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Monitoring Spatial and Temporal Seaweeds Variation Using Remote Sensing Data in Al-Shoaiba Coast, Red Sea

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Authors' contributions

This work was carried out in collaboration between the two authors. Author GAES managed macroalgal vegetation, physical analyses and performed the statistical analysis and, author MFK managed remote sensing data and image processing analyses of this study. Both authors wrote the protocol, designed the study and wrote the first draft of the manuscript. Both authors read and approved the final manuscript.

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ABSTRACT

Aims: Spatial variability and temporal dynamics of benthic seaweeds using the field investigation and Landsat Thematic Mapper images

Place and Duration of Study: Al-Shoaiba area, Saudi Arabia, Red Sea was investigated and the study area was divided into four sites extending about 10 km. The study period extended seasonally from summer 2011 to spring 2012.

Methodology: The assessment of seaweeds abundance and distribution were performed using quadrate method. Methodology includes analyses of the Enhanced Landsat Thematic Mapper (ETM+) images.

Results: A total of 46 seaweed taxa were collected from Al-Shoaiba region belonging to three different algal phyla to extend on reef flat to hundreds of yards to open sea. The field observations showed the broad macroalgal groups as optically mixture. The main confusion was distinguished between macroalgal groups. The contribution of seaweeds

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varied significantly not only between seasons, but also between sites. The physical parameters showed a close relationship between air and sea water temperatures. Generally, the weather tends to be warm at the selected sites. The pH values were slightly alkaline. Water salinity was relatively high especially in summer and autumn. Diverse of macroalgal communities was shown pronounced seasonal changes. Image classifications of remote sensing data showed large visual appearance of algal vegetation in summer and autumn on the reef flat than in winter and spring. High temperature and evaporation during summer and autumn may causes decline in sea water level. In contrary, low temperature leads to increasing the sea water level to cover most of the reef flat in winter and spring.

Conclusion: This study emphasizes the significant impact of seasonal variations, especially temperature, on the spatial and temporal distribution of seaweeds in Al-Shoaiba coast, Saudi Arabia, Red Sea.

Keywords: Al-Shoaiba coast; physical parameters; remote sensing analyses; seaweeds; seasonal variations.

1. INTRODUCTION

The Red Sea is one of the most important repositories of marine biodiversity in the world. Its natural coastal resources supported populations of sea organisms for thousands of years, and nourished the development of a maritime and trading culture linking Arabia and Africa with Europe and Asia. Its relative isolation has given rise to an extraordinary range of ecosystems, biological diversity and endemism, particularly among reef fishes and reef-associated organisms. The Red Sea received its algae from nearby African and Arabian coasts, (mainly Indian Ocean), which are occupied chiefly by members of the widespread tropical Indo-Pacific marine flora.

Nearly 500 species of algae was recorded in the Red Sea [1]. The marine algae in the Red Sea coast of Saudi Arabia had not been studied comprehensively [2]. The Danish botanist Forsskal [3] was the first explorer of marine algae from the Saudi Arabian Red Sea Coast and created a collection of seaweeds from the Sea of Jeddah. Red algae are considered the main group and included some species that grow deeper in the Red Sea than anywhere else due to water transparency and energy-conserving growth patterns. In contrary, calcareous red algae are mainly restricted to very shallow areas.

Benthic algae are regard as indicators of water state in coastal areas [4]. Mapping of substrate cover types and their biophysical properties were carried out successfully in optically clear, shallow coastal and reef waters [5-9]. For many species, vigorous water movement is essential, although dense algal growth also occurs on unconsolidated substrate, helping to stabilize it.

Since the first collection of Forsskal in 1762, Aleem [10] studied the history of marine algal in the Saudi Arabian Red Sea Coast. The number of species is relatively small. He listed entails 16 species of blue green algae all of which are new records to the Arabian Coast. The *Chlorophyta* comprises 27 spp. of which 15 spp. is new records to the coast. *Phaeophyta* also includes 27 spp. of which 19 spp. are new records, while *Rhodophyta* comprises 35 spp. of which 25 spp. are new to the Saudi Coast. In Papenfuss's catalogue [11], 101 algae (including 57 taxa of *Sargassum*) were recorded in the southern part of the

Red Sea. The absence of these species in the northern Red Sea indicated that the richness of the marine flora of the Red Sea decreases northward. Many Red Sea seaweed species have a cosmopolitan distribution; some taxa are diagnostic to the Red Sea, whereas others are found in the Indo-West Pacific. The southern and central parts of the Red Sea, especially those of Saudi Arabia, are poorly known [12,13].

