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Comparison of the impacts of climate change and anthropogenic disturbances on the El Arish coast and seaweed vegetation after ten years in 2010, North Sinai, Egypt

KEYWORDS
Anthropogenic disturbances
Climate change
El Arish coast
El Arish Harbour
El Arish Power Plant
Erosion
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Abstract

Human activities on coasts and climate changes during the past ten years have given rise to considerable shoreline changes along the El Arish coast (the northern coast of the Sinai Peninsula). In the El Arish Power Plant, sediment accretion has reached the tip of the breakwater of the cooling water intake basin, necessitating extensive dredging inside the basin. To the east of El Arish Harbour, the shoreline has been in continuous retreat. The differences between the year 2000 and 2010 in the shoreline along the El Arish coast were determined by analysing satellite images from NOAA-AVHRR images. The analyses revealed erosion and accretion patterns along the coast. The physical parameters showed that the minimum water temperature of 18°C was recorded at site I in winter and that the maximum was 40°C at site II in summer. The latter temperature can be attributed to the effluent discharge of cooling water from the El Arish power plant. Spatial and temporal patterns in the distribution and abundance of macroalgae were measured at four sites (I, II, III and IV) along the El Arish coast. The percentage cover of the successional macroalgae exhibited environmental fluctuations. After ten years, the phytocommunity showed that red and green algae were dominant at the study sites. Significant differences between past and current flora were observed. 39 taxa recorded in 2000 were absent in 2010, while 9 taxa not previously reported were present in 2010. These changes are discussed in the context of possible global warming effects. PERMANOVA showed significant changes ($p < 0.001$) between sites, seasons, species abundance and macroalgal groups along the El Arish coast in 2000 and 2010. The similarity matrix showed a significant difference between the flora in 2010 and that recorded in 2000, indicating poor similarity and changes in species composition among the seasons at the different sites. Most of the algae belonged to the filamentous, coarsely branched and sheet functional form groups.

1. Introduction

Anthropogenic activities in recent centuries have led to atmospheric changes that directly influence the climate, resulting in global warming (IPCC 2007). Coastal ecosystems have been subjected to global threats by their sensitivity to the chemical and physical characteristics of seawater. Seaweed communities are considered good indicators of environmental changes (Harley et al. 2006, Faveri et al. 2010). Species distribution and resource dynamics in both terrestrial and aquatic ecosystems have been affected by climate changes and human activities. Consequently, they can interact with biological invasions (Vitousek et al. 1997, Dukes & Mooney 1999, Stachowicz et al. 2002, Walther et al. 2002, Parmesan & Yohe 2003, Parmesan 2006, Halpern et al. 2008, Dijkstra et al. 2010). On the other hand, the increase in temperature, one of the most hotly debated aspects of global climate change, has directly or indirectly affected the ecosystem. In addition, the synergistic action of other physical, chemical and biological factors should be evaluated (Russell et al. 2009).

Factors including warming and ocean acidification are causing the reorganization of local communities as species are added or deleted and as interactions among species change in importance (Wootton et al. 2008, Harley 2011). Although a great deal of research has focused on systems like coral reefs and terrestrial forests (Hoegh-Guldberg et al. 2007, Aitken et al. 2008), considerably less attention has been devoted to seaweed-dominated ecosystems (Wernberg et al. 2012).

Anthropogenic changes in seaweed diversity, community and functional groups have been observed in nearshore marine environments from many regions throughout the world (Bates & DeWreede 2007). Thus, studies of the marine algal flora in a given region have not only set out the distributional data concerning each species, but have also provided much valuable ecological information on local communities (Boo & Lee 1986).

Climate warming primarily causes physiological stress, which acts more strongly on species already near their tolerance limit (Laubier

2001). Anomalous temperature stress can cause mass mortality in benthic organisms (Pérez et al. 2000, Garrabou et al. 2001), which results in empty niches for new colonizers.

The survival and growth of marine organisms generally depend on the seawater temperature, although many species have a variety of physiological strategies that allow them to adapt to lower or higher water temperatures. Being stationary organisms, macroalgae can be useful bioindicators for detecting various kinds of environmental change. Therefore, monitoring macroalgae distribution in space and time may help to anticipate the effects of global changes on biota and guide policies for environmental conservation and the planning of mitigation initiatives (Langford 1990).

Enclosed seas such as the Mediterranean are probably more at risk of developing such revolutionary changes in ecosystem properties and services, where the influence of climatic forcing is not so easily demonstrable, even if it is abundantly clear that they are the consequence of global changes in both climatic conditions and the increased pressure of propagules being transported across biogeographic ranges by human-mediated transfer (Anna & Romano 2009). Today, Mediterranean coasts are inhabited by a rich seaweed flora, including endemic, tropical, warm and cold-temperate species (Orfanidis 1992).

The northern coast of Sinai is an important region of the Sinai Peninsula because it lies in the eastern basin of the Mediterranean (Levantine nanism) of Egypt. The El Arish coast has suffered from many problems due to climatic and human influences, which might lead to environmental degradation and substantial changes in its ecosystem. The location of coastal infrastructures at El Arish has obstructed longshore sediment transport, which in turn has resulted in shoreline advance/retreat (Emanuelsson & Mirchi 2007). The climate of North Sinai is basically determined by the following factors: the semi-permanent pressure in each season, such as the cold Siberian anticyclone in winter, the hot lows of Africa in spring and summer, and the huge low over south-west Asia in summer (Abdel Rahman et al. 2001). Increased wave impact will cause greater coastal erosion, damaging harbours and other coastal structures (Jeftic 1993) and lead to the collapse of cliffs along the shoreline. However, a number of protective structures, such as detached breakwaters have been constructed along the El Arish coast to reduce coastal erosion. Shoreline erosion at El Arish has advanced to the west of the El Arish Power Plant and to the east of El Arish Harbour. At the same time, similar erosion has occurred in the immediate eastern vicinity of these structures.

