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Is the change in biodiversity of macro-algae in Alexandria coastal waters related to climate change?

Khalil, A.N.; Ismael, A. A.; Halim, Y. and El-Zayat, F. M.
Oceanography Dept., Faculty of Science, Alexandria University, Egypt.

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ABSTRACT

Over the past fifty years, the warming hypothesis of Mediterranean waters has been supported by a series of physical and ecological observations. In order to study the potential role of climate change on the distribution and composition of the macroalgae and its associated epiphytic microalgae, a total number of 61 water and macro-algal samples were collected from Abu Qir area during the period from June 2005 to December 2007.

A 22-year series of the sea surface temperature (SST) at Abu Qir Coast (AQ) in Alexandria; from 1985 to 2007 showed a pronounced increase of SST during this period. There was a pronounced change during the last decade with evidence for a stepwise increase in 1994. The maximum SST reached 30˚C compared to 28.1˚C before 1994. On the other hand, the minimum in SST increased since 2005 from 14.3˚C (1985-1994) to 16.9˚C (2006). The most alterations occurred during the winter months with differences of 2.6˚C. Also along with less change during the summer months reached 1.9˚C.

In parallel, long term changes in the algal community structure appear to have taken place during the last 60 years; there is a remarkable decrease in the number of species of macroalgae from 1948 to 2007. The effect of global warming on benthic macroalgae in AQ area seems to be a decrease in species richness, disappearance of large, canopy-forming species and disturbed seasonality.

INTRODUCTION

Alexandria is the second-largest city of Egypt, extending about 60 km along the coast of the Mediterranean Sea in the north central part of the country. It is almost rocky with some narrow sandy beaches in the embayment’s (El-Wakeel and El-Sayed, 1978). Rocky shore communities are often highly productive compared to those of sediment communities (Lundalv, 1987). Among marine flora, seaweeds dominate intertidal and subtidal environments (Lüning *et al.*, 1990).

There are evidences of how climate change is affecting marine communities and consequently, the ecosystem services they provide (Cheminée *et al.*, 2013; Doney *et al.*, 2012; Liquete *et al.*, 2016). Among marine flora, seaweeds dominate intertidal and subtidal environments (Lüning *et al.*, 1990). Their role as engineering species defines the structure and functioning of the benthic assemblages through biotic and non-biotic interactions (Schiel, 2006). Therefore, a comprehensive understanding of consequences of climate change in their distributional patterns is a core requirement for adopting an ecosystem-based management (Sax *et al.*, 2013), such as resources management, establishment of marine protected areas or measures to face invasions (Tamburello *et al.*, 2014; Duarte *et al.*, 2017). To reach this objective it is required the identification of the variables and parameters that determine species ecology (Araújo *et al.*, 2019**)**. When working in large areas, hydrological variables are usually not considered, although there is evidence of their relevance in species distribution (Ramos *et al*., 2014; Pace *et al.*, 2017; de la Hoz *et al.*, 2018).

Monitoring is the collection of information about the state of a system and its changes over time (Chiappone & Sullivan, 1994). A goal in monitoring natural communities is the identification of natural fluctuation in communities or populations from changes induced by anthropogenic impacts (Brown & Howard, 1985). Recent evidence indicates that marine macroalgae play a larger role in coastal productivity than previously suspected (Mann, 1973).

The first records of algae in Egypt were made by Forsskal (1775), a pupil of Linnaeus two centuries ago. Forsskal made an expedition to Egypt and Southern Arabia collecting marine algae and other natural history specimens from the Red Sea. In 1813, Delile mentioned 35 species of algae, 23 of which were collected from the Mediterranean and the rest from the Red Sea. Areschoug (1870) identified 64 species, including 35 Rhodophyceae, 17 Phaeophyceae, and 12 Chlorophyceae.

Muschler (1908) enumerated 64 species collected from Alexandria coast, which comprise 4 Cyanophyta, 16 Chlorophyceae, 13 Phaeophyceae and 31 Rhodophyceae. Four of his species, *Cystoseira myrica*, *Rissoella verruculosa*, *Liagora viscida* and *Pteridium alatum*, have not been found during the survey of Aleem (1945). Nasr (1940 a, b) collected and described about 50 species from Alexandria, 20 of which were new records to Alexandria shores. Aleem (1945) collected and described 147 species from Alexandria and its vicinities, 62 species of which were new records for Egypt. Negm (1976) collected and described 56 species at two locations (Abu Qir and Ras El-Tin) from Alexandria coast during 1971. Khalil (1987) , depending on more than 5 years collections investigated the occurrence, distribution and periodicity of the benthic marine algae at 15 localities along the Alexandria coast and recorded 116 taxa, from them 25 were new records to the area. Most of them were filamentous. The first study of the benthic marine algae as related to different environmental factors was done by Khalil *et al.* (1988a) at 9 localities. Moreover, the first study of the macroalgae benthic biomass was accomplished by Khalil *et al.* (1988b) at 5 sites along Alexandria coast. Nabih (1989) collected and described about 89 species belonging to the three main classes, including 24 Chlorophyceae, 20 Phaeophyceae and 45 Rhodophyceae, 15 of which were new records at the 9 sites along the Alexandria coast. On the other hand, Khalil (1993) reported the species composition, distribution and seasonality of benthic marine algae along the Alexandria coast. Later, Khalil (1994) studied the algal flora at three localities and recorded 51 species comprising 15 Chlorophyceae, 12 Phaeophyceae and 24 Rhodophyceae. Soliman (1997) collected and described about 27 species belonging to the three main classes, including 8 Chlorophyceae, 5 Phaeophyceae and 14 Rhodophyceae, at the 6 sites along the Alexandria coast.

Soliman (1997) collected and described about 27 species belonging to the three main classes, including 8 Chlorophyceae, 5 Phaeophyceae and 14 Rhodophyceae, at the 6 sites along the Alexandria coast.

El-Zayat (2012) studied the algal flora at the 5 sites along the Alexandria coast during 2006-2007 revealed the occurrence of 40 species belonging to the three main classes, including 15Chlorophyceae, 6 Phaeophyceae and 19 Rhodophyceae.

The purpose of the present study is to survey the occurrence and distribution of some conspicuous benthic marine algae during a complete year cycle over an extended horizontal range. Tracking any changes may happened in the seaweeds community over more than 60 years in the Abu Qir region that has been subjected to several studies on algal associations since the 1940s. It is to be mentioned that although earlier investigations of the marine macroalgae of Alexandria have provided valuable floristic data, no information is available either on the biomass or on the effect of environmental conditions.