Al-Shoaiba coast, as a part of Red Sea, contains some of the world's most unique and diverse marine and coastal habitats. The sediments and rocks are mainly fossil coral reef limestone extending over the entire range of the intertidal zone of the Red Sea. The study area of Al-Shoaiba coast is characterized by fringing reef which grows directly from the shoreline to form the reef flat. This area is distinguished by strong dry climate [14]. Rain fall is very rare and seasonal, usually occurs during the winter months. The atmospheric temperature is very high, allowing the plant *Avicennia* to develop. This region is characterized by extremely high summer temperatures. The tide is generally affected by winds which drift the seawater towards the land [14].

Seaweeds compromised a chance for establishment in Al-Shoaiba coast. Khoja [2] recorded 29 species of marine algae from Jeddah and Al-Shoaiba (19 *Cyanophyta*, 3 *Chlorophyta*, 5 *Rhodophyta* and 2 Phaeophyta). These species are new records for the Saudi Coast, while 15 species are new records for the Red Sea. Accurate mapping and monitoring of seaweeds is required in Al-Shoaiba coast. Remote sensing techniques have been successfully applied for operational mapping of the biophysical properties of clear waters [8].Remote Sensing and GIS techniques were used in accurate mapping and quantification of seaweeds [15]. This research aims to study spatial variability and temporal dynamics of benthic seaweeds using field investigation and Landsat Thematic Mapper images for the first time in Al-Shoaiba area, Saudi Arabia, Red Sea.

2. MATERIALS AND METHODS

2.1 Area of Study

Al-Shoaiba (Makkah Sea) lies on the western area of Saudi Arabia approximately 90km south of Jeddah city and about 100km of Makkah city. It is located between latitudes 20º48` & 20º51` N and longitudes 39º24` & 39º28` E (Fig. 1). The study period extended seasonally from summer 2011 to spring 2012. Al-Shoaiba coast consisted mainly of sandy and muddy substrata but the sediments and rocks are largely from fossil coral reef limestone extending over the entire range of the intertidal zone along the shoreline. The reef flat grows hundreds of yards from shore and slightly sloped towards the open sea. Al-Shoaiba region includes hypersaline lagoons not affected by tides.

The study area was divided into four sites extending about 10 km of the coast. The sites were from north to south:

Site I (Al Kattan): It lies directly beside Al Kattan village.
Site II: It is situated between Al Kattan village and Al Hofra site.
Site III (Al Hofra): It lies at the connection of the Red Sea and closed Al-Shoaiba lagoon.
Site IV: It is located in front of soaked Fahd ship after the end of closed Al-Shoaiba lagoon.

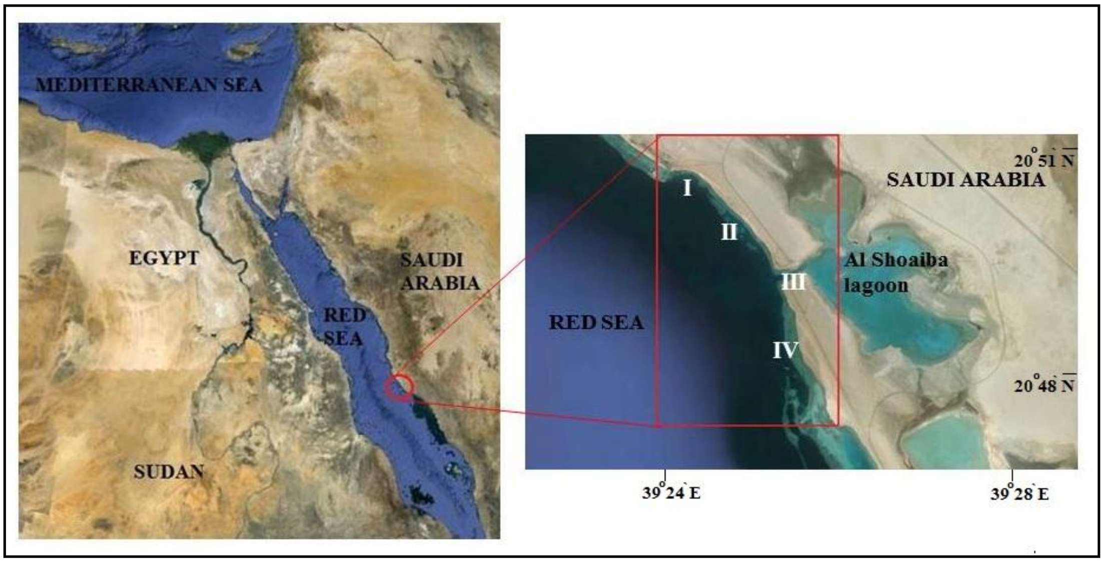


Fig. 1. Area of study and studied sites

2.2 Hydrographic Parameters

Seawater samples were measured seasonally at the same time of collection using a mercury thermometer for air and surface water temperature, a conductivity Meter (JENWAY, Model 4520) for salinity and a digital pH meter (pH Benchtop, ORION 3 Star) for pH.