Studies of the relative composition of the algal flora in 2000 along the El Arish coast revealed the presence of around 90 species. The distribution of seaweeds and species richness along the El Arish coast was affected by seasonal variations (El Shoubaky 2005). The present study aimed to evaluate the effect of spatial and seasonal variations in the seaweed vegetation and coastal shoreline change on the El Arish coast by comparing recent data (from 2010) with past data (from 2000) over a period of ten years. The coastal erosion data set based on NOAA-AVHRR measurements was used.

2. Material and methods

2.1. Study area

The study area is located at latitude 31.124 and longitude 33.801 (Figure 1). Artificial constructions such as breakwaters are found in different areas of the El Arish coastline. Four sampling study sites were chosen along the El Arish coast (∼ 20 km). A power plant located in the El Masaid area 10 km to the west of El Arish city represents sites I, II and III on the coast of the Sinai Peninsula area. Site I lies beyond the Power Plant intake, site II represents the Power Plant outlet, and site III is influenced by the discharge waters of the El Arish Power Plant (Figure 2). Site IV is located to the east of El Arish harbour at El Risa (Figures 3 and 4 respectively). El Arish Harbour was modelled over a stretch of 10.5 km. Analysis of multi-temporal satellite images is one of the best means of assessing coastal erosion and coastline shifting; satellite images of 2000 and 2010 of the El Arish coast were analysed. Shoreline erosion was determined along the El Arish coast using vectors obtained and

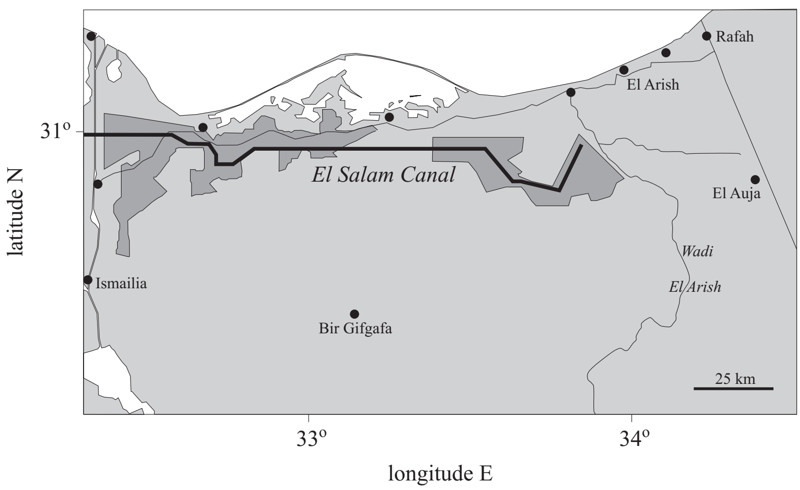

Figure 1. The El Arish coast on the Mediterranean Sea in northern Sinai

Figure 2. NOAA-AVHRR satellite image showing the location of sites I (outside the inlet), II (outlet) and III (beside the outlet) at the El Arish Power Plant