A comprehensive understanding of consequences of climate change in their distributional patterns is requirement for adopting an ecosystem-based management (Sax *et al.* 2013), such as resources management, or for measures to face invasions (Duarte *et al.*, 2017; Tamburello *et al.*, 2014). Marine algae predominate in tidal environments and have a role with benthic communities through biological and non-biological interactions. Therefore, studying and understanding the consequences of climate change in their distribution patterns is a prerequisite.

AREA OF STUDY AND INVESTIGATED SITES

DESCRIPTION

The study area extends along the shore of Alexandria city, about 40 km between El-Mex to the west and Abu-Qir to the east (Fig.1). The shore line is more or less undulated, forming embayment at some places such as the Eastern Harbour and Stanly Bay.

Fig. 1: Alexandria coast from Abu-Qir east to El-Mex west and the investigated sites (Source: Google earth 2010).

A widening process of the coastal road of Alexandria City from El-Montazah to El-Shatby was achieved during the period from 1998 to 2003. This process caused fundamental changes in the topography and environmental characteristics of the coastal strip of this area (Hamdy 2008). During this process, several coastal engineering works were carried out, such as infilling with terrigenous materials at several parts, building of breakwaters and dumping of concrete blocks along the shoreline for shore protection.

Each year, large amounts of desert sand are spread over the beaches to compensate the lost material; however, the added sand will gradually be removed by the wave action and winter storm surges, ultimately to blanket the near shore bottom (Halim & Abou-Shouk, 2000).

Sampling Sites:

Five sites were chosen representing different ecological entities along Alexandria coast. These localities are: Abu-Qir beach (AQ), El-Mandara beach (MN), Stanly beach (ST), Eastern Harbour (EH) and El-Mex beach (MX). These sites include different benthic habitats, protected and exposed, with natural and artificial hard substrates, as well as of different grain sizes.

Abu-Qir (AQ):

Rocky plate at the western edge of Abu-Qir Bay; with substrate consisting of a chains of natural rocks surrounded by pools, close to massive rocky outcrops that have numerous small and fine holes that afford excellent domains for algal attachment. This site is subjected to wave action, and considered as an exposed site, but no source of pollution is known in the area. Abu-Qir site offers considerable variety of algal habitats due to the presence of different substrata with varying degrees of suitability for algal growth (Khalil and EI-Tawil, 1982) (Fig. 2).

Fig. 2: Abu-Qir site (original).See line of rocks in the foreground.

El-Mandara (MN):

This site is characterized by fine sandy beach including distant batches of small fragments of calcareous shells (Fig. 3). It is sheltered by a breakwater of cement concrete that extends east to El- Montazah and west to Miami, it was constructed perpendicular to the shoreline during the widening process of the coastal road and extends about 100 m seaward (Hamdy 2008).

Fig. 3: El-Mandara site (Photo by Hamdy, 2008).

Stanly (ST):

This site lies in a semicircular embayment. The hard substratum is represented by a curved low wall of concrete blocks surrounding a part of the beach, for protection and covered with seawater most of the time. (Fig. 4).

Fig. 4: Stanly site (Photo by Hamdy, 2008)

Eastern Harbour (EH):

The Eastern Harbour (E.H.) is a shallow semi-enclosed bay with an area of about 2.8 km^2 (Massoud & Abdel Wahed, 2006), its mouth protected from the sea by an artificial breakwater barrier leaving two openings to the sea, El-Boughaz and El-Silsila. Water is exchanged between the harbour and the open sea through the two openings. The harbour has an average depth of 6.5 m and water volume of 16.44 million m^3 (Massoud & Abdel Wahed, 2006). For a long time, E.H. has been affected by sewage waste disposal through several outfalls (Youssef and Lees-Gayed, 2003). In 1996–1997, however, all outfalls but one were closed (Ismael & Khadr, 2003), (Fig. 5).

Fig. 5: Eastern Harbour site (Front of Oceanography department) (original).

El-Mex (MX):

El-Mex Bay extends about 15 km between El-Agamy headland to the west and the Western Harbour to the east, with a mean depth of 10 m. It receives huge volumes of drainage water via El-Umum Drain consisting of agricultural runoff mixed with polluted Lake Mariut overflow. The sampling site is subject to large temporal and spatial salinity fluctuations, consisting from less than 20 to higher than 38‰.

The beach of this site consists mainly of broken corals, molluscan shells, and hard remains of barnacles and others (Fig. 6).

Fig. 6: El-Mex site (Photo by Hamdy, 2008).

The chemical nature of the substratum is hardly of importance to benthic algae. Coastal water of El-Mex Bay receives also large amounts of untreated industrial wastes (Fe, Mn, Cu, Zn, Cd, Pb and Ni) as revealed by sediment analysis and water analysis (Fahmy 1995). These wastes, which contain potentially toxic metals, are dumped directly into the bay via a pipeline in its southern part.

SAMPLING AND METHODOLOGY

Samples were collected monthly from April 2006 to April 2007 for the analysis of abiotic and biotic parameters, from five sites; Abu-Qir (AQ), El-Mandara (MN), Stanly (ST), Eastern Harbour (EH) & El-Mex (MX).

1- Water samples for the measurements of physico-chemical parameters.

2- Benthic algal samples.

Physico-chemical methods:

Water characteristics:

Water temperatures, salinity, hydrogen ion concentration (pH), dissolved oxygen (DO), were measured in the surrounding sea water of algal samples at the sites mentioned above.

Temperature and Hydrogen ion concentration (pH):

The pH and temperature value of the water at site were measured directly in the field by digital portable pH-meter (Cyberscan 10 ^{pH} ; pH - °C Meter) and Thermometer.

Salinity:

Sea water samples for salinity measurements were collected using salinity bottles. The salinity was determined using a calibrated Salinometer (Beckman Induction Salinometer (Model RS-7C).

Dissolved oxygen (DO):

DO was determined using Winkler Technique as described by Strickland and Parsons (1972).

The percentage saturation of DO was calculated by dissolved oxygen (%sat) program by http://www.fivecreeks.org.

Biological methods

Macroalgae:

Monthly collections and observations of the macroalgal species were carried out at the 5 sites along the Alexandria coast at depth ranging from 0 to 1.5m.

Three quadrates of 0.1 m^2 were randomly placed on the hard substratum and all biota inside the quadrate were completely removed by scraping the hard substrates. The samples were then transferred into plastic bags containers. Representative samples from each quadrate were preserved in 4% formalin for identification.