2.3 Seaweeds Vegetation

Seaweed species were collected and preserved in 4% formalin in seawater until transported to the laboratory. The assessment of seaweeds abundance and distribution were performed using quadrate method of Russell and Fielding [16]. Seaweed vegetation was described quantitatively through measuring percentage cover of each species inside the quadrate. The abundance of the species 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 [11,17-20].

2.4 Satellite Data

Four sets of remote sensing data are utilized in this study aiming to detect, outline and monitor the distribution of seaweeds along Al-Shoaiba in Saudi Arabia, Red Sea coastal zone. These data includes Enhanced Landsat Thematic Mapper plus (ETM+) images for summer 2011, autumn 2011, winter 2012 and spring 2012 (Table 1). Image classification was applied to automatically categorize all pixels in an image into land cover classes or themes. Unsupervised classification was conducted using a histogram peak cluster technique to identify dense areas or frequently occurring pixels [21]. In the unsupervised approach, spectrally separable classes are determined and defined relative to class informational utility to form a supervised classification scheme. Each class was verified in the field using a Garmin 38 GPS unit; more than 25 ground control points (data sites) were visited and verified. ENVI 4.8 was processed to analyze remote sensing data.

Unsupervised/Supervised classification (Isodata) was applied to monitor the study area during 2011-2012. Multispectral classification consists of a compression of all information in a multispectral data set into a single image that depicts the major types of surfaces in different colors [21]. Clusters representing land cover types that were similar were combined [22]. Based on these spectral signatures, natural and cultural surface features can be discriminated and a new output image could be created having specific number of classes or categories [23].

Table 1. Landsat ETM+ satellite images data

Data	Resolution (m)	Date (season)
ETM+	30	July (Summer) 2011
ETM+	30	September (Autumn) 2011
ETM+	30	January (Winter) 2012
ETM+	30	April (Spring) 2012

2.5 Statistical Analysis

The resulting data were expressed and statistically analyzed using the software MINITAB version 16.1. Statistical significance of differences among seasons, air temperature, water temperature, sites, species and counts was evaluated by one-way analysis of variance (ANOVA) at $\rho \leq 0.05$.

3. RESULTS AND DISCUSSION

Considerable spatial and temporal variation was evident in the timing and area of macroalgal vegetation in Al-Shoaiba coast. Quantitively, the contribution of seaweeds varied significantly not only between seasons, but also between sites. The study area is found in a dry region where evaporation rate is high compare to the rainfall. The selected sites I, II, IV are viewed directly to the open sea while site III is located at the narrow tidal channel which connects with the open sea. Reef flat extended to hundreds of yards to open sea. The physical parameters in the selected sites were estimated seasonally (Fig. 2). A close relationship is observed between air and sea water temperatures. The air temperature ranged between 27ºC in autumn and 40 ̊C in summer at sites I & III in spring (ρ = 0.000). Water temperature varied from 26ºC (sites I & IV in autumn) and (sites III & IV in winter) to 38ºC at the sites III in spring. Sea surface temperature is the most significant seasonal parameter controlling seaweed distribution (ρ = 0.000). Water temperature in the Red Sea increases from north to south showing wide variability between the different seasons [24]. In Eritreain the west of Red Sea, Ateweberhan et al. [25] showed that this region is characterized by extremely high summer temperatures and strong seasonal shifts in the relative contribution of each group to the total macroalgal biomass.

The value of pH was slightly alkaline at the selected sites. It fluctuated between 7.6 in summer at site I and 8.88 in spring at site IV. This agrees with Khoja [2], who mentioned that pH ranged between 8.2--8.8. Water salinity at Al-Shoaiba coast was relatively high. The sites III and IV recorded the highest values of salinity (43‰) in summer, while it decreased at site II (39‰) in winter. Water salinity at Al-Shoaiba coast was relatively high especially in summer and autumn. The sites III and IV recorded the highest values of salinity. This may attribute to owing near these sites from Al-Shoaiba lagoon and Al-Shoaiba desalination plant.