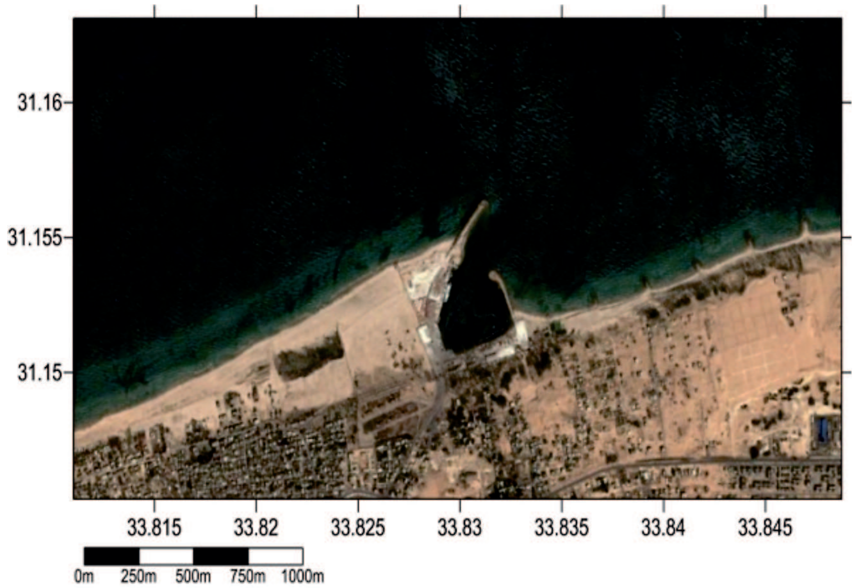

Figure 3. NOAA-AVHRR satellite image showing the location of El Arish harbour

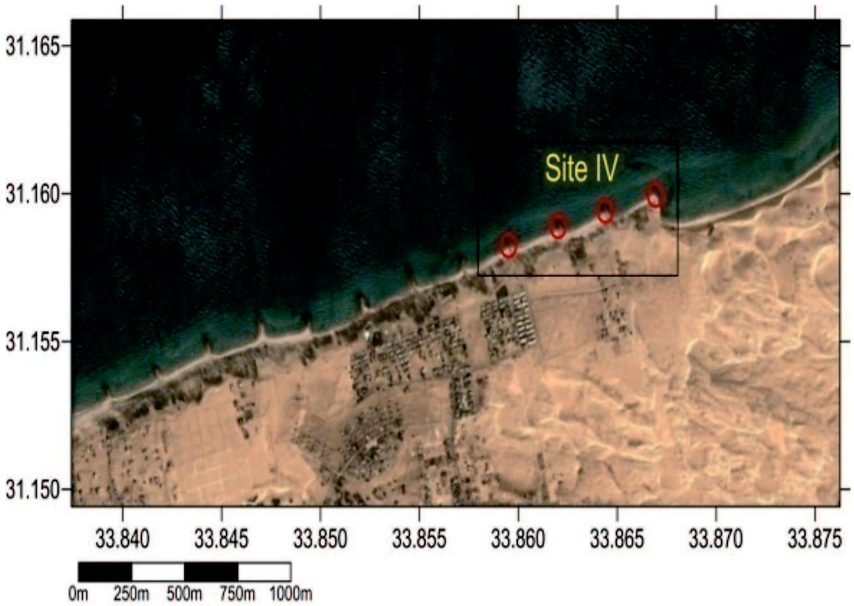

Figure 4. NOAA-AVHRR satellite image of the El Risa area (east of El Arish harbour) showing the location of site IV

modelled using Satellite Images from NOAA (U.S. National Oceanic and Atmospheric Administration) – AVHRR (Advanced Very High Resolution Radiometer) (Li et al. 2001, Nardelli et al. 2005) to investigate the spatial and temporal differences in longshore sediment trends and to compute the sediment transport rate.

2.2. Physical parameters

Four seasonal samplings were carried out for each location from winter to summer in 2010. Abiotic parameters were measured during each sampling period. Water and air temperatures were measured with an ordinary thermometer, salinity was measured with a portable Refractometer (ATAGO S /Mill Chem. Lab. Scientific Products Ltd), pH with a digital pH meter (Teleko AQUAMETR N 5211), and dissolved oxygen was estimated by the modified version of Winkler's method by Strickland & Parsons (1972).

2.3. Macroalgal collection

Intertidal macroalgae were collected and observed seasonally from winter 2010 to autumn 2010 at the four sites, which were chosen as representative areas. The study of the distribution of the algal flora was based on the quadrat method along a vertical transect set up across the intertidal zone to the coastline. The specimens were removed from the substratum using a paint-scraper. All samples were preserved in a 4% formalin-seawater solution and transferred to the laboratory for identification. Examination and identification were carried out using standard taxonomic keys as described by Papenfuss (1968), Cribb (1983), Womersley (1984, 1987) and Aleem (1993). All the seaweeds collected were classified into six functional form groups (sheet, filamentous, coarsely branched, thick leathery, jointed calcareous and crustose) by the methods of Littler & Littler (1980), Littler & Arnold (1982) and Littler & Littler (1984).

2.4. Statistical analysis

To compare the changes between 2010 and 2000, species diversity indices such as the number of species, number of individuals, species richness, Pielou evenness index (J') and Shannon-Wiener diversity index ($H'(\log)$) were used to assess algal community changes (Shannon & Weaver 1949). The statistical analyses were done using STATISTICA v. 5.0. Permutational multivariate analysis of variance (PERMANOVA) (Anderson 2001) was used to test significant differences in changes at the sites (I, II, III and IV) with respect to seasons, species abundance and macroalgal group assemblage distributions along the El Arish coast in 2000 and 2010. All the statistical analyses were done using SPSS statistical software (version 9.00) and Microsoft Excel XP professional (2003). The floristic similarity between the study in 2010 and the previous one in 2000 was evaluated using Sorensen's similarity matrix ($S = [2C/(A + B)] \times 100$, where A and B are the respective numbers of species in samples A and B, and C is the number of species common to both two samples (Citadini-Zanette et al. 1979, Cullen et al. 2003).

3. Results

The air temperature was 20°C at sites I and II in winter and 30°C at sites II and IV in summer (Figure 5). The minimum water temperature was 18°C at site I in winter, while the maximum was 40°C at site II in summer (Figure 6). The DO contents varied between 2.4 mg l^{-1} at site II in summer and 13.5 mg l^{-1} at site IV in autumn (Figure 7). The pH varied during the study period between 7.0 at site II during summer and 8.5 at site IV in autumn (Figure 8). Salinity values ranged between 38‰ at site II in winter to 41‰ at sites I and IV in summer (Figure 9).

The shoreline of the El Arish coast west of the El Arish Power Plant and east of El Arish Harbour was subject to accretion. At the same time, erosion occurred to the east of these structures. Satellite Remote Sensing between

