

Ecological Quality Status of the Algiers coastal waters by using macroalgae assemblages as bioindicators (Algeria, Mediterranean Sea)

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Abstract

Macroalgal assemblages have been used as a quality element for the assessment of the ecological status classes (ESCs) in coastal water bodies for the implementation of the European Water Framework Directive (WFD, 2000/60/EC). To assess the suitability of this quality element in the coastal waters off Algiers, seven sampling sites with five (5) replications covering a wide range of anthropogenic pressures were studied during spring and summer 2015. Coverage data for the macroalgae at each sampling site were analyzed at the biological levels of species, i.e., structural (species number, nMDS, clustering, K-dominance and Simper analysis based on Bray-Curtis similarity), and ecological status groups, i.e., functional (nMDS, clustering, K-dominance, ecological evaluation index/EEI-c). Key water variables (temperature, salinity and pH) along with the anthropogenic stress index MALUSI were also estimated. The obtained results revealed a significant effect of anthropogenic stress on the macroalgal assemblages. The structural analysis showed the following: (1) species richness of 86 taxa in total; (2) dominance of *Cystoseira amentacea* var. *stricta* (late-successional) associated with *Lithophyllum incrassans* and *Jania rubens* at nonimpacted sites and with *Ulva rigida*, *Ulva intestinalis* and *Caulerpa cylindracea* (opportunistic) species at impacted sites; and (3) a higher proportion of low-abundance species in polluted communities than in less polluted communities. The functional analysis showed the following: (1) classification of sites based on multivariate and K-dominance analyses into four groups, three in agreement with the water degradation information and one in agreement with a low salinity influence; (2) classification of sites into “bad”, “high”, “moderate” and “good” ESCs based on the EEI-c index; and (3) a strong nonlinear relationship ($R^2=0.85$) of the EEI-c index with the MALUSI index. Therefore, the EEI-c index will be a suitable tool to implement a national monitoring program within the scope the WFD along Algerian coasts.

Keywords: Ecological evaluation index (EEI-c); functional groups; macroalgae; species richness.

Introduction

The Algerian coasts are the ultimate receptacle of pollutants of various origins (Boutiba *et al.*, 2003; Grimes, 2003; Taleb *et al.*, 2007, 2009; Houma *et al.*, 2013; Belkacem *et al.*, 2016). These pollutants not only affect the ecological and biological quality of the environment but also indirectly lead to a devaluation of coastal economic interests. Although not a member of the European Union, Algeria is a Mediterranean country signatory to the Barcelona Convention. It is included in the subregion of the Framework Directive for the Monitoring of the Marine Environment (DCSMM, 2008). Indeed, it is called upon to align in terms of objectives for maintaining a good ecological status (ES) of the marine environment, which implies developing a network comparable, where possible, to the Mediterranean networks in terms of objectives, approaches and protocols.

Macroalgal assemblages have been proposed as a quality element for the assessment of the ecological status of coastal water bodies within the implementation of the European Water Framework Directive (WFD, 2000/60/EC) (Clarke, 1993; Panayotidis *et al.*, 2004; Rombouts *et al.*, 2013; Ar Gall *et al.*, 2016). The WFD identifies the use of macroalgae as biological indicators with the goal of maintaining and improving aquatic environments (Soltan *et al.*, 2001; Pinedo *et al.*, 2007; Patrício *et al.*, 2007; Juanes *et al.*, 2008). For the implementation of the WFD, some ecological quality indices were suggested, such as the Greek EEI-c index (Orfanidis *et al.*, 2001, 2011) and the Spanish index CARLIT (cartography of littoral and upper-sublittoral rocky communities) proposed by Ballesteros *et al.* (2007). In contrast to the CARLIT index, EEI-c follows a nonaligned block design protocol, where random quantitative samples are analyzed, enabling a scale-based community assessment. EEI-c also allows a complete taxonomic inventory of species.

The continuous Ecological Evaluation Index formula (EEI-c) is a biotic index based on the concept of morphological, ecophysiological traits and functional groups and is inspired by the 'alternative stable stages' theory (Holling, 1973; May, 1977). Human-induced shifts may be assessed by classifying benthic macrophytes into two functional groups that respond differently to an environmental disturbance: a late-successional group with low growth rates and long life histories [ecological status group (ESG) I, mostly K-selected], such as *Cystoseira*, *Gymnogongrus*, and *Fucus*, and an opportunistic group with high growth rates and short life histories such as *Ulva*, *Enteromorpha*, and *Ceramium* (ESG II, mostly r-selected) (Mac Arthur & Wilson, 1967). These two ESGs have also been hierarchically classified into further subgroups (Orfanidis *et al.*, 2011). While the oligotrophic-pristine and eutrophic-degraded conditions have been assumed to represent two alternative stable states or attractors, the coexistence of opportunistic and late-successional macroalgae is regarded as a symptom of intermediate theoretically unstable conditions (Orfanidis *et al.*, 2008).