The species composition, local distribution and the seasonal periodicity of the algal species were recorded. The algae were blotted and fresh weight biomass of the dominant algal species determined and expressed as wet weight (g ww m^2).
Identification of the algal species was determined by microscopic examination.

The primary sources of identifications were Funk (1927), Feldmann (1937), Kylin (1954), Taylor (1957), Zinova (1967), Abbott and Hollenberg (1976)and Menez and Mathieson (1981). The nomenclature of Parke and Dixon (1976), Dixon and Irvine (1977) were followed.

RESULTS AND DISCUSSION

PHYSICO-CHEMICAL ENVIRONMENT

In the following the distribution and monthly variati on of the physico-chemical parameters investigated are reported for the five stations from April 2006 to April 2007. The following parameters were recorded monthly at each station: water temperature, salinity, dissolved oxygen, and pH.

Water temperature:

The water temperature fluctuated from 16.2 ^oC to 31.3 ^oC throughout the year (Table. 1). Among sites, the temperature was the highest at AQ in August (Fig. 7). Water temperature increased in all stations in the period from April 2006 to August 2006 and fell in the period from August 2006 to December 2006 then increased again from December 2006 to April 2007.

It was observed that, water temperature in all stations increased in August 2006 with increasing salinity in the same month.

Table 1: Monthly variation of water temperature at the sampled sites (April 2006 - April 2007).

	Apr-06	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	Apr-07
AQ	22.8	24.8	27.5	28.5	31.3	27.5	23.8	21.2	17.3	16.9	17.3	19.6	18.6
MN	22	23.3	26.6	27.5	30.2	27.1	23.4	19.6	16.5	16.2	17	20.2	17.99
ST	20.9	22	25.5	28	30.4	26.9	23.6	20.2	17.2	16.6	17	17.4	17.6
MX	21.2	24	28	28	30.4	28.1	23.1	19.45	17.16	16.6	17	17.4	18.5
EH	21.1	23.5	28	29	29.9	28.6	23.9	20.4	16.2	16.3	17.7	18	20

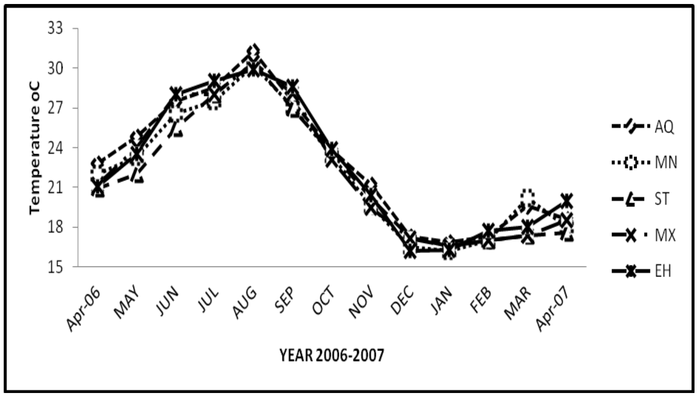

Fig. 7: Monthly variation of water temperature at the sampled sites (April 2006 - April 2007).

Salinity:

With the exception of its markedly low values at MX, salinity displayed small differences among the other four sites , ranging between 33 ‰ (October in EH) and 39‰ (August in MN, July and January in EH) over the year (Fig. 8).

At MX, salinity showed pronouncedly high values, during winter months, due to mixing with offshore waters caused by strong wave action (Table 2). However, the salinity variation at MX is mainly related to the monthly changes in the volume of discharged runoff waters to the area from El Umum drain. Among sites, the average salinity decreased at EH, AQ, ST and MN in October.

Table 2: Monthly variation of surface salinity at the sampled sites (April 2006 - April 2007).

	Apr-06	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	Apr-07
AQ	37.6	36.6	38.4	37	38	37	35.5	38.25	37.5	37.5	37.9	37	38
MN	38	37.6	38.7	34.5	39	37	38	38.5	38	37	37.5	36.5	37
ST	37	38.2	37.5	38.5	37.5	38	37	38	38	38	37.5	37.5	38
MX	29.4	20.8	23.6	28	35	26	26	37.5	36.5	37	38	36	35
EH	37.5	37.9	37.7	39	37.5	37.4	33	37.5	37.5	39	37	37	36.5

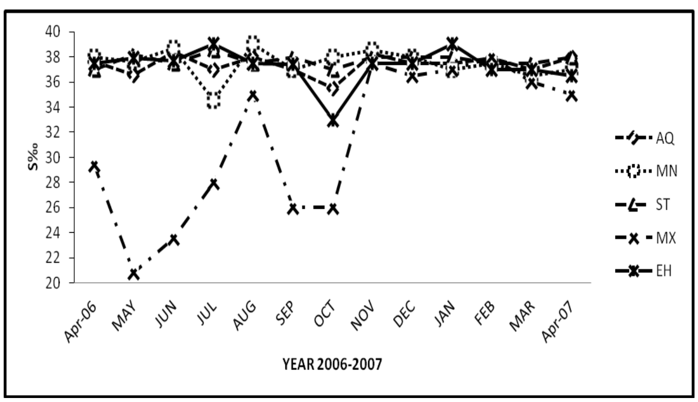

Fig. 8: Monthly variation of Surface salinity at the sampled sites (April 2006 - April 2007).

Hydrogen ion concentration (pH):

The pH displayed relatively large fluctuations during most of the year within variation from 7.57 (November at MX) to 8.38 (March at AQ) (Fig. 9). The annual average pH attained the highest value at AQ, followed by MN then MX while ST and EH sustained the same pH value (Table 3). The pH values lie within the normal range for seawater (7.57 - 8.38).