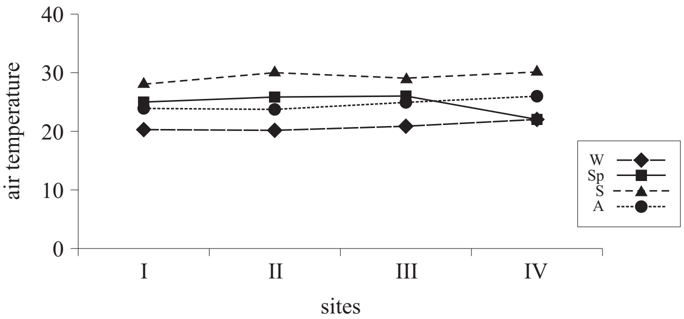

Figure 5. Air temperature [°C] during the study period

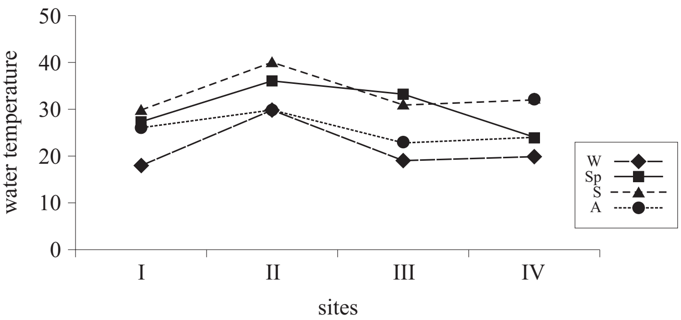

Figure 6. Water temperature [°C] during the study period

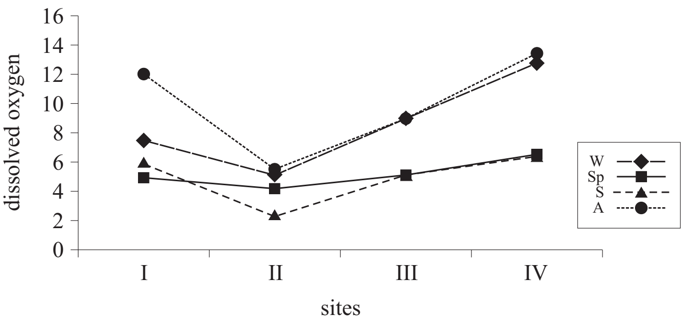

Figure 7. Dissolved oxygen [mg l^{-1}] during the study period

2000 and 2010 showed that accretion had increased on the shore beyond the inlet on the western side and beyond the outlet of the El Arish power plant at sites II and III on the eastern side, while there was an evident increase in erosion on the shore beyond the El Arish power plant inlet at site I (Figure 10). Erosion to the east of the El Arish Harbour area at site IV increased eastwards, but was minimal westwards (Figures 11 and 12).

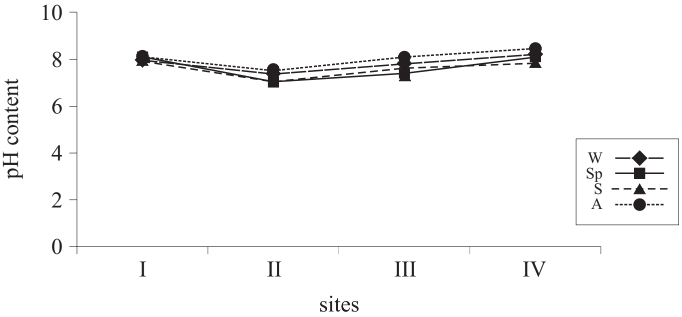

Figure 8. pH during the study period

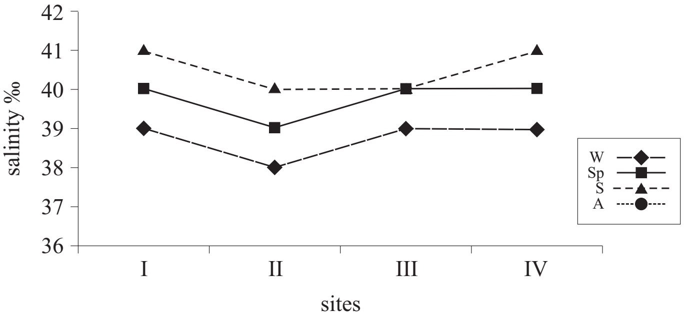

Figure 9. Salinity [$^0/_{00}$] during the study period

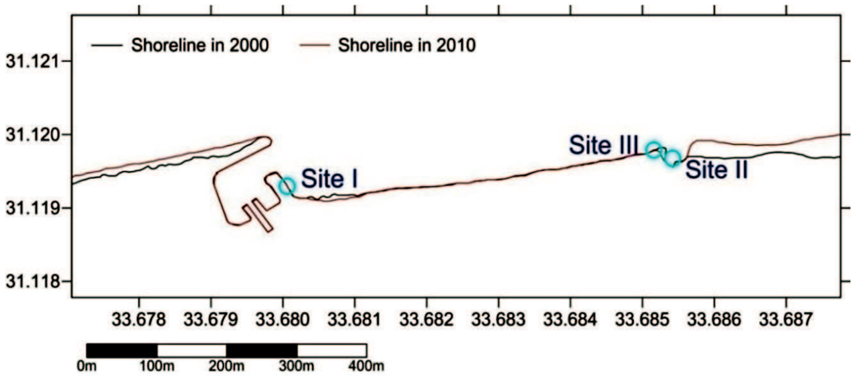

Figure 10. NOAA–AVHRR satellite images showing the spatial differences in longshore sediment erosion trends at sites I, II and III on the El Arish coast in 2000 and 2010

A total of 49 macroalgal taxa were recorded seasonally in the study area. Red and green algae still formed the highest total average percentage cover

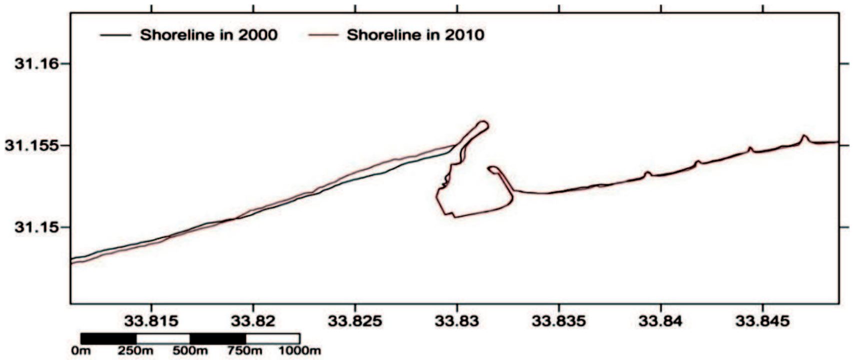

Figure 11. NOAA-AVHRR satellite images showing the spatial differences in longshore sediment erosion trends in El Arish harbour in 2000 and 2010