Several studies have confirmed the effectiveness of the EEI classification methodology developed by Orfanidis *et al.* (2001; 2003 and 2011). Orlando-Bonaca *et al.* (2008) applied the EEI index as a tool for delineating, monitoring and assessing ES in Slovenian coastal waters. Gabriel *et al.* (2014) used the EEI index to assess the environmental quality of the coastal waters off the Azorean Islands. Orfanidis *et al.* (2014) tested the relationships among different structural and functional metrics with key abiotic parameters and an anthropogenic stress index in Mediterranean and Black Sea transitional waters. Recently, Caldeira *et al.* (2017) and Amaral *et al.* (2018) evaluated the ES off Brazilian coasts and lagoons, respectively, by using the functional features of macroalgal assemblages and the EEI-c methodology. Buosi *et al.* (2017) showed how macrophyte assemblage composition reflects the presence of anthropic stressors at four sites in the northern Adriatic Sea determined by EEI-c. Unfortunately, there are no studies on the application of the EEI-c index to macroalgae inhabiting waters off African coastal countries and Algerian coasts. Most related studies have focused on macrofauna to assess the water quality (Bakalem *et al.*, 2009; Grimes *et al.*, 2010) or measuring the concentration of heavy metals in an accumulator species and seawater (Soualili *et al.*, 2008; Laib & Leghouchi, 2012; Belkacem *et al.*, 2016).

The main objective of this study was to perform an inventory of the macroalgae assemblage composition at seven coastal sites off the central region of Algiers (Mediterranean Sea) to elucidate the structure and function of the communities and to assess the ecological status classes (ESCs) of the Algerian coasts using the EEI-c index. This work can be seen as a step toward the implementation of the WFD in Algerian coasts to prevent any further deterioration of these marine waters.

Materials and Methods

Site description

The Algiers region is located in northeast Africa, with more than 4.3 million inhabitants (950 inhabitants km⁻²) in a coastal zone that is 115 km long. The regional climate is classified as a Mediterranean climate with hot, dry summers and mild, wet winters (Köppen classification). Along the Algiers coastline, the human population is exposed to anthropogenic disturbances of many origins. Moreover, 1000 companies have operations in the areas of building materials; petrochemistry; pharmaceutical, mechanical, electrical and electronic engineering industries; and food and paper production (Larid, 2003; PAC, 2005). Two rivers flow into the Bay of Algiers, El Hamiz and El Harrach; the latter drains the domestic and industrial waste waters of the city of Algiers itself. The sampling sites were located in the central region of Algiers (Fig. 1). Sampling sites were designated as follows: the Agueli Islet (Reghaia, CEA), with 64.709 inhabitants and located 30 km east of Algiers, is considered a marine area of good water quality and biological, ecological and socioeconomic interest at the local, regional and international levels. This natural heritage site is now the subject of special attention because of the increasing urban and industrial waste being dumped untreated into Lake Reghaia, which flows out to the coastal site of El Kadous (Reghaia, CEK). At 3 km west of these two sites is located a small marina with 29.183 inhabitants, Sercouf (Ain Taya, CES). The Lidou (Bordj El Kiffan, CCL), El Kittani (Beb El Oued, COO) and Fontaine (Ain El Benian, COF) sites located in the center and west of Algiers, respectively, are exposed to strong demographic expansion and coastal development and harbor the main Algerian port facilities (Table 1). Thalasso (Sidi Fredj, COT) is a

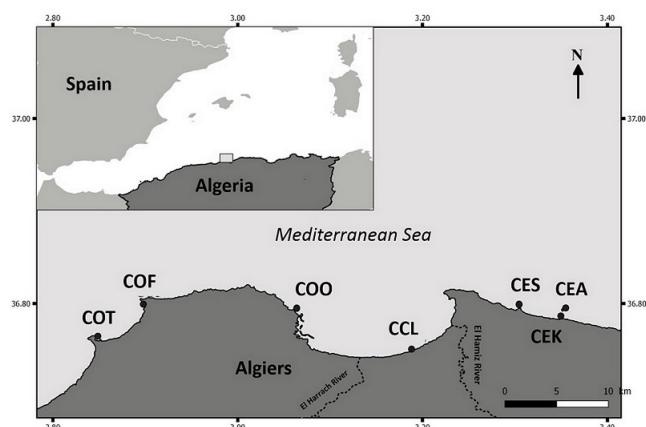


Fig. 1: A map of sampling sites in the study area (Algiers, Mediterranean Sea): Agueli islet (Reghaia, CEA), El Kadous (Reghaia, CEK), Sercouf (Ain Taya, CES), Lidou (Bordj El Kiffan, CCL), El Kittani (Beb El Oued, COO), Fontaine (Ain El Benian, COF), and Thalasso (Sidi Fredj, COT).