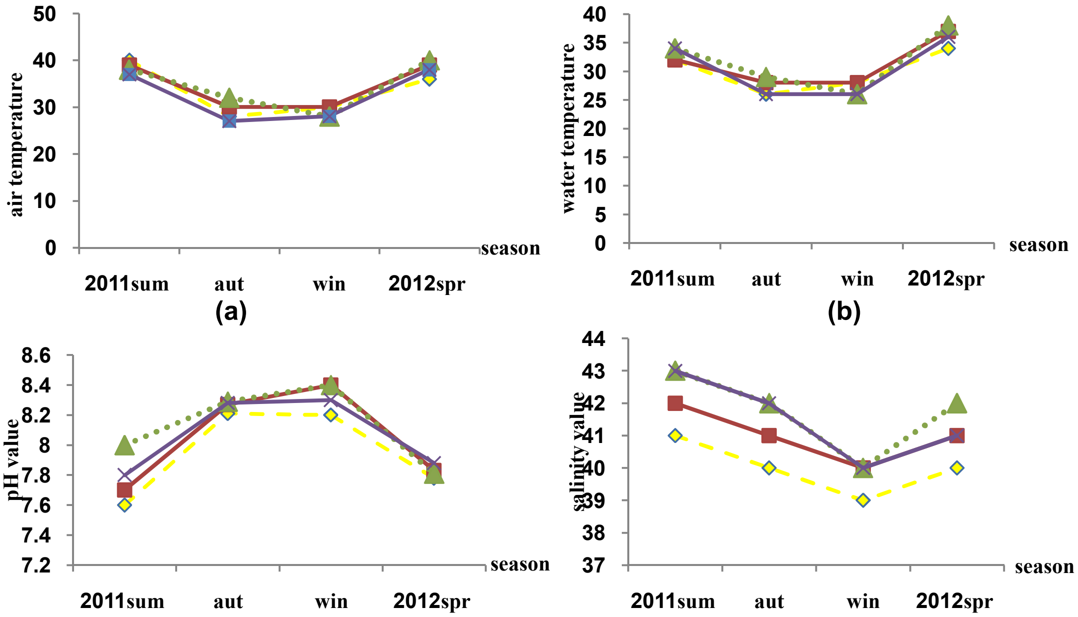


Fig. 2. Physical parameters during the study period at the selected sites
a) air temperature; b) water temperature; c) pH values and d) salinity values.

Because of the high evaporation rate and the complete lack of fresh water input, the Red Sea is one of the most saline water bodies in direct connection with the world oceans [24]. Seasonal blooms of filamentous macroalgae occurred at site IV. The green macroalga *Enteromorpha* blooms on the reef flat during summer as a result of Al-Shoaiba desalination plant which found near of site IV. Hariri [14] mentioned that the out flow from desalination plant is typically 5-10ºC higher in temperature and up 3-10ppt higher in salinity than normal seawater. The higher salinity of the discharges increases coral mucus production, expulsion of Zooxanthellae, eventual bleaching and algal overgrowth. This is coincided with our study, where the salinity was recorded increasing at sites IV and III in summer. In recent years the environmental conditions in the coastal area of the Red Sea have changed due to the increasing development activities and utilization of the coast [26]. As a result of the coastal areas are seriously threatened due to over-utilization and the increase in sewage and industrial effluent discharges (e.g. desalination plants). Many of the southern Red Sea species are typical of warm waters from the tropics, while the northern species include members typical of slightly cooler areas [11].

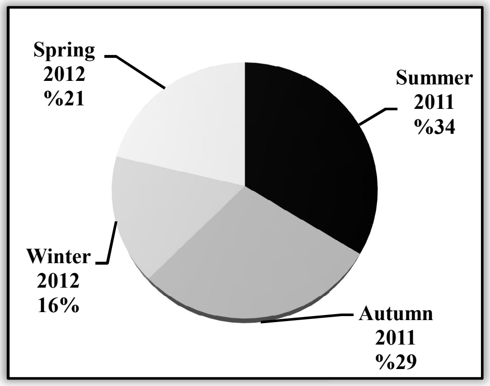
A total of 46 seaweed taxa were collected from the selected sites at the same day in Al-Shoaiba region belonging to three different algal phyla (Table 2). The *Rhodophyta* is the most diverse division and prevailed with 20 taxa followed by *Chlorophyta* (16 taxa), then Phaeophyta (10 taxa).

The number of species in Al-Shoaiba area was increased than recorded by Khoja [2] and Aleem [10]. Khoja [2] recorded 29 species of marine algae from Jeddah and Al-Shoaiba (19 *Cyanophyta*, 3 *Chlorophyta*, 5 *Rhodophyta* and 2 Phaeophyta). He recommended by accurate mapping and monitoring of seaweeds in Al-Shoaiba coast. Aleem [10] studied the marine algae from Obhor, in the vicinity of Jeddah, Saudi Arabia. He recorded 27 spp of *Chlorophyta*, 27 spp. of Phaeophyta 19 spp. and 35 spp. of *Rhodophyta*. He registered little species in Al-Shoaiba coast as *Enteromorpha compressa, Enteromorpha flexuosa, Ulva reticulate, Dictyosphaeria cavernosa, Caulerpa racemosa*, *Avrainvillea amadelpha, Sphacelaria tribuloides, Dictyota dichotoma, Centroceros clavulatum* and *Herposiphonia tenella.*