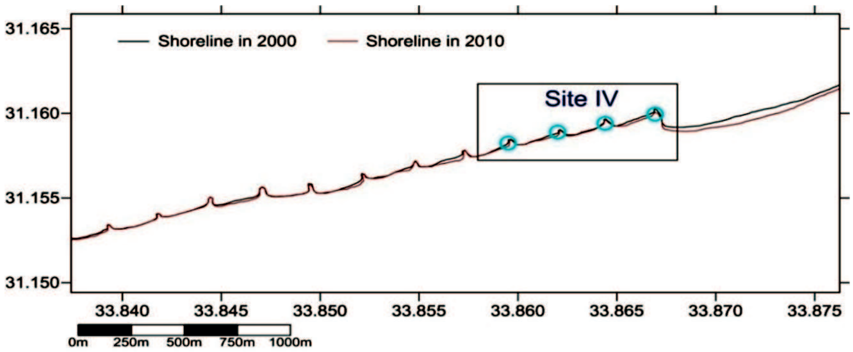

Figure 12. NOAA-AVHRR satellite images showing the spatial differences in longshore sediment erosion trends at site IV on the El Arish coast in 2000 and 2010

with 23 species (47%) and 21 species (43%) respectively, while brown algae were represented by a very low total average percentage cover with 5 species (10%) (Figure 13). The distribution of the macroalgae varied at the study sites, since each species was affected by the presence of the El Arish Power Plant and El Arish Harbour. The marine algal species inhabiting the sites during the study period are listed in Table 1.

Seasonal variations of macroalgal communities were observed between the sites in the periods studied. The largest numbers of red and green algae were recorded at site IV in winter, whereas species numbers were lower at site II in summer. At site II, seaweeds were reduced due to the effect of the thermal discharge effluents from the El Arish Power Plant. The following species turned out to be temperature-tolerant: the green algae

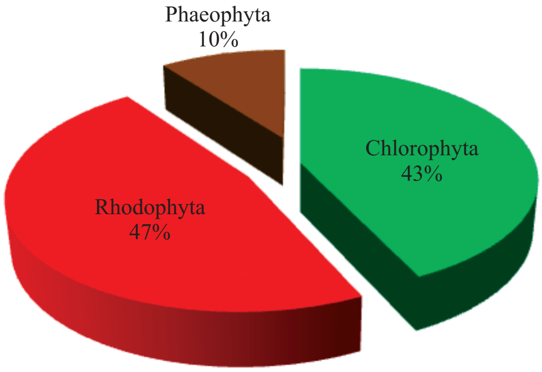

Figure 13. Percentage cover of macroalgal divisions at selected sites on the El Arish coast in 2010

Table 1. A list of marine algal species found at the selected sites

Chlorophyta:

1 – *Chaetomoropha area* (Goodenough & Dillwyn) Kützing
2 – *Chaetomoropha indica* (Kützing) Kützing
3 – *Chaetomoropha linum* (Mueller) Kützing
4 – *Cladophora albida* (Hudson) Kützing
5 – *Cladophora crispata* (Roth) Kützing
6 – *Cladophora crystallina* (Roth) Kützing
7 – *Cladophora fracta* (Nil.) Kütz.
8 – *Cladophora prolifera* (Roth) Kützing
9 – *Cladophora rupestris* (Linnaeus) Kützing
10 – *Enteromorpha clathrata* (Roth) Greville
11 – *Enteromorpha compressa* (Linnaeus) Greville
12 – *Enteromorpha flexuosa* (Wulfen *ex* Roth) Agardh
13 – *Enteromorpha intestinalis* (Linnaeus) Link
14 – *Enteromorpha prolifera* (Mueller) Agardh
15 – *Enteromorpha ralfsii* Harvey
16 – *Enteromorpha ramulosa* (Smith) Hooker
17 – *Enteromorpha tubulosa* (Kützing) Kützing
18 – *Ulva lactuca* Linnaeus
19 – *Ulva rigida* Agardh
20 – *Ulva spathulata* Papenfuss
21 – *Urospora penicilliformis* Areschoug

Rhodophyta:

22 – *Acanthophora nayadiformis* (Delile) Papenfuss
23 – *Acrochaetum unifilum* Levring
24 – *Asterocystis ornata* (C. Agardh) Hamel
25 – *Bangia fuscopurpurea* (Dillwyn) Lyngbye
26 – *Ceramium gracillimum* (Kützing) Zanardini

Table 1. (*continued*)

27 – *Ceramium taylorii* Dawson
28 – *Champia parvula* (C. Agardh) Harvey
29 – *Erythrotrichia carnea* (Dillwin) Agardh
30 – *Fosliella farinose* (Lamouroux) Howe *in* Britton & Millspaugh
31 – *Gelidium crinale* (Turner) Lamouroux *in* Bory
32 – *Gelidiella bornetii* (Weber-van Bosse) J. Feldmann & G. Hamel
33 – *Gelidiella myrioclada* (Borgesen) Feldmann & G. Hamel
34 – *Gracilaria* sp.
35 – *Heterosiphonia tenella* (C. Agardh) Nägeli by Doty and Morrison
36 – *Hypnea cornuta* (Kützing) J. Agardh
37 – *Jania adhaerenes* Lamouroux
38 – *Jania rubens* (Linnaeus) Lamouroux
39 – *Laurencia obtuosa* (Hudson) Lamouroux
40 – *Polysiphonia infestans* Harvey
41 – *Polysiphonia variegata* (C. Agardh) Zanardini
42 – *Pterocladia nana* Okamura
43 – *Pterocladia parva* E.Y. Dawson
44 – *Sarconema filiforme* (Sonder) Kylin