Table 1. General characterization of Algiers coastal sites (UNEP/MEDPOL, 2004).

| Sites | Geographical Coordinates | Distances from the center of Algiers | Permanent Populations (in Thousands) | Port in the proximity at 3 Km | Wadis / Lake in the proximity at 5 Km | Waste-water purification plant | Degree of wastewater treatment | Treated wastewater (M3 / day) |
|-------|-------------------------------|--------------------------------------|--------------------------------------|-------------------------------|---------------------------------------|--------------------------------|--------------------------------|-------------------------------|
| CEA | 36°47'36.36"N 3°21'4.92"E | | | | | | | |
| CEK | 36°47'2.72"N 3°20'45.92"E | 30 km | 64.709 | * | Reghaia Lake | SEEU of Reghaia | 30% | 400.000 |
| CES | 36°47'31.60"N 3°18'26.77"E | 27 km | 29.183 | Marina | | | | |
| CCL | 36°44'49.82"N 3°10'56.71"E | 15 km | 99.459 | * | Wadi of El Harrach | | | |
| COO | 36°47'29.37"N 3° 3'42.40"E | 7 km | 86.804 | Port of Algiers | * | SEEU of Baraki | 60% | 750.000 |
| COF | 36°47'32.2"N 2°53'58.1"E | 16 km | 51.695 | Port of Madrague | Wadi of Beni Messous | SEEU of Beni Messous | IN PROJECT | * |
| COT | 36°45'42.14"N 2°50'18.48"E | 37 km | 23.681 | Marina | * | SEEU of Staouali | 75% | 15.000 |

small town 37 km west of Algiers with 23.681 inhabitants and is located in front of a tourist complex and a thalassotherapy center.

Sampling

Benthic macroalgae were sampled at seven sampling sites, reef areas of ca. 10×10 m, once in the spring and again in the summer period of 2015. Each site was selected along the coastline at a depth range of 0.1 to 0.5 m. The samples were obtained by scraping using a hammer and a chisel on an immersed 900 cm² surface using a metallic square of 30 cm x 30 cm for five replicates (n=5; Boudouresque, 1970, 1971; Peres & Picard, 1964). The surface area sampled was greater than the minimal area that gave a good representation of the photophile seaweed species pool (Verlaque, 1976; Ballesteros, 1984). The samples were placed in plastic bags with a small quantity of seawater, transported to the laboratory, and retained in seawater and 5% formalin until later analysis. The samples were examined in the laboratory; the process consisted of first sorting the species and ESGs present under a binocular microscope and then determining those below the microscope. The nomenclature adopted was that used in algaebase.org (Guiry & Guiry, 2017). The abundance of each algal species was estimated by its coverage (percentage of the sampling surface area covered horizontally). In cases where the coverage of morphologically similar species could not be measured precisely, these species were grouped together as spp.

Physical and chemical analysis of seawater: Water temperature, pH and salinity were measured during sampling using a multiparameter meter (HI 9829 HANNA).

Data analysis

The macroalgal communities were studied using different metrics such as species and ESG number, multi-dimensional scaling ordination (nMDS) and clustering analyses based on the Bray-Curtis similarity index after 4th-root transformed covers (%) at the species and ESG levels. Simper analysis was used to determine the species and ESGs making the greatest contributions to the dissimilarity between assemblages. Two-way ANOSIM was performed to test for significant differences in species assemblages in terms of the season and site. Due to nonsignificant effects of the season, one-way ANOVA and a posteriori Tukey test were performed to compare the means between sites. Because the results of Levene's tests of homogeneity of variance were significant ($p < 0.05$), a more stringent criterion of $\alpha=0.01$ was applied. A k-dominance curve was used to compare the diversity patterns between sampling sites. All analyses were performed with Past 3.15.

Application of the continuous Ecological evaluation index (EEI-c)

The ESGs of the seven sites were determined by the EEI-c (Orfanidis *et al.*, 2011; www.eei.gr). To ensure that the coverage data was compatible with the application of the index, a transformation of the coverage data was performed [max sum of old coverage = 100%; coverage % = (old coverage/max sum of old coverage) *100]. The macroalgal species were divided into two ESGs. The following were grouped in ESG I: thick perennial (IA), thick plastic (IB) and shade-adapted plastic (IC) species. ESG

II included fleshy opportunistic (IIB) and filamentous sheet-like opportunistic (IIA) species.

To test whether the number of quadrates sampled was sufficient to estimate the ESC, a graph of the average EEI-c EQR value versus the cumulative number of quadrates sampled (and hence the amount of area sampled) was produced (EQR-area graph).

Relationship of the EEI-c index with anthropogenic pressures: The MALUSI index

This index is based on a combination of factors that reflect continental influences in coastal water bodies: (i) land use (urban, industrial, and agricultural), (ii) the vicinity and typology of rivers, and (iii) the shape of the coast (concave, convex or straight). The land use simplified index (LUSI) uses publicly available data. The calculation of LUSI is described in Flo *et al.* (2011):

$$\text{LUSI} = (\text{Urban Score} + \text{Agricultural Score} + \text{Industrial Score} + \text{Typology Score}) * \text{Correction number.}$$

MED-GIG (Mediterranean Geographical Inter-Calibration Group) for macroalgae added new descriptors to the calculation of the LUSI index (MED-GIG, 2013). The MALUSI index (LUSI for shallow-water macroalgal communities) of a coastal site is calculated as follows (see Supplementary Material: Table S2):

$$\text{MALUSI} = (\text{Urban Score} + \text{Agricultural Score} + \text{Commercial and Industrial Score} + \text{Mariculture Score} + \text{Sediment nutrient release score} + \text{Sewage outfall score} + \text{Irregular Freshwater inputs score} + \text{Harbor score}) * \text{Background trophic status} * \text{Stability of water column} * \text{Confinement.}$$