Table 2. List of the recorded species at the selected sites in Al-Shoaiba region during the study period

Chlorophyta	25. *Gigartina* sp.
1. *Caulerpa racemosa* (Forsskål) J.Agardh	26. *Gracilaria arcuata* Zanardini
2. *Caulerpa serrulata* (Forsskål) J.Agardh	27. *Herposiphonia tenella* (C.Agardh) Nägeli by Doty and Morrison
3. *Chaetomorpha linum* (Mueller) Kützing	28. *Hypnea valentiae* (Turner) Montagne
4. *Cladophora crystallina* (Roth) Kützing	29. *Jania adhaerens* Lamouroux
5. *Cladophora prolifera* (Roth) Kützing	30. *Jania rubens* (Linnaeus) Lamouroux
6. *Cladophora serica* (Huds.) Kiitz. Hoek	31. *Laurencia papillosa* (C.Agardh) Greville
7. *Cladophora* sp.	32. *Leveillea jungermannioides* (Hering et Martens) Harvey
8. *Cladophoropsis herpestica* (Montagne) Howe	33. *Polysiphonia* sp.
9. *Codium fragile* (Suringar) Hariot	34. *Pteriocladia capillacea* (Gmelin) Santelices & Hommersand
10. *Enteromorpha clathrata* (Roth) Greville	35. *Spyridia filamentosa* (Wulfen) Harvey
11. *Enteromorpha compressa* (Linnaeus) Greville	36. *Tolypiocladia glomerulata* (C. Agardh) Schmitz.
12. *Enteromorpha prolifera* (Mueller) Agardh	**Phaeophyta**
13. *Halimeda opuntia* (Linnaeus) J.V.Lamouroux	37. *Dictyota corvicornis* Kuetzing
14. *Halimeda tuna* (Ellis et Solander) Lamouroux	38. *Dictyota dichotoma* (Hudson) J.V. Lamouroux
15. *Valonia aegagropila* C. Agardh	39. *Hormophysa triquetra* (C. Agardh) Kützing
16. *Valonia ventricosa* J. Agardh	40. *Hydroclathrus clathratum* (C. Agardh) Howe
Rhodophyta	41. *Padina pavonica* (L.) Thivy
17. *Acanthophora specifera* (Vahl) Børgesen	42. *Sargassum carssifolium* J.Agardh
18. *Bangia fuscopurpurea* (Dillwyn) Lyngbye	43. *Sargassum fluitans* (Børgesen) Børgesen
19. *Bostryshia radicans* (Montagne) Montagne	44. *Sphacelaria* sp.
20. *Ceramium gracellimum* (Kützing) Zanardini	45. *Sphacelaria tribuloides* Meneghini
21. *Chondria repens* Børgesen	46. *Turbinaria ornata* (Turner) J. Agardh
22. *Digenea simplex* (Wulfen) C.Agardh	
23. *Fosliella farinose* (Lamouroux) Howe *in* Britton & Millspaugh	
24. *Gelidiella acerosa* (Forsskal) Feldmann & Hamel	

Seasonally, summer represented the highest percentage cover of seaweeds (34%), followed by autumn (29%), then spring (21%) and finally winter (16%) as shown in (Fig. 3). The percentage cover showed significance between counts versus season ($\rho = 0.028$). There was a marked variation in the temporal distribution of species. Highly significance was observed by One Way ANOVA test ($\rho = 0.000$). *Rhodophyta* were characterized in all the studied seasons especially in summer> autumn and spring (Fig. 4). *Chlorophyta* were increased in summer, autumn and spring whereas reached to the lowest in winter. In autumn, the number of Phaeophyta was the highest to reach their minimum number in spring season.



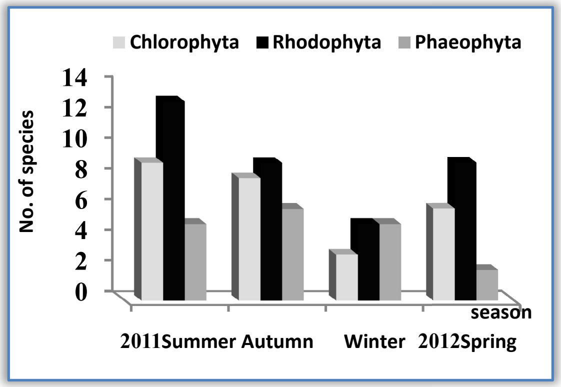


Fig. 3. Percentage cover of seaweeds

Fig. 4. No. of seaweeds phyla in each vegetation in seasons at the studied region

The number of species through seaweed divisions at the selected sites in the different seasons was showed in (Fig. 5). One Way ANOVA test recorded high significance ($\rho = 0.001$). The red algae recorded the maximum number at site IV in summer whereas the minimum one at sites I, III and IV in winter. The highest number of green algae was registered at sites I & II in summer and site I in autumn. Site III in summer not detected green algae. The number of brown algae increased at site II in summer then decreased in summer and spring at sites III and IV.