Phaeophyta:

45 – *Ectocarpus siliculosus* (Dillwyn) Lyngbye
46 – *Giffordia indica* (Sonder) Papenfuss & Chihara
47 – *Pilayella littoralis* (Linnaeus) Kjellman
48 – *Scytosiphon lomentaria* (Lyngbye) Link
49 – *Sphacelaria tribuloides* Meneghini

Enteromorpha compressa, *E. prolifera*, *E. ralfsii* and *E. tubulosa* in winter, *E. flexuosa* and *Urospora penicilliformis* in spring and the red alga *Hypnea cornuta* in autumn. After ten years, the vegetation coverage in 2010 was relatively low compared to the macroalgae studied at the same sites in 2000. PERMANOVA revealed significant differences at sites I, II, III and IV, in seasons, species abundance and macroalgal group assemblage distribution on the El Arish coast in 2010 and 2000 ($p < 0.001$). A further reduction of macroalgal overgrowth was recorded in the study area in 2010. The absence of 39 taxa observed in 2000, and the appearance of 9 taxa not previously recorded in the area is reported. The similarity matrix shows a significant difference between the flora in 2010 and 2000, indicating poor similarity and a change in the species composition among the seasons at the different sites (Tables 2 and 3).

Diversity indices for the number of species, number of individuals and species richness, as well as the Pielou evenness index (J') and the Shannon-Wiener diversity index ($H'(\log)$), exhibited intermediate to low values in 2010 compared to the macroalgae recorded in 2000 at the study sites in

Table 2. Sorensen similarity matrix results with comparison through four seasons at 2010 and the four sites

IVW	IVSp	IVSu	IVAu	IIIW	IIISp	IIISu	IIIAu	IIW	IISp	IISu	IIAu	IW	ISp	ISu	IAu	
IVW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IVSp	40.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IVSu	15.9	30.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IVAu	52.5	38.0	26.2	0	0	0	0	0	0	0	0	0	0	0	0	0
IIIW	53.0	37.0	28.2	45.3	0	0	0	0	0	0	0	0	0	0	0	0
IIISp	7.5	11.1	0	6.8	14.7	0	0	0	0	0	0	0	0	0	0	0
IIISu	6.6	5.6	0	6.07	12.7	0	0	0	0	0	0	0	0	0	0	0
IIIAu	19.7	18.6	18.8	17.4	28.9	31.5	0	0	0	0	0	0	0	0	0	0
IIW	8.6	8.4	0	6.4	13.5	0	0	0	0	0	0	0	0	0	0	0
IISp	7.5	11.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IISu	6.6	8.0	0	6.1	12.7	0	29.3	0	45.6	0	0	0	0	0	0	0
IIAu	23.3	18.0	17.9	12.0	19.5	27.6	22.7	63.5	0	0	0	0	0	0	0	0
IW	54.5	14.4	0	27.1	35.7	0	0	8.3	16.2	0	0	13.6	0	0	0	0
ISp	32.0	45.8	17.8	41.4	45.6	12.4	7.6	17.4	11.4	0	7.6	9.7	31.3	0	0	0
ISu	32.7	16.5	14.7	26.8	48.1	18.7	12.9	31.9	0	0	12.9	30.4	24.1	26.1	0	0
IAu	50.2	26.8	20.5	48.3	49.8	14.5	10.8	33.4	0	0	10.8	24.0	23.9	37.3	42.4	0

Table 3. Sorensen similarity matrix results with comparison through four seasons at 2000 and the four sites

IVW	IVSp	IVSu	IVAu	IIIW	IIISp	IIISu	IIIAu	IIW	IISp	IISu	IIAu	IW	ISp	ISu	IAu	
IVW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IVSp	50.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IVSu	35.7	40.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IVAu	38.9	32.1	31.3	0	0	0	0	0	0	0	0	0	0	0	0	0
IIIW	49.8	33.2	29.9	35.3	0	0	0	0	0	0	0	0	0	0	0	0
IIISp	7.3	14.8	21.7	10.7	34.0	0	0	0	0	0	0	0	0	0	0	0
IIISu	5.0	20.6	11.1	9.2	32.5	49.1	0	0	0	0	0	0	0	0	0	0
IIIAu	7.1	22.1	20.9	10.4	22.5	50.4	43.3	0	0	0	0	0	0	0	0	0
IIW	9.0	12.9	0	12.8	11.0	0	16.3	32.8	0	0	0	0	0	0	0	0
IISp	8.4	9.3	11.7	5.9	12.3	42.3	0	41.3	0	0	0	0	0	0	0	0
IISu	4.8	6.2	5.4	9.3	9.6	0	21.2	0	31.0	0	0	0	0	0	0	0
IIAu	6.8	21.2	9.3	5.0	19.2	45.1	42.4	63.9	31.0	27.6	0	0	0	0	0	0
IW	51.6	31.8	10.8	33.1	51.5	7.7	14.6	0	18.7	0	7.0	7.0	0	0	0	0
ISp	29.6	34.2	20.3	25.9	33.8	14.2	13.6	5.7	24.7	0	7.7	7.7	38.2	0	0	0
ISu	33.1	35.8	30.0	29.2	51.9	35.5	32.1	22.6	14.2	16.0	17.2	23.5	36.5	37.14	0	0
IAu	42.3	35.1	29.9	46.7	60.1	28.7	26.4	18.3	11.4	12.3	8.9	18.8	44.3	26.2	46.5	0