In the absence of Corine Land Cover map data in Algeria and Africa, we evaluated the pressures by expert judgment. The scores were calculated by taking into account a circle of 3 km from the sampling sites. The rela-

Table 2. Mean values (\pm Standard Error, n=3) of environmental parameters of the study sampling sites during spring and summer 2015 (Algiers-Mediterranean).

| | Temperature (° C) | Salinity | pH |
|-----|----------------------|------------------|-----------------|
| CEA | 19 \pm 1.01 | 36.51 \pm 0.21 | 8.06 \pm 0.65 |
| COF | 22 \pm 0.51 | 36.43 \pm 0.32 | 8.12 \pm 0.23 |
| CES | 19 \pm 1.31 | 36.71 \pm 0.91 | 8.17 \pm 0.38 |
| CCL | 21 \pm 0.92 | 36.84 \pm 0.41 | 8.86 \pm 0.02 |
| COT | 20 \pm 0.57 | 36.25 \pm 0.56 | 8.19 \pm 0.54 |
| COO | 21 \pm 0.50 | 36.91 \pm 0.32 | 8.98 \pm 0.03 |
| CEK | 22 \pm 0.71 | 36.50 \pm 0.28 | 9.12 \pm 0.17 |

tionship between the scores of the MALUSI index and the mean EEI-c EQR value at marine sites was obtained from a correlation curve with a correlation coefficient (R^2).

Results

Abiotic data

The average results of the physicochemical parameters (water temperature, pH and salinity) of the seawater during spring-summer 2015 at the sampling sites are shown in Table 2. Temperature and pH variability was low, with a minimum at CEA (mean \pm standard error: T=19 \pm 1.01 °C; pH=8.06 \pm 0.65) and maximum values at CEK (T= 22 \pm 0.71 °C; pH=9.12 \pm 0.17). The salinity values showed a minimum at COT (36.25 \pm 0.56) and maximum values at COO (36.91 \pm 0.32).

Structural analysis

A floristic inventory was established from the dataset of seventy samples (7 sites x 2 seasons x 5 replicates). The analysis identified a total of 86 taxa (Table S1). This list includes a number of indeterminant species corresponding to young or poorly characterized individuals. Bray-Curtis multidimensional scaling ordination and cluster analyses of the sites and seasons at the species level showed three different assemblages (A, B and C) at 60% similarity (Fig. 2). The sites COT, CEA and CES belong to group A, with a dominance of *Cystoseira amentacea* var. *stricta* associated with *Lithophyllum incrassatum* and *Jania rubens* (see Simper analysis in Table 3). The sites CCO, CCL and COF belong to group B with a dominance of *Ulva rigida*, *Ulva intestinalis* and *Caulerpa cylindracea* species. The site CEK belongs to group C, which is dominated by *Chaetomorpha aerea*, *Ulva intestinalis* and *Ulva rigida*. The ANOSIM test revealed significant differences among sites (global R = 0.969, p=0.001) but not among seasons (see also Fig. 3).

The species number showed significant differences (F= 210, 5, p<0.01, Table 4) in the mean values among sites (Fig. 3). The maximum values of species richness were noted at nonimpacted sites: COT, CEA, and CES. Tukey post hoc comparisons showed dissimilarity between COT and the other sampling sites as well as between impacted sites (CCL, COO, CEK and COF) and nonimpacted sites (CEA and CES).

The K-dominance curves of the sites subjected to different degrees of pollution showed that the curve of the less polluted site COT lie below the polluted curves (CEK and COO) on the left-hand side of the plot, indicating that there is a higher proportion of low-abundance species in the polluted communities (Fig. 4A).

Functional analysis

All taxa were classified into five ESGs (Table S1). Bray-Curtis multidimensional scaling ordination and

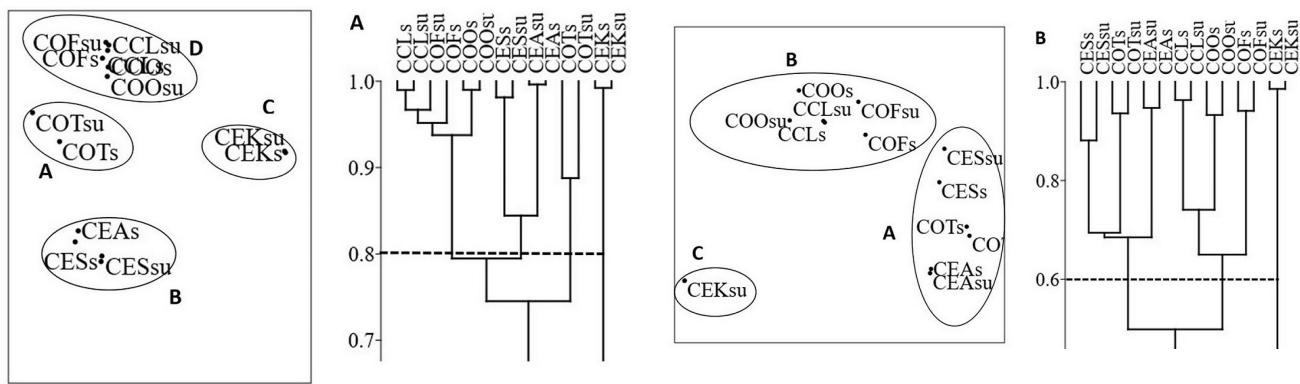


Fig. 2: Bray-Curtis multidimensional scaling ordination (nMDS) and clusters analyses of the sites at of similarity at 80% on Ecological Status Group level (A) and at 60 % on species level (B).