Table 3: Monthly variation of pH at the sampled sites (April 2006 - April 2007)

	Apr-06	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	Apr-07
AQ	7.99	8	7.97	7.86	8.07	8.03	8.02	8.35	8.09	8.18	8.13	8.38	8.11
MN	7.81	7.83	7.71	7.56	8.11	7.98	7.98	8.15	8.01	8.17	8.11	8.08	7.99
ST	7.7	7.96	7.88	7.98	7.78	7.88	8	7.79	7.95	8.17	8.02	8.13	8.03
MX	7.73	7.97	8	8.06	8.16	7.86	7.97	7.57	8.12	8.13	8.02	8.01	7.8
EH	7.6	7.83	7.86	7.59	8.07	7.89	7.96	7.83	7.95	8.17	8.23	8.12	8.1

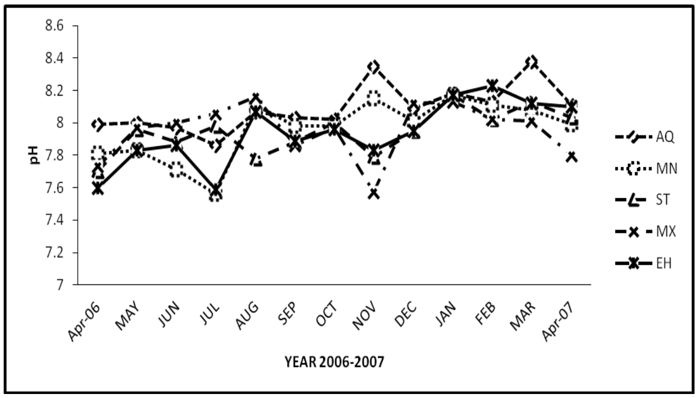

Fig. 9: Monthly variation of pH at the sampled sites (April 2006 - April 2007).

Dissolved Oxygen:

Surface layer at the sampled sites was almost always saturated with oxygen with but few exceptions. The oxygen saturation of ranged from 25% to 125%, the lowest values were observed at the MN and the highest at the MX (Table 5).

The percentage saturation of oxygen from April 2006 to July and dropped with fluctuation from September to February then increased again (Fig. 10). Furthermore, the fluctuations in oxygen saturation was noticed from April 2006 to April 2007 at EH, MX and ST.

Table 4: Monthly variation of dissolved oxygen at the sampled sites (April 2006 - April 2007).

	Apr-06	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	Apr-07
AQ	8.0	8.64	8.5	6.4	7.2	5.5	7.6	7.7	7.6	7.7	7.1	7	8
MN	7.1	6.6	6.2	6.5	6.8	7.5	7.7	7.6	7.3	6.8	6	6	6.2
ST	8.2	8.6	7.2	6.6	6.4	8.5	7	6.7	8	8.3	8.2	8.1	7.9
MX	7.6	10.4	8.4	1.9	2.6	7.5	7.3	6.9	4.5	2.8	4.3	6.3	7.3
EH	7.5	7.6	7.1	6	6.4	7.1	7.4	7.1	7.6	3.5	2.5	3.9	6.6

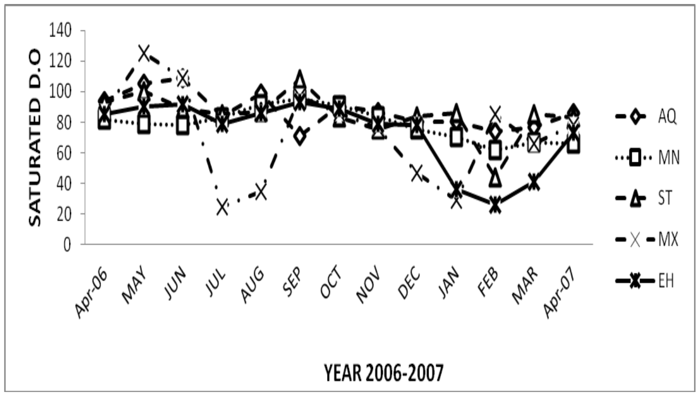

Fig. 10: Monthly percentage saturation of dissolved oxygen at the sampled sites (April 2006 - April 2007).

Table 5: Monthly percentage saturation of dissolved oxygen at the sampled sites (April 2006 - April 2007).

	Apr-06	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	Apr-07
AQ	94	105	109	84	99	71	91	87	80	80	74	77	86
MN	82	79	78	83	92	95	91	84	75	70	62	67	66
ST	93	100	89	85	87	108	83	75	84	86	44	85	83
MX	87	125	109	25	35	97	86	76	47	29	85	66	78
EH	85	90	92	79	86	93	89	79	78	36	26	41	73

MACROALGAL COMMUNITY

The present taxonomical study of the algal flora at the 5 sites along the Alexandria coast revealed the occurrence of 40 species belonging to the three main classes, including 15 Chlorophyceae, 6 Phaeophyceae and 19 Rhodophyceae. Five taxa are new records for the area. These are: *Enteromorpha prolifera*, *Porphyra columbina*, *Porphyra umbilicalis*, *Grateloupia turuturu* and *Grateloupia doryphora*. The recorded species are given in Table (6) .Several surveys of the algal flora of Alexandria have been carried out by earlier authors as shown in Introduction.

OCCURRENCE AND BIOMASS OF MACROALGAE

Environmental factors:

The results revealed that, water temperature experienced the classical seasonal trend known to the Egyptian Mediterranean coast, varying between a minimum of 16.2 ^{o}C in January and a maximum of 31.3 ^{o}C in August. Salinity displayed wide differences (33 ‰ -39‰) from Abu-Qir to Eastern Harbour and wide monthly variation at El-Mex due to waste waters discharged from El-Umoum Drain. However, high salinity (38‰) was observed at MX as a result of strong wave action.

The pH values lie within the normal range for seawater (7.57 - 8.38). It displayed small differences over the whole coast (0.22-0.3) and comparatively wide monthly variation at each site (0.25-0.43). Surface layer at the sampled sites was almost always saturated with oxygen with but with few exceptions. The oxygen saturation ranged from 25% to 125%. Numerous surveys of the macroalgae of Alexandria coastal waters have been carried out by different authors. However, the present study is to be considered as the second attempt after Nabih (1985-1986) to survey and determine the seasonal variations in the biomass of the dominant algal species at five stations along the Alexandria coast. The wet weight biomass in the 5 stations would be in the following sequence.AQ > EH > ST > MX >MN.