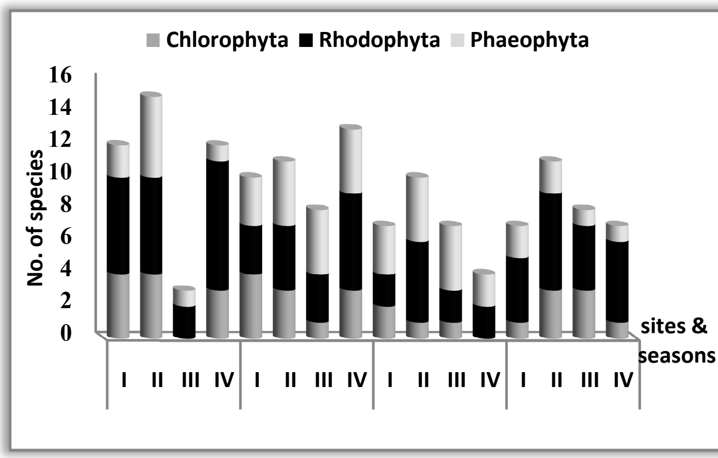


Fig. 5. The number of seaweed divisions at the selected sites in the different seasons

Regardless, *Caulerpa racemosa*, *Enteromorpha prolifera*, *Halimeda tuna*, *Acanthophora specifera*, *Digenea simplex*, *Jania adhaerens*, *Jania rubens*, *Dictyota dichotoma*, *Hormophysa triquetra* and *Padina pavonica* were the most dominant species in the studied seasons. The red alga *Jania* (jointed calcareous) and the brown alga *Padina* (Thick leathery) formed high pastures in the study area. It is mainly distributed at all sites, in particular, site III in the studied seasons which covered the connection open area that joins with the closed lagoon by a narrow channel. This may attributed to the algal communities which are adapted to changing sea levels [13,27]. The calcification *Jania* group may play an important role in survival under conditions of warm temperature. This opinion agrees with Morgan & Grant [28] and Kim et al. [29]. According to Phillips et al. [30], jointed calcareous-group and thick leathery-group were more abundant at higher levels of disturbance, because their structural complexity has a relatively high degree of resistance to physical damage. The brown alga *Padina* also is considered as tolerant-species. This may attributed to the environmental changes as high temperature and salinity which characterized the open area at the site III. This is agreeing with Gardner et al. [31] and Collado-Vides et al. [32].

Algal communities in most of the study area showed a strong seasonality. Many species appear to be annual. This seasonality is correlated with water temperature [27]. Summer and autumn were characterized by the abundance of the red algae (*Acanthophora specifera*, *Digenea simplex*, *Jania rubens*, *Jania adhaerens*, *Bostryshia radicans*, *Fosliella farinose*& *Spyridia filamentosa*), the brown algae (*Dictyota dichotoma, Padina pavonica*& *Hormophysa triquetra*) and the green algae (*Caulerpa racemosa* & *Cladophora prolifera*), in addition to some species were distinguished in each season. The algal species were found in summer only as *Cladophora crystallina, Cladophora* sp., *Cladophoropsis herpestica, Enteromorpha clathrata*, *Herposiphonia tenella, Spyridia filamentosa, Hydroclathrus clathratum* and *Sargassum carssifolium* while *Chaetomorpha linum, Cladophora serica, Halimeda opuntia, Valonia aegagropila, Valonia ventricosa, Bangia fuscopurpurea, Leveillea jungermannioides, Dictyota corvicornis* and *Sargassum fluitans* were distinguished in autumn only. In comparison with winter and spring, the algal species were decreased in these seasons. *Gracilaria arcuata, Gracilaria* sp., *Laurencia papillosa* and *Sphacelaria tribuloides* were recorded in winter only whereas *Codium fragile, Gigartina* sp., *Pteriocladia capillacea* and *Tolypiocladia glomerulata* appeared in spring season.