Table 3. Dissimilarity values among MDS groups of sites (SIMPER analysis).

| Overall average dissimilarity A and C= 81.85 | Av. dissim | Contrib. % | Cumulative % | Mean A | Mean C |
|--|------------|------------|--------------|--------|--------|
| <i>Chaetomorpha aerea</i> (Dillwyn) Kützing 1849 | 8.44 | 10.31 | 10.31 | 3.4 | 94.8 |
| <i>Ulva compressa</i> Linnaeus 1753 | 7.19 | 8.79 | 19.1 | 4.63 | 82.5 |
| <i>Cystoseira amentacea</i> var. <i>stricta</i> Montagne 1846 | 6.64 | 8.12 | 27.22 | 72 | 0 |
| <i>Ulva rigida</i> C.Agardh 1823 | 6.54 | 7.99 | 35.2 | 23.1 | 93.9 |
| <i>Lithophyllum incrustans</i> Philippi 1837 | 4.39 | 5.36 | 40.57 | 47.5 | 0 |
| <i>Asparagopsis armata</i> Harvey 1855 | 3.78 | 4.61 | 45.18 | 40.9 | 0 |
| <i>Jania rubens</i> (Linnaeus) J.V.Lamouroux 1816 | 3.64 | 4.45 | 49.63 | 51.8 | 12.4 |
| <i>Sargassum vulgare</i> C.Agardh 1820 | 3.44 | 4.21 | 53.83 | 37.3 | 0 |
| Overall average dissimilarity A and B= 63.39 | Av. dissim | Contrib. % | Cumulative % | Mean A | Mean B |
| <i>Ulva compressa</i> Linnaeus 1753 | 4.58 | 7.22 | 7.22 | 4.63 | 86.6 |
| <i>Cystoseira amentacea</i> var. <i>stricta</i> Montagne 1846 | 4.08 | 6.34 | 13.56 | 72 | 0 |
| <i>Ulva rigida</i> C.Agardh 1823 | 3.8 | 5.99 | 19.55 | 23.1 | 91.2 |
| <i>Ulva intestinalis</i> Linnaeus 1753 | 3.78 | 5.97 | 25.52 | 6.93 | 74.7 |
| <i>Pterocladiella capillacea</i> (S.G.Gmelin) Santelices & Hommersand 1997 | 3.56 | 5.62 | 31.14 | 9.86 | 73.7 |
| <i>Chaetomorpha aerea</i> (Dillwyn) Kützing 1849 | 3.29 | 5.19 | 36.33 | 3.4 | 62.3 |
| <i>Ulva lactuca</i> Linnaeus 1753 | 3.18 | 5.01 | 41.34 | 11.3 | 68.3 |
| <i>Caulerpa cylindracea</i> Sonder 1845 | 3.16 | 4.98 | 46.32 | 3.88 | 60.4 |
| Overall average dissimilarity B and C= 53.01 | Av. dissim | Contrib. % | Cumulative % | MeanC | Mean B |
| <i>Ulva intestinalis</i> Linnaeus 1753 | 5.08 | 9.59 | 9.59 | 0 | 74.7 |
| <i>Pterocladiella capillacea</i> (S.G.Gmelin) Santelices & Hommersand 1997 | 5.01 | 9.45 | 19.05 | 0 | 73.7 |
| <i>Caulerpa cylindracea</i> Sonder 1845 | 4.11 | 7.75 | 26.80 | 0 | 60.4 |
| <i>Gratelouphia lanceola</i> (J.Agardh) J.Agardh 1851 | 3.8 | 7.16 | 33.97 | 0 | 55.8 |
| <i>Gracilaria dura</i> (C.Agardh) J.Agardh 1842 | 3.48 | 6.57 | 40.54 | 0 | 51.2 |
| <i>Asparagopsis taxiformis</i> (Delile) Trevisan 1845 | 3.20 | 6.03 | 46.58 | 0 | 47 |
| <i>Chaetomorpha aerea</i> (Dillwyn) Kützing 1849 | 2.21 | 4.17 | 78.56 | 94.8 | 62.3 |
| <i>Ellisolandia elongata</i> (J.Ellis & Solander) K.R.Hind & G.W.Saunders 2013 | 1.66 | 3.13 | 81.7 | 40.9 | 65.3 |