Table 6: Specific composition of macroalgae - Alexandria coast.
*** New records.**

Chlorophyceae
Ulvales
Enteromorpha clathrata (Roth) Greville
Enteromorpha compressa (Linnaeus) Greville
Enteromorpha flexuosa (Roth) J . Agardh
Enteromorpha intestinalis (Linnaeus) Link
Enteromorpha linza (Linnaeus) J . Agardh
**Enteromorpha prolifera* (O. F. Müller) J. Agardh
Ulva fasciata Delile
Ulva lactuca Linnaeus
Cladophorales
Cladophora albida (Hudson) Kützing
Cladophora dalmatica KÜtzing
Cladophora gracilis (Griffiths ex.Harvey) KÜtzing
Cladophora laetevirens (Dillwyn) Harvey
Cladophora rupestris (Linnaeus) Kützing
Caulerpales
Caulerpa racemosa (Forsskal) j . Agardh
Codiales
Bryopsis pennatula J . Agardh
Phaeophyceae
Ectocarpus parvus (saunders) Hollenberg
Dictyotales
Padina pavonia (Linnaeus) Lamouroux
Scytosiphonales
Colpomenia sinuosa (Roth) Derbes & Solier
Petalonia fascia (Müller) Küntze
Fucales
Cystoseira compresssa (Esperi) Gerloff et nizamuddin
Sargassum salicifolium (Bertoloni) J . Agardh
Rhodophyceae
Bangiales
Bangia fuscopururea (Dillwyn) Lyngbye
Erythrotrichia carnea (Dillwyn) J. Agardh
**Porphyra columbina* f. kunthiana (Kützing) G. Hamel
**Porphyra umbilicalis* f. laciniata (C.Agardh) Thuret
Gelidiales
Gelidium crinale (Turner) Lamouroux
Gelidium latifolium (Greville) Bornet et Thuret
Pterocladia capillacea (Gmelin) Bornet et Thuret
Cryptonemiales
Corallina mediterranea Areschoug
Corallina officinalis Linnaeus
**Grateloupia turuturu Yamada*
**Grateloupia doryphora* (Montagne)
Jania rubens (Linnaeus) Lamouroux
Amphiroa rigida Lamouroux
Gigartinales
Hypnea musciformis (Wulfen) Lamouroux
Ceramiales
Ceramium elegans (Ducluzeau) C . Agardh
Ceramium fastigiatum (Roth) Harvey
Ceramium rubrum (Hudson) C . Agardh
Callithamnion corymbosum (J . E . Smith) Lyngbye
Laurencia papillosa (Forsskal) Greville

A total of 4٠ macroalgal species belonging to the main three classes were recorded. The Chlorophyceae contributed 37.5%, the Phaeophyceae 15% and the Rhodophyceae 47.5% .

In Abu Qir (AQ) the Chlorophyceae were dominant, *Enteromorpha* and *Ulva* spp. were found in all collected samples. In Eastern Harbor (EH), 20 species occur (about 50% of the total records in Alexandria), belonging to the main three classes of algae. *Corallina* spp., *Ulva* spp., *Enteromorpha* spp. and *Cladophora* spp. were found in mass quantities throughout the year, (Table 7).

Table 7: Composition and monthly occurrence of macroalgae at the five study sites along Alexandria coast.

* New records. Numbers 1 to 5, respectively AQ, MN, ST, MX, EH

Chlorophyta

	APR 2006	MAY	JUN	JUL	AUG	SEP	OCT	NO V	DEC	JAN	FEB	MAR	APR 2007
Chlorophyceae													
Ulvales													
Enteromorpha clathrata (Roth) Greville	1,3	1	1	1	1	4	1,3,4	1,3,4	1,2	1	3	1	1,3
Enteromorpha compressa (Linnaeus) Greville		3				3			1,3	4	2,3,4	2,3	
Enteromorpha flexuosa (Roth) J . Agardh	1,2		1,4	1,3,4	1,4	5	5	5		1,2	3	2,3,5	1,2
Enteromorpha intestinalis (Linnaeus) Link	1,2	2,4	1	1	1			1	1	1,2,3	1,3	All	1,2,4
Enteromorpha linza (Linnaeus) J . Agardh	4,5	1,2,3,4									1,3	1,2,3	2,4,5
**Enteromorpha prolifera* (O. F. Müller) J. Agardh										1	1	1	
Ulva fasciata Delile	All	All	All	All	All	All	All	All	All	All	All		All
Ulva lactuca Linnaeus	1	1,2	1	1,2	1,2	1	1	1	1,2	1	1	All	1
Cladophorales													
Cladophora albida (Hudson) Kützing	4	1	1,2	1	1,2			2,3	1,2,3	3	3,4	5	4
Cladophora dalmatica KÜtzing				5	5	5		2		4	3,4	3	
Cladophora gracilis (Griffiths ex.Harvey) KÜtzing	4	1,4	1	1	1				2,3	3,5	3	1,2,3,5	4
Cladophora laetevirens (Dillwyn) Harvey	1												1
Cladophora rupestris (Linnaeus) Kützing		4		1	1,5	1,5	1	1					
Caulerpales													
Caulerpa racemosa (Forsskal) j . Agardh		1										1	
Codiales													
Bryopsis pennatula J. Agardh	1		1	1		1		1	1				1

Table 7 (Continued)
PHAEOPHYTA

	APR 2006	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR 2007
Phaeophyceae													
Ectocarpus parvus (saunders) Hollenberg		1,2		1	1	1	1	1	1,2	1,2			
Dictyotales													
Padina pavonia (Linnaeus) Lamouroux		1		1	1	1	1	1					
Scytosiphonales													
Colpomenia sinuosa (Roth) Derbes & Solier		1,3											3
Petalonia fascia (Müller) Küntze									1	1			
Fucales													
Cystoseira compresssa (Esperi) Gerloff et nizamuddin				1	1	1	1		1	1			
Sargassum salicifolium (Bertoloni) J . Agardh		1	1	1	1	1		1					

Table 7 (Continued)
RHODOPHYTA

	APR 06	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR 07
Rhodophyceae													
Bangiales													
Bangia fuscopururea (Dillwyn) Lyngbye		3											
Erythrotrichia carnea (Dillwyn) J. Agardh		3				1	1	1					
**Porphyra columbina* f. kunthiana (Kützing) G. Hamel	2	2					2						2
**Porphyra umbilicalis* f. laciniata (C.Agardh) Thuret	2					2							2
Gelidiales													
Gelidium crinale (Turner) Lamouroux								1			4		
Gelidium latifolium (Greville) Bornet et Thuret	1,4	4	1		1			1,4	1			4	1,4,5
Pterocladia capillacea (Gmelin) Bornet et Thuret		1,3,5	1	1,5	1,3,4	1,4	1	1	1	1	1	1,4	1
Cryptonemiales													