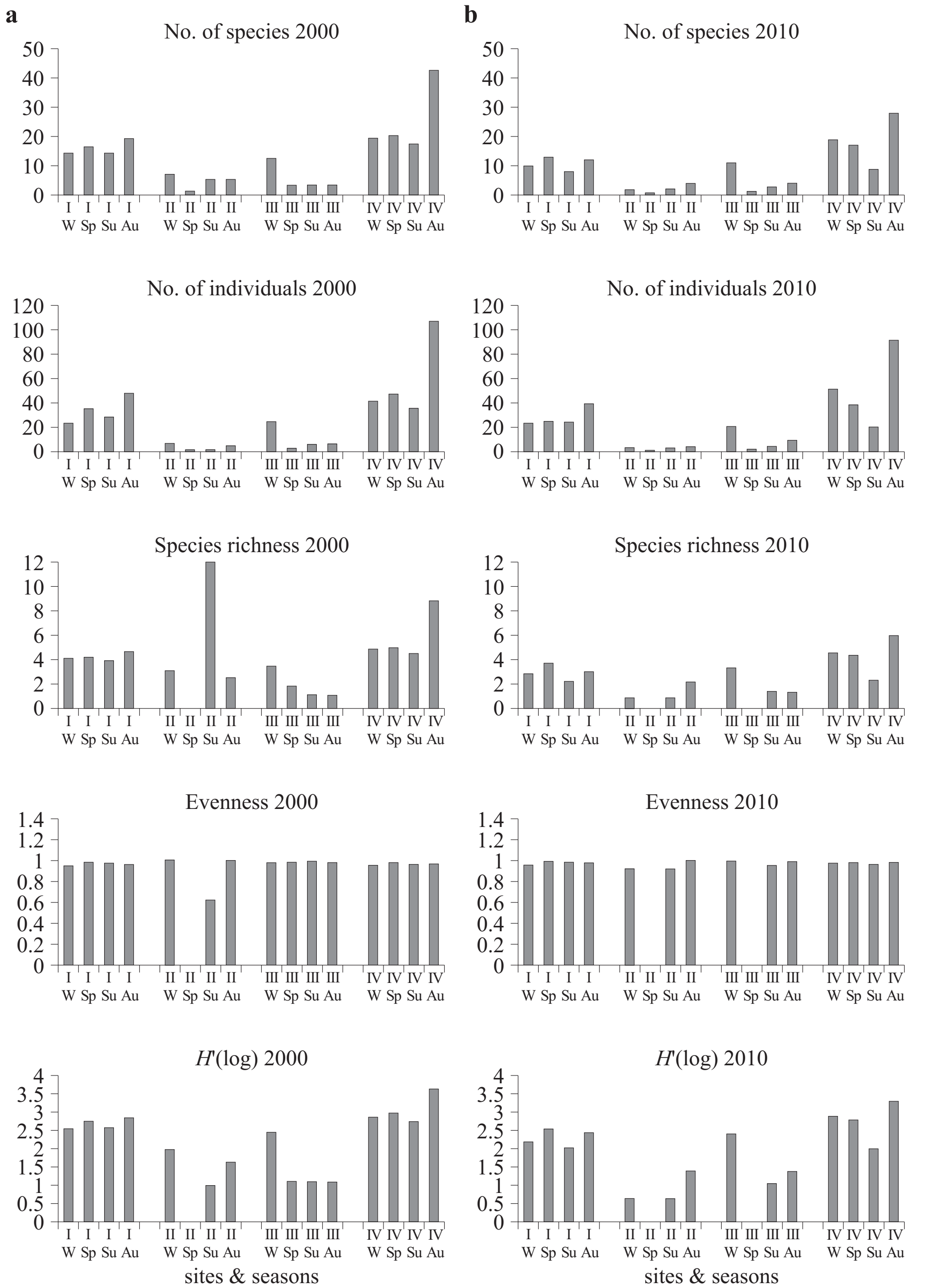

Figure 14. Diversity indices of the macroalgal species in a) 2000 and b) 2010 at the selected sites in the different seasons

Table 4. Functional-form groups for macroalgae on the El Arish coast during the period from winter to autumn 2010

Functional-form group	External morphology	Taxa examined
a) sheet	thin tubular and sheet like (foliose)	*Enteromorpha*, *Ulva*, *Scytosiphon*, *Fosliella*
b) filamentous	delicately branched (filamentous)	*Chaetomoropha*, *Cladophora*, *Acrochaetum*, *Ceramium*, *Gelidium*, *Gelidiella*, *Asterocystis heterosiphonia*, *Polysiphonia*, *Giffordia*, *Sphacelaria*, *Ectocarpus*, *Pilayella*, *Bangia*, *Erythrotrichia*, *Rhizoclonium*
c) coarsely branched	coarsely branched, upright	*Acanthophora*, *Laurencia*, *Pterocladia*, *Hypnea*, *Sarconema*, *Champia*
d) thick leathery	thick bladders and branches	*Gracilaria*,
e) jointed calcareous	articulated, calcareous, upright	*Jania*
f) crustose	epilithic, prostrate, encrusting	–

the different seasons (Figure 14). Functional form groups (sheet, coarsely branched, thick leathery, filamentous and jointed calcareous) were observed and fluctuated seasonally at the study sites in 2010 (Table 4). Most of the macroalgae belong to the filamentous group, for which the highest percentage of 57.14% was recorded. This was followed by the coarsely branched group (21.43%) and the sheet group (14.3%). The thick leathery and jointed calcareous groups had the smallest percentages – 3.57% each.