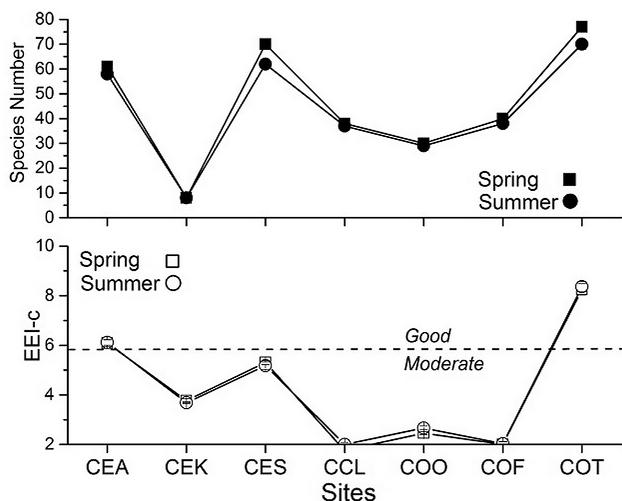


Fig. 3: Comparative presentation of the number of species and EEI-c variations (Mean±Standard Error, n=5) in the studied sites.

cluster analyses of the sites at the ESG level showed four different assemblages at 80% similarity. Group A includes the less impacted COT site, and group B includes the CEA and CES sites showing the first signs of degradation. The most degraded sites, CCL, COO and COF, belong to group C, and CEK is a degraded site probably with freshwater influence in group D (Fig. 2). Group A is dominated by shade-adapted plastic (IC) and thick plastic (IB) species such as *Ellisolandia elongata*, *Jania rubens* and *Sargassum vulgare*. Group B includes filamentous sheet-like opportunistic (IIA) and shade-adapted plastic (IC) species such as *Asparagopsis armata*, *Pterocladiella capillacea* and *Lithophyllum incrassans*. Group C is dominated by fleshy opportunistic (IIB) and filamentous sheet-like opportunistic (IIA) species with a dominance of *Caulerpa cylindracea*, *Ulva rigida* and *Chaetomorpha aerea*. The last group (D) includes only fleshy opportunistic (IIB) and shade-adapted plastic (IC) species, such as *Ellisolandia elongata*, *Chaetomorpha aerea* and *Ulva compressa*.

Table 4. Comparisons between sampling sites for structural (species number) and functional (Ecological Evaluation Index-EEI-c) metrics using one-way ANOVA.

| Taxa_S | Structural - Species Number | | | | | Functional - EEI-c index | | | | |
|-------------------------|---|-------------|----------|-------------|-------------------------|---|-----------|-------------|---|--|
| | Variations : | Sum of sqrs | df | Mean square | F | Sum of sqrs | df | Mean square | F | |
| Between groups: | 12684.3 | 6 | 2114.06 | 210.5 | 351.828 | 6 | 58.638 | 873.4 | | |
| Within groups: | 632.8 | 63 | 10.0444 | | 4.22961 | 63 | 0.0671367 | | | |
| Total: | 13317.1 | 69 | 1.00E-05 | | 356.058 | 69 | 1.00E-05 | | | |
| Permutation p (n=99999) | Welch F test in the case of unequal variances: F=644.1, df=25.53, p=1.362E-26 | | | | Permutation p (n=99999) | Welch F test in the case of unequal variances: F=675. df=27.71, p=1.078E-28 | | | | |

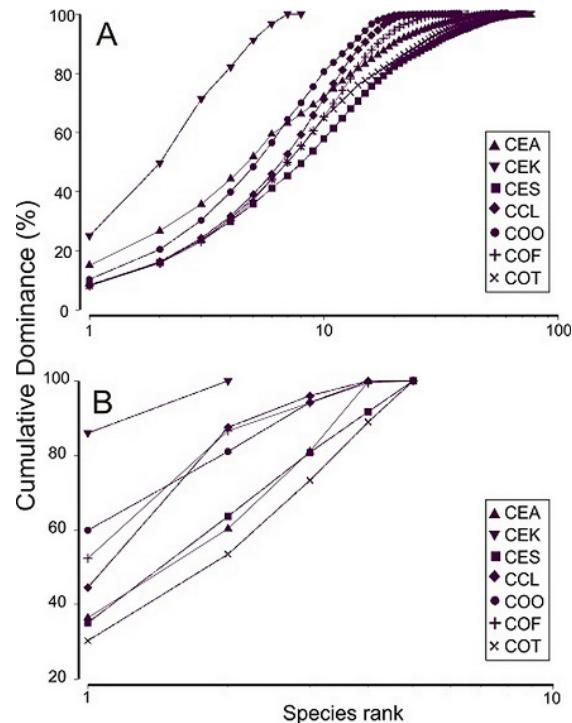


Fig. 4: K-dominance curve for mean coverage at each sampling sites at species (A) and Ecological Status Group (B) level.

Using EEI-c, the seven sampling sites were classified into five ESCs (Tab VI). While the COT site showed the highest EQR value (score: 0.79) and was classified as a “high” ESC, the CCL and COF sites had the lowest values (0) and were classified as “bad” ESCs. The site CES was classified as a “moderate” ESC (0.41), and the COO and CEK sites were classified as “low” ESCs (scores: 0.07 and 0.22, respectively). One-way ANOVA showed significant differences between the sampling sites and mean values for the EEI-c index (Table 4). The plot of the mean EEI-c EQR value versus the number of samples (Fig. 6) indicated that the number of samples collected was adequate.