Corallina mediterranea Areschoug		1,3,5	1,5	1,5	1,5	1	1	1,2,3,5	1,5	1,5	1,2,3,5	1,5	
Corallina officinalis Linnaeus	1,5	1,4,5	All	All	1,4,5	All	1,5	1,4,5	All	All	1,5	1,4,5	1,5
**Grateloupia turuturu Yamada*		1											
**Grateloupia doryphora* (Montagne)				4	4			4			2	4,5	
Jania rubens (Linnaeus) Lamouroux	1	1	1	1	1	1	1	1,5	1	1	1	1	1
Amphiroa rigida Lamouroux		1,3		1	1			2,3	5		5	1,5	
Gigartinales													
Hypnea musciformis (Wulfen) Lamouroux	1		1		1	1	1	1	1				1
Ceramiales													
Ceramium elegans (Ducluzeau) C . Agardh	1	1,3			1	1		3,4	1,5	4,5	2,5	4,5	1
Ceramium fastigiatum (Roth) Harvey								5					
Ceramium rubrum (Hudson) C . Agardh		1			1	1	1	5					
Callithamnion corymbosum (J. E. Smith) Lyngbye								3,5	5		5	5	
Laurencia papillosa (Forsskal) Greville		1			1	1				1			

OBSERVED LONG TERM TREND IN MACROALGAL BIODIVERSITY

The present survey showed clearly a steady long term decrease in biodiversity of macroalgae along the coast of Alexandria compared to the results of earlier surveys. The present study deals with this problem. An attempt was made to understand this change in relation to the changes which occurred in the marine environment in Egypt.

There are two items:

I - Changes in macroalgal biodiversity from 1940 to 2007:

II- Changes in marine environment.

Changes in macroalgal biodiversity from 1940 to 2007:

Records and observations on macroalgal flora in the area of Alexandria began with Nasr (1940). Nasr was followed by Aleem (1945), Khalil (1987), Nabih (1989), Soliman (1997) in addition to the present work.

Although the sampling sites and the duration of the surveys differ, they provide biodiversity data on relatively long period. The data available have been brought together to make clear the trend of biodiversity variation for this period.

The results are given in Table 8 and illustrated in Fig. 11. The observations of Nasr (1940) are not taken in consideration since it is obvious that author did not intend to make an exhaustive survey of the algal flora.

As stated above the present survey shows a clear and steady decreasing trend in biodiversity since the records of Aleem (Fig. 11).

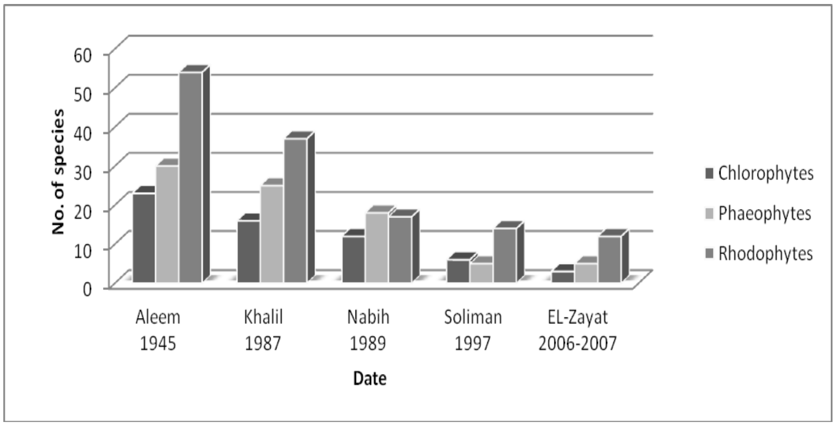

Fig. 11: Number of macroalgal species for the period 1948-2007 in Abu-Qir site (filamentous algae excluded)

As mentioned above the decline in biodiversity since 1945 until present is a fact which we will attempt to discuss in the light of parallel changes in some environmental conditions.

It is probable that several factors interact, in other words, it is not exclusively due to a single factor. In the following the steady decline will be described and discussed in the light of major change in the marine environment:

1- The potential effect of global warming: Temperature change pattern.

2- The change in the fertility of marine environment resulting from the absence the Nile flood in the post High Dam period.

3-The drop in nutrient salts observed in Abu-Qir site since 1985-1986.

The trend of variability in biodiversity shown by the successive surveys is reflected in both the richness of species and the species composition of the community. Aleem (1945) enumerated 107 species collected from Alexandria coast, which comprise 23 green, 30 brown and 54 red forms. Ninety-two species from his records disappeared. Examples are *Ulva rigida*, *Valonia utricularis* and *Halimeda tuna*. (Table 8).

On the other hand, several others which were absent in 1945 are commonly found at present. Examples are: *Cystoseira compresssa*, *Sargassum salicifolium* and *Caulerpa racemosa*. Five species are new records in the present work namely *Enteromorpha prolifera*, *Porphyra columbina*, *Porphyra umbilicalis* cf, *Grateloupia turuturu* and *Grateloupia doryphora* cf.

Ulva fasciata, *Ulva lactuca*, *Colpomenia sinuosa*, *Pterocladia capillacea*, *Corallina officinalis*, *Jania rubens* and *Laurencia papillosa* are in common to the last successive surveys. Most of these species are widely distributed in warm temperate and tropical waters.

Khalil (1987), depending on more than 5 years collections investigated the occurrence, distribution and periodicity of the benthic marine algae at Alexandria coast. He recorded 78 macroalgal species, belonging to the three main classes, including 16 Chlorophyceae, 25 Phaeophyceae and 37 Rhodophyceae. From them, 22 were new records to the area.

Table 8: Macroalgal biodiversity from 1940 to 2007 Abu-Qir site:

		Nasr 1940 a & b	Aleem 1945	Khalil 1987	Nabih 1989	Soliman 1997	Present work 2006-2007
	Chlorophyceae						
1	*Acetabularia parvula* Solms-Laubach		■				
2	*Anadyomene stellata (*Wulf.) *Ag.*	■	■				
3	*Bryopsis adriatica* (J.Ag.) *Meneigh.*	■	■				
4	*Bryopsis cupressina Lamour.*		■				
5	*Bryopsis disticha* (J. Ag.) *Kutz.*		■				
6	*Bryopsis hypnoides* Lamouroux		■	■			
7	*Bryopsis pennata* Lamour.	■	■	■			
8	*Bryopsis pennatula* J. Agardh			■	■		
9	*Bryopsis plumosa* (Hudson) C.Agardh			■	■		
10	*Caldophoropsis zollingerii* (Kützing) Reinbold		■				
11	*Caulerpa prolifera* (Forsskal) Lamouroux	■	■	■	■		
12	*Caulerpa racemosa* (Forsskal) j. Agardh				■	■	■
13	*Caulerpa scalpelliformis* (Brown ex Turner) C. Agardh			■	■		
14	*Codium bursa* (Linnaeus) C. Agardh		■	■	■		
15	*Codium dichotomum (*Huds.) *Setchell*	■	■				
16	*Codium effusum* (Rafinesque) Delle Chiaje		■				
17	*Codium elongatum* (Turner) C. Agardh	■	■	■	■		
18	*Codium taylorii* Silva		■				
19	*Codium tomentosum* (Huds.) *Stackhouse*			■	■	■	
20	*Codium vermilara (Delle Chiaje) Silva*			■	■		
21	*Dasycladus vermicularis* (Scopoli) Krasser		■				
22	*Halicystis parvula* Schmitz ex G. Murray		■				
23	*Halimeda tuna* (Ellis et Solander) Lamouroux	■	■	■	■	■	
24	*Udotea minima Ernst.*		■				
25	*Udotea petiolata* (Turra) Børgesen	■	■	■			
26	*Ulva fasciata Delile*	■	■	■	■	■	■
27	*Ulva lactuca* Linnaeus		■	■	■	■	■
28	*Ulva rigida* C. Agardh		■	■			
29	*Valonia utricularis* (Roth) C. Agardh	■	■	■		■	
	Phaeophyta						
30	*Cladostephus spongiosus* (Hudson)	■					
31	*Cladostephus verticillatus* (Light foot) Lyngbye		■	■	■		
32	*Colpomenia peregrina* (Sauvageau) Hamel			■			
33	*Colpomenia sinuosa* (Roth) Derbes & Solier	■	■	■	■	■	■
34	*Cystoseira abrotanifolia C. Ag.*		■				
35	*Cystoseira amentacea* (C. Agardh) Bory		■				
36	*Cystoseira barbata* (Good. And Woodw.) J.Ag.		■				
37	*Cystoseira compresssa* (Esperi) Gerloff et nizamuddin			■	■		■

38	*Cystoseira crinita* (Desfontaine) Bory		■				
39	*Cystoseira discors* (Linnaeus) C.Agardh			■			
40	*Cystoseira mediterranea* Sauvageau		■				
41	*Cystoseira spinosa* Sauvageau		■	■			
42	*Cystoseira tamariscifolia* (Hudson) Papenfuss			■			
43	*Dictyopteris polypodioides* (De Candolle) Lamouroux		■				
44	*Dictyopteris membrancea* (Stackhouse) Batters	■	■	■	■		
45	*Dictyota dichotoma* (Hudson) Lamouroux		■	■	■	■	
46	*Dictyota linearis* (J. Ag.) Greville		■	■			
47	*Dilophus fasciola* (Roth) Howe			■	■		
48	*Dilophus ligulatus* (Kützing) Feldm.	■	■				
49	*Halopteris filicina* (Grateloup) Kützing		■				
50	*Halopteris scoparia* (Linnaeus) Sauvageau	■	■	■	■		
51	*Hydroclathrus clathratus* (C.Ag.) Howe	■	■	■	■		
52	*Myrionema strangulus* Greville		■				
53	*Nereia filiformis* (J. Agardh) Zanardini		■	■			
54	*Padina boryana* Thivy		■				
55	*Padina pavonia* (Linnaeus) Lamouroux	■	■	■	■	■	■
56	*Petalonia fascia* (Müller) Küntze		■	■	■	■	■
57	*Punctaria latifolia* Greville		■	■	■		
58	*Sargassum acinarium* Linnaeus C. Agardh		■				
59	*Sargassum hornschuchii* C. Agardh			■	■	■	
60	*Sargassum linifolium (Turn.) J. Ag.*	■	■				
61	*Sargassum salicifolium* (Bertoloni) J.Agardh			■	■		■
62	*Scytosiphon lomentaria* (Lyngbye) J. Agardh	■	■	■	■		
63	*Spatoglossum solierii* (Chauvin) Kützing			■	■		
64	*Spatoglossum variabile Figari et De Notaris*			■			
65	*Sphacelaria cirrhosa (Roth.) C.Ag.*		■	■	■		
66	*Sphacelaria furcigera Kutz.*		■				
67	*Sphacelaria tribuloides* Meneghini		■	■	■		
68	*Taonia atomaria* (Woodward) J. Agardh		■	■	■		
69	*Zanardinia prototypus* (Nardo) Nardo		■				
	Rhodophyceae						
70	*Acanthophora delilei Lamour.*		■				
71	*Acanthophora najadiformis* (Delile) Papenfuss			■			
72	*Ahnfeltia plicata* (Hudson) E.M.Fries				■		
73	*Amphiroa beauvoisii Lamour.*	■	■				
74	*Amphiroa rigida* Lamouroux		■	■	■		■
75	Asparagopsis taxiforms (Delile) Trevisan		■				■
76	Botryocladia botryoides (Wulfen) Feldmann	■	■	■			
77	Botryocladia chiajeana (Menegh.) Kylin		■				
78	Caulacanthus ustulatus (Mert.) Kutz.		■				
79	Champia parvula *(C. Agardh) Harvey*		■	■			
80	*Chondria dasyphylla* (Woodward) C. Agardh		■				