4. Discussion

Climate change, attributed directly or indirectly to human activity, alters the composition of the global atmosphere in addition to natural climate variability observed over comparable time periods. Schils & Wilson (2006) mentioned that the effect of a temperature threshold results in such major differences for the marine flora over the entire Indian Ocean that a single factor can dominate the effects of other interacting and complex environmental factors. Temperature-wise, macroalgal growth and diversity is in most cases drastically inhibited by upper temperature limits, whereas coral development and diversity is strongly affected by low temperature thresholds (Coles 2003). Anthropogenic impacts have affected a range of species and habitats along the El Arish coast. Human activities, together with the El Arish Power Plant and El Arish Harbour, have seriously disturbed the natural balance of algal communities living in such environments. Seaweeds have been subjected to changes in the environment. Seaweeds serve as early warning indicators for the impacts of climate change. The mechanisms of change in species are usually complex, involving the interaction of many factors and, as abundances change, can be highly sensitive to the strengths of interactions among species (Menge 2000). The processes responsible for the changes are directly or indirectly driven by climate and local anthropogenic stressors such as reduced water quality (Connell 2007, Connell et al. 2008).

The minimum water temperature of 18°C was recorded at site I in winter and the maximum of 40°C at site II in summer. Whereas seawater temperature is rather homogeneous and changes gradually with seasons, the highest temperatures at site II can be attributed to the effluent discharge of power plant cooling water. In the Mediterranean Sea, there was a general surface temperature increase of about 1°C in the period 1974–2004 (Salat & Pascual 2002).

Measured salinity values ranged from 38‰ at site II in winter to 41‰ at sites I and IV in summer. The stretch of El-Arish coastline with high salinity corresponded to the beach suffering from erosion, whereas low salinities were recorded off the accreted beach (Kaiser & Geriesh 2007). The pH varied significantly during the study period from 7.0 at site II during summer to 8.5 and at site IV in autumn. The DO contents varied between 2.4 mg l^{-1} at site II in summer and 13.5 mg l^{-1} at site IV in autumn. The lowest values of DO at site II can be attributed to the influence of cooling water from the power plant.

Satellite Remote Sensing was used to examine the probable changes of the shoreline after 10 years. Accretion obviously increased along the shore beyond the inlet on the western side and the El Arish power plant outlet at sites II and III on the eastern side, whereas erosion increased along the shoreline beyond the inlet of the El Arish power plant. The presence of the El Arish harbour accelerated accretion to the west whereas erosion increased to the east at site IV. This is in agreement with Frihy et al. (2002), Emanuelsson & Mirchi (2007), Kaiser & Geriesh (2007) and El Banna & Hereher (2009). They stated that the area west of the El Arish Power Plant has accreted to full capacity and that littoral drift passes the tip of the breakwater of the cooling water intake basin. In El Arish Harbour the predominant longshore sediment transport is completely obstructed by the western breakwater so that no sediment can bypass the harbour. The large area of sediment accretion west of the breakwater clearly indicates this trend.

Seasonal variations of macroalgae showed that a total of 49 macroalgal taxa were recorded in 2010 in comparison with 2000, when 80 species were recorded. A further reduction in macroalgal coverage was recorded in comparison with coverage values in the study area. 39 of the taxa that had been recorded in 2000 were absent in 2010 (10 green, 25 red and 4 brown), while 9 taxa (5 green, 3 red and 1 brown) not reported in 2000 were new to the area. Red algae followed by green algae formed the highest average percentage cover, while brown algae were represented by a very low average percentage cover. The numbers of red and green algae were the highest at site IV in winter, whereas the numbers of species were lower at site II in summer. This may be due to the thermal effluents discharged from the El Arish Power Plant, which was the main reason for the reduction in number of seaweed species. Temperature-tolerant species included the green algae *Enteromorpha compressa*, *E. prolifera*, *E. ralfsii* and *E. tubulosa* in winter, *E. flexuosa* and *Urospora penicilliformis* in spring and the red alga *Hypnea cornuta* in autumn. Shams El Din (2004) listed Enteromorpha among the eurythermal and euryhaline genera that can flourish over a wide range of temperature and salinity.

Significant changes in sites (I, II, III, & IV), seasons, species abundance and macroalgal assemblage distributions were detected on the El Arish coast between 2000 and 2010 ($p < 0.001$). Olsvig-Whittaker (2010) stated that the direct impact of global climatic temperature rise is thought to be minor because of the wide temperature tolerance of macroalgae, but the high diversity of macroalgae species makes the net response unpredictable. According to Occhipinti-Ambrogi (2007), environmental changes will first manifest themselves in algae. Over a short time scale, algae respond rapidly to environmental changes. Over longer timescales, algal assemblages can be extremely useful for documenting changes to or disturbances in biological conditions. (McCormick et al. 1994). Frond bleaching and cell plasmolysis of algae found in areas affected by power plants are directly caused by thermal effluents (Lobban et al. 1985). These negative effects reduce the survival and growth of seaweeds, resulting in extensive reductions in the number of species of marine algae (Wood & Zieman 1969). This is much the same as what happened at site II in our study.

Recently, global climate and anthropogenic changes in marine algae diversity as a driver of ecological patterns across local through biogeographic scales has long been of legitimate concern to ecology (Choi 2007, Russell et al. 2009). Therefore, the currently observed decrease in marine algal species and reduced biomass is likely to be exacerbated under future climates, human activities and anthropogenic changes in coastal areas. This is in agreement with the diversity indices and similarity matrix in this study where in 2010 macroalgal values were intermediate to low compared with those recorded in 2000. This may be attributed to human activities such as the El Arish Power Plant and El Arish Harbour.

Functional form groups were observed and fluctuated seasonally at the study sites. Most of them belong to the filamentous, coarsely branched and sheet groups. The leathery and jointed calcareous groups had the smallest percentages. 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 (Littler & Littler 1980, 1981, 1984). Those authors propose a functional-form model to recognize the importance of morphology, which has led to ecological classifications of seaweeds based on thallus morphology, longevity and life history.

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