Enhanced Landsat Thematic Mapper images acquired during summer 2011 to spring 2012 are used to monitor spatial and temporal distribution of seaweeds in Al-Shoaiba coast of Saudi Arabia (Figs. 6 and 7). Seven classes were extracted from the images data. It includes deep water, seaweeds, fossil coral reefs, limestone, shale, sand and shale & limestone. Fieldwork was undertaken in order to validate the remote sensing results, improve the accuracy of image registration, and detect the land covers at the study site. The total number of GCPs was 25, with 0.005 and 0.002 pixel root main square (RMS) errors in X and Y, respectively. These GCPs were collected to check the accuracy of the images to map registration and were used to calculate the geometric transformation model. Re-sampling was used to determine the pixel values or was used in the completion of the output matrix from the original image matrix. Ground truthing was conducted in the field to validate the remote sensing results, improve the accuracy of image registration and identify the type and condition of ground cover at the study site. The latitude and longitude of the 25 ground control points, obtained during the field visit, were recorded using a Garmin 12 channel hand-held GPS receiver with 15-m accuracy relative to map-derived control points.

The images showed the relative amount of algal vegetation (green color) in the studied seasons which was increasing in summer> autumn> spring> winter. It was compatible with in (Fig. 3). Large visual appearance of seaweeds on the reef flat recorded in remote sensing data. This may attributed to the high temperature, evaporation and salinity during summer and autumn, which causes regression in sea water level. In these conditions, sea water level was retreated to appear most of seaweed beds (Fig. 6) in summer 2011 and autumn 2011. Enhanced Landsat Thematic Mapper images analyze the land cover features without any penetration beneath sea water. Therefore, there is no bottom reflectance effect in the shallow water along the coastal region.

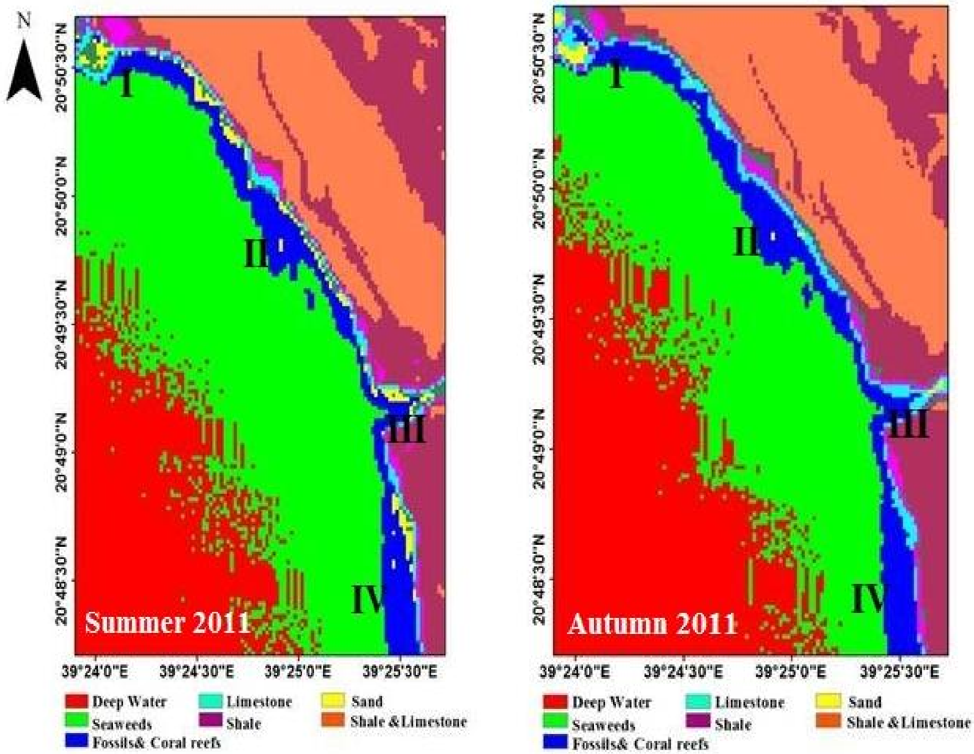


Fig. 6. Monitoring seaweeds along Al-Shoaiba coast in Saudi Arabia using Landsat images data during summer 2011 and autumn 2011

In contrary, with low temperature in winter and spring, the sea water level increased to cover most of the reef flat and then seaweed beds appeared with little areas especially in winter than spring (Fig. 7). The algal species were decreased in these seasons. Albarakati [26] mentioned that the tidal motion within the Red Sea is generated by the sea's own response to tide generating forces and by the co-oscillating tide of the Gulf of Aden.

Diverse of macroalgal communities was show pronounced seasonal changes. In our study, the images showed the broad macroalgal groups as optically mixture. The main confusion was distinguished between macroalgal groups. Reflectance spectra of benthic macroalgae were used to map broad categories of bottom types at medium spatial resolution in shallow clear coastal water [33]. Remote sensing image processing analyses can potentially provide a tool for fast mapping of benthic algal cover based on their optical signatures [34]. Spectral bands required to discriminate between different benthic substrates is often narrow [6,35,36] Therefore, hyperspectral data are desired to study benthic habitat. However, remote sensing data used in this research did not acquired to identify benthic algal communities. It was utilized to classify the landcover at the study sites. Seaweeds were monitored temporally and spatially along the coastal zones. Therefore, depth of water has not significant impact on the amount of visible light. In addition, tide was so little to affect significantly on the distribution of seaweeds.