The K-dominance curve showed that the sites were subjected to different degrees of pollution, with the curves of the less-polluted site (COT, CEA, and CES) lying well below the curves of the heavily polluted sites (CEK and COO) at the left-hand side of the plot, indicating that there is a higher proportion of low-abundance ESCs in the polluted communities (Fig. 4B).

Relationship of the EEI-c index with anthropogenic pressures

The MALUSI stress index showed maximal values, corresponding to the highest human impacts, at the CEK and COO sites (MALUSI= 12 and 11.25, respectively) and the lowest values, corresponding to low human pressure, at the CEA site (MALUSI=2; Table 5). The human pressure scores matched sufficiently to the ESCs calculated by the EEI-c index, showing a nonlinear relationship with a high correlation coefficient ($R^2=0.85$, Fig. 5).

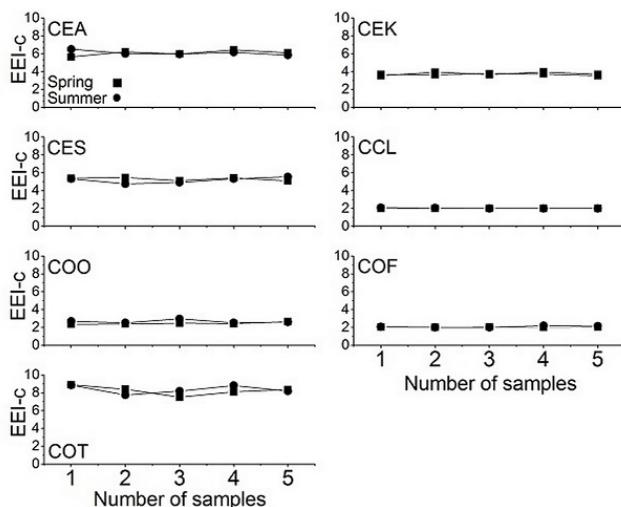


Fig. 6: Mean Ecological Evaluation Index (EEI-c) values versus increasing number of samples (quadrates) curves in the studied sites (Algiers coast line).

Table 5. Ecological status assessment and classification based on the Ecological Evaluation Index continuous (EEI-c) formula. The MALUSI anthropogenic stress index values are also presented.

| Sites | CEA | CEK | CES | CCL | COO | COF | COT | Average |
|--------------------------|-------|-------|----------|-------|-------|------|-------|--------------|
| Total coverage of ESG I | 23.64 | 2.72 | 5.99 | 8.18 | 9.82 | 9.40 | 57.67 | 16.77 |
| Total coverage of ESG II | 20.92 | 27.74 | 12.18 | 77.73 | 59.92 | 2.01 | 24.06 | 32.08 |
| EEI-c value | 6.10 | 3.72 | 5.24 | 1.82 | 2.56 | 1.96 | 8.31 | 4.23 |
| EEI-c EQR | 0.51 | 0.22 | 0.41 | 0.00 | 0.07 | 0.00 | 0.79 | 0.28 |
| ESC | Good | Low | Moderate | Bad | Low | Bad | High | Low/Moderate |
| MALUSI index | 2 | 12 | 5.25 | 7.5 | 11.25 | 9.38 | 2.25 | 7.09 |

Discussion

The results of this study showed that there are considerable differences between the structural and functional approaches to studying benthic macroalgal assemblages, with the latter related to chronic pollution (Panayotidis *et al.*, 2004; Orfanidis *et al.*, 2014) and in agreement with ecological theory (Odum, 1985; Scheffer *et al.*, 2001). Obviously, functional grouping of organisms reduces spatial and temporal community variability and allows patterns to emerge without losing important information (Steneck & Watling, 1982). A well-known pattern suggests that highly stressed or disturbed marine environments, mainly due to changes in nutrient input and light transparency leading to eutrophication (Cloern, 2001; De Jonge *et al.*, 2002; Mc Glathery *et al.*, 2004), are inhabited by annual species with high growth rates and reproductive potential. On the other hand, undisturbed marine environments are dominated by perennial species with low growth rates and reproductive potential (Regier & Cowell, 1972; Murray & Littler, 1978; Sousa, 1980; Duarte, 1995; Schramm 1999; Karez *et al.*, 2004).

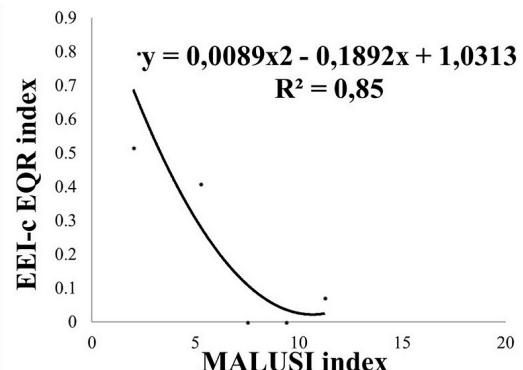


Fig. 5: Non-linear relationship between the EQR values obtained by the EEI-c index (Algiers marine sites) and corresponding MALUSI index of anthropogenic pressure.

