Lake and Suez Bay exposed to environmental variables and man-made modifications. The noticeable lack in seaweeds species number and different seaweeds vegetation composition compared with the previous studies may refer to the importance of studying and following the temporal and spatial patterns in the Suez Canal district. The changes of the physico-chemical parameters seasonally which were recorded during the period from summer 2020 to spring 2021, could explain comparatively decreasing of seaweeds number and changes in seaweed composition.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that there is no any conflict of interest.

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