81	*Chrysymenia ventricosa* (Lamouroux) J. Agardh		■	■			
82	*Corallina elongata* Ellis et Solander		■				
83	*Corallina granifera* J.Ellis & Solander		■	■			
84	*Corallina mediterranea* Areschoug	■	■	■	■	■	■
85	*Corallina officinalis* Linnaeus		■	■	■	■	■
86	*Digenea simplex* (Wulfen) C. Agardh		■				
87	*Gelidiella tenuissima (Thur.) Feldm. et Hamel*	■	■				
88	*Gelidium crinale* (Turner) Lamouroux		■	■	■	■	■
89	*Gelidium filicinum Bory*		■				
90	*Gelidium latifolium* (Greville) Bornet et Thuret		■	■	■	■	■
91	*Gelidium pusillum* (Stackhouse) Lejolis		■				
92	*Gigartina acicularis Lamour.*	■	■				
93	*Gigartina teedii*, (Roth) Lamouroux	■	■	■			
94	*Gigartina tepida* Hollenberg				■	■	
95	*Gracilaria arcuata* Zanardini		■	■			
96	*Gracilaria armata* (C. Agardh) Greville		■	■	■	■	
97	*Gracilaria bursa-pastoris* (S.G.Gremlin) Silva			■			
98	*Gracelaria compressa (Ag.) Grev.*		■				
99	*Gracelaria confervoides (L.) Grev.*	■	■				
100	*Gracilaria dura* (C. Agardh) J. Agardh	■	■	■	■		
101	*Gracilaria verrucosa (Hudson) Papenfuss*			■			
102	*Grateloupia doryphora* (Montagne)						■
103	*Grateloupia prolongata* J. Agardh						■
104	Griffithsia furcellata J. Ag.		■	■			
105	Griffithsia opuntioides (J. Ag.)		■				
106	*Gymnogongrus griffithsiae* (Turner) Martius		■				
107	*Halopitys incurvus (Huds.) Batters*			■			
108	*Halopitys pinastroides (Gmel.) Kutz.*		■				
109	*Halymenia fastigiata J. Agardh*			■			
110	*Halymenia floresii* (Clemente) C. Agardh		■	■			
111	*Halymenia ulvoides Zanard.*		■				
112	*Hypnea cornuta* (Kützing) J. Ag.		■				
113	*Hypnea musciformis* (Wulfen) Lamouroux		■	■	■	■	■
114	Hypoglossum woodwardii *Kützing*			■			
115	*Jania adhaerens* J.V. Lamouroux			■		■	
116	*Jania rubens* (Linnaeus) Lamouroux		■	■	■	■	■
117	*Laurencia obtusa* (Hudson) Lamouroux		■	■	■		
118	*Laurencia paniculata* (C. Agardh) J. Agardh	■		■			
119	*Laurencia papillosa* (Forsskal) Greville		■	■	■	■	■
120	*Laurencia pinnatifida* (Gmelin) Lamouroux		■	■			
121	Liagora viscida *(Forsskål) C.Agardh*			■			
122	Lithophyllum incrustans *Philippi*		■	■			
123	*Lithophyllum pustulatum* (Lamouroux) Foslie	■	■		■		
124	*Lomentaria articulata (Huds.) Lyngb.*		■	■			
125	*Nemalion helminthoides* (Velley) Batters	■	■	■	■	■	

126	*Peyssonnelia rubra* (Greville) J. Agardh		■				
127	*Peyssonelia squamaria (Gmel.) Decsne.*		■				
128	*Phyllophora nervosa* (Decaisne) Greville		■				
129	*Porphyra columbina* f. kunthiana (Kützing) G. Hamel						■
130	*Porphyra leucosticta Thuret*		■	■			
131	*Porphyra umbilicalis* f. laciniata (C.Agardh) Thuret						■
132	*Pterocladia capillacea* (Gmelin) Bornet et Thuret	■	■	■	■	■	■
133	*Rhodophyllis bifida (Good. et Wood.) Kutz.*		■				
134	*Rhodymenia palmate* (Linnaeus) Greville		■	■	■		
135	Rytiphloea tinctoria *(Clemente) C. Agardh*			■			
136	Sarconema furcellatum Zanard.		■				
137	Scinaia furcellata *(Turner) J Agardh*		■	■		■	
138	*Sebdenia dichotoma* Berthold		■				
139	*Sphaerococcus coronopifolius (Good. et Wood.) C. Ag.*		■				
140	Tricleocarpa oblongata (Ellis et Solander)					■	
	Total number of macroalgal species	30	107	78	47	25	21

Khalil (2005) reported that the algal biomass in Alexandria area is relatively low and in some areas consisting mostly of *Penicillus* spp. and *Caulerpa* spp. associated with *Udotea* and others. In addition *Codium fragile* has rapidly expanded over the other larger perennial seaweeds in the last few decades. Moreover, *Caulerpa racemosa* has invaded and taken over large areas of Alexandria coastal seabed.

Nabih (1989) collected and described about 47 species belonging to the three main classes, including 12 Chlorophyceae, 18 Phaeophyceae and 17 Rhodophyceae, 3 of which were new records.

The average WW biomass of algal species ranged from 1.4 to 6.2 Kg WW m^{-2} in November and April respectively (Khalil, 1988). *Cystoseira compresssa* was quantitatively dominant in AQ ranging from 26 g DW in January to 466 g DW m^{-2} in April followed by *Ulva fasciata* and *Pterocladia capillacea*. The quantitative importance of the Phaeophyceae and the minor contribution of the Chlorophyceae are noteworthy.

Soliman (1997) collected and described about 25 species belonging to the three main classes, including 6 Chlorophyceae, 5 Phaeophyceae and 14 Rhodophyceae, at the same site. *Tricleocarpa oblongata* was new records to the area.

The red algae were the major contributor for the total biomass at AQ .The biomass significantly decreased toward the west. The highest biomass (2.564 kg WW.m^2) was recorded from the exposed site at AQ

The species *Ulva fasciata, Ulva lactuca, Padina pavonia, Petalonia fascia, Colpomenia sinuosa, Pterocladia capillacea, Corallina officinalis, Jania rubens, Laurencia papillosa* are in common to the last three successive surveys (Nabih (1989), Soliman (1997) and present work). Most of these species are widely distributed in warm temperate and tropical waters.

In the present work, the biomass of the AQ algal community is mainly composed of *Enteromorpha* and *Ulva* spp. beside *Cladophora* spp., *Petalonia fascia, Sargassum* *salicifolium*, *Corallina* spp. *Pterocladia capillacea* , *Hypnea musciformis* and *Jania rubens*. The highest biomass (3.250 $kg.m^{-2}$) was recorded from the exposed site at AQ.

Over the past 50 years, the warming hypothesis of Mediterranean waters has been supported by a series of physical and ecological observations.

Climate change in the past 50 years that followed the occurrence of the powerful El Niños (from 1971 to 2015) during which was followed by the emergence of global warming. These changes have a faster impact on the relatively small semi-closed Mediterranean region. The recent rapid global warming may have had an impact on the observed changes in El Niño (Wang *et al*. 2019).

The great changes in the distribution of living organisms in the Mediterranean are related to the changes recorded in temperature, precipitation and other matters over the past 50 years through the movement of hundreds of organisms that arrived and settled in the Mediterranean basin, most of them from warm water areas, and thus higher temperatures may cause changes in species other than Local influences the distribution of native species. Therefore, high temperatures are expected to cause changes in the occurrence and distribution of native species (de la Hoz *et al*. 2019).

The present study represents an attempt to deal with the observed long term changes in relation to environmental changes.

Rising temperatures cause changes in the occurrence and distribution of native species.

The results of the current research are consistent with what de la Hoz *et al*. (2019) pointed out about rising temperatures leading to changes in the occurrence and distribution of native species

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