Cystoseira amentacea var. *stricta*, a perennial species with high heritage (Delepine *et al.*, 1987; Boudouresque *et al.*, 1996; Boudouresque, 2002; Bulleri *et al.*, 2002) and indicative of good water quality (Ballesteros *et al.*, 2007), is strictly protected species at the European level by the Berne Convention. However, its abundance has declined or reached zero under the polluted conditions at most studied sites. Additionally, the abundance of *Cystoseira compressa*, the most pollution-tolerant *Cystoseira* species (Benedetti-Cecchi *et al.*, 2001; Thibaut *et al.*, 2005), declined as well. Green algae, such as *Ulva rigida*, *Ulva intestinalis* and *Caulerpa cylindracea*, establish a dominant structure in the environment and restrict the living areas of other algae (Cirik *et al.*, 2001). Previous studies have shown that along with a gradient of nutrient enrichment, the most impacted sites are consistently characterized by low taxon richness and the presence of nitrophilic taxa such as *Ulva* spp. and *Cladophora* spp. (Arévalo *et al.*, 2007; Pinedo *et al.*, 2007). Although multivariate techniques have been used successfully to identify disturbance at the macrobenthic community level (Clarke, 1993; Warwick & Clarke, 1993), only when studied at a functional (ESG) level were the sites clearly classified into three clusters, in agreement with the water degradation information (Fig. 2B). This is an expected result because the ESGs used (Orfanidis *et al.*, 2011, 2014) have been defined using functional traits related to nutrient and light responses that indicate species adaptation across a water pollution gradient. One site was separated from this scheme due to low benthic macrophyte abundance values and neighboring low-salinity water sources (CEK). This pattern has been confirmed for the first time using the K-cumulative dominance at the ESC level. This value corresponds to the proliferation of a small number of species, such as *Chaetomorpha aerea*, *Ulva intestinalis* and *Ulva rigida*, belonging to ESG IIB.

A low value of the structural species diversity index might also be explained by the presence of *Caulerpa racemosa*, which after implantation in sediment, their crawling axes and their rhizoids quickly weave a compact coverage that traps sediments and blocks light. The substrate gradually becomes inaccessible to other organisms, particularly to other macrophytes (Verlaque & Fritayre, 1994; Piazzu *et al.*, 2001).

Out of all the functional metrics tested, the biotic index EEI-c classified the sampling sites into different ESCs, from bad to high ESCs, which possessed a strong correlation to the MALUSI index of anthropogenic stress. On average, the part of the Algerian coast studied belongs to the low/moderate ESCs. Several other studies confirmed that seawater quality is degraded in the central region near Algiers. Benamar *et al.* (1999) evaluated the degree of pollution in Algiers Bay by studying heavy metals and confirmed that the anthropogenic origin of the pollution in the bay consisted of urban and industrial wastes and harbor activity. Houma *et al.* (2013) combined the information required by various satellites to characterize seawater pollution by hydrocarbons along the Algerian coast

and confirmed that the study area is mainly contaminated by pollution from various sources and is subjected to several types of urban, industrial and oil wastes. Soualili *et al.* (2008) assessed marine pollution due to heavy metals in the area by looking at chemical and toxicological data acquired through analyses of sediments and sea urchin, *Paracentrotus lividus*, gonads on the coast of Algiers. Of all the sites, Algiers Beach had the greatest load of heavy metals in the sediments, and the most heavily contaminated site was dominated by Pb. These authors noted that Sidi-Fredj and Tamentfoust were less polluted by heavy metals because of their location far from the highly industrialized area impacted by the metropolis of Algiers.

The EEI-c successional model enabled classification of the ecological status of the different basins of water bodies along the coast of Algiers and could now be considered well adapted for implantation into the WFD. The index is based on the same conceptual framework: anthropogenic pressures can cause a decrease in abundance or even the disappearance of the most sensitive species, while the most tolerant taxa will remain (e.g., Gorostiza & Díez, 1996; Crowe *et al.*, 2000; Mascaró *et al.*, 2013). EEI-c provided a detailed taxonomic composition, structure and functioning of the macroalgal community, also providing better evidence of possible changes in the qualitative abundance of habitat-forming species (Guinda *et al.*, 2008; O'Connor, 2013). Cartography of habitats can provide more information to assess the evolution of macroalgal coastal communities, which can be especially useful for conservation programs of threatened and/or protected organisms such as seagrasses or *Cystoseira* species (Bermejo *et al.*, 2014).

In conclusion, this study indicated that macroalgae are excellent indicators of degradation in Algerian coastal waters with the application of the EEI-c index to adequately assess ESCs. Although the results of this study have to be validated by additional studies, we suggest the following: (1) the EEI-c index should be applied in spring or summer to ensure that the results are comparable with the previous and present results, (2) the number of sampling quadrates per site should be reduced to 3, and (3) a national coastal monitoring program should be implemented to survey the quality of water off Algeria, as the WFD requires of European countries. It is, therefore, preferable to act now before the environmental damage reaches a critical degree of severity.

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