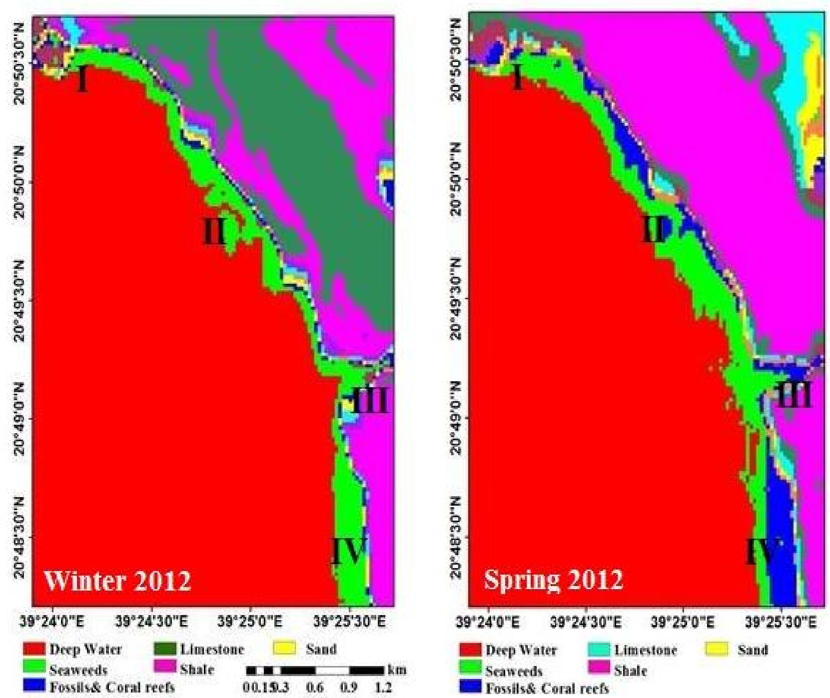


Fig. 7. Monitoring seaweeds along Al-Shoaiba coast in Saudi Arabia using Landsat images data during winter 2012 and spring 2012

Among the identified species, *Caulerpa racemosa was recorded in the selected sites*. It has probably been introduced to the Mediterranean Sea. *Caulerpa racemosa* is the alien macroalgae found in Red Sea that exhibits invading behavior. Many Red Sea seaweed species have a cosmopolitan distribution. Some taxa are reported to be endemic to the Red Sea, whereas others are found in particular localities in the Red Sea and also in the Indo-West Pacific. However, the coasts in the southern and central parts of the Red Sea, especially those of Saudi Arabia, are poorly known [12,13]. Geological events have clearly been of major importance for the formation of disjunct distribution patterns of seaweeds. An originally continuous distribution range may be split in two disjunct regions due to tectonic or paleoclimatic events (vicariance). On the other hand, disjunct distributions may also be the result of dispersal, which involves the crossing of barriers and colonization of new areas [37].

In general, Climatic changes that lead to sea-level rise will affect coastal zones of the region considerably. Fouda and Gerges [24] showed that the direct effect of inundation would produce a large loss of inhabited areas, wetlands and low islands of the Red Sea. The temperature increase in the Red Sea and the Gulf of Aden is expected to be less than the average global temperature increase. Macroalgae also attain high growth rates but in time a population of one algal species may be replaced by more shade tolerant species, whilst new submerged areas may tum into algal or seagrass beds [38].

4. CONCLUSION

Seaweed communities varied seasonally and spatially along Al-Shoaiba coast.Sea surface temperature is the most significant seasonal parameter controlling seaweed niche distribution models. A total of 46 seaweed taxa were collected from the selected area belonging to three different algal phyla. *Rhodophyta* prevailed followed by *Chlorophyta* then Phaeophyta. Some species were recorded dominantly in all seasons whereas other species appeared specifically in one season. Remote sensing image processing analyses for the Enhanced Landsat Thematic Mapper plus (ETM+) images in summer 2011, autumn 2011, winter 2012 and spring 2012 were used to monitor the seasonal variations of seaweeds on the reef flat in Al-Shoaiba coast. In summer and autumn, the reef flat appeared with larger landcover than in spring and winter. High evaporation of sea surface water in summer and autumn contributed to the large visual appearance of seaweeds. However, in winter and spring, the sea level increased on the reef flat and covered seaweed vegetation. In this research, the impact of seasonal variations on the spatial and temporal distribution of seaweeds could be emphasized.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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