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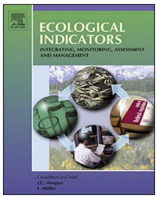

Research paper

First assessment of the ecological status in the Levant Basin: Application of the CARLIT index along the Lebanese coastline

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ABSTRACT

Macroalgae is one of the Biological Quality Elements (BQE) used by several indexes conceived in the European Water Framework Directive (WFD) for the assessment of the Ecological status of coastal water bodies. Among them, CARLIT index, based on the cartography of rocky-shore littoral communities, has been extensively and successfully applied in the Western Mediterranean Sea. In this study CARLIT was applied for the first time in the Levantine Sea, along the Lebanese shoreline in order to test the suitability of this method in the peculiar ecological conditions of the Levantine Sea and have a first assessment of its ecological status. The choice of proper reference sites is a focal point in the fulfillment of the WFD. In order to ensure accurate calculation of the ecological status of the Lebanese coast, the calculations of the reference conditions (RC) were performed using the values calculated in the Lebanese reference area, the Northwestern (NW) Mediterranean RC proposed in the first application of the CARLIT method and the Adriatic Sea RC. The results showed that the calculated ecological quality ratio values (EQR) based on Lebanese RC is particularly important when considering the principle of the WFD to reach and maintain a good Ecological Status. Overall, the EQR values were well correlated with anthropogenic pressures, as assessed by the LUSI and MA-LUSI indexes. In addition, this method allowed the collection of accurate information on the distribution and abundance of shallow-water communities, especially of those deserving protection (e.g. *Cystoseira* forests). Thus, the present paper represents a baseline for future studies and gives useful tools for the management of human impacts on the Lebanese coast.

1. Introduction

Habitat loss and degradation, pollution, eutrophication, introduction of invasive species and, recently, climate change are the most important threats affecting coastal marine ecosystems and their ability to deliver ecosystem services at the global scale (Halpern et al., 2008; Waycott et al., 2009; Worm et al., 2006). The Mediterranean Sea is considered one of the first 25 global biodiversity hotspots (Myers et al., 2000) for its high biodiversity, the high level of endemism and the greatest proportions of species recorded (Bianchi and Morri, 2000; Coll et al., 2010). However, anthropogenic impacts are also relevant in the Mediterranean Sea (e.g. Bianchi and Morri, 2000; Coll et al., 2010; Costello et al., 2010; Lotze et al., 2006; Zenetos et al., 2012). The cumulative effects of human disturbances on marine coastal ecosystems worldwide and particularly in the Mediterranean Sea (Coll et al., 2012; Costello et al., 2010; Lotze et al., 2011), has led to the development of many methods and strategies to prevent a further deterioration of coastal ecosystems and to improve their ecological quality (Mann, 2000). The Water Framework Directive (WFD) 2000/60/EC, is one of the legislative monitoring networks that was adopted by the European Community in 2000, with the goal of using biota for assessing the water quality of inland surface waters, transitional waters, groundwaters and coastal waters. The objective of the WFD is that natural water bodies should reach and maintain a good ecological status (ES), i.e. the assemblages developing in the water bodies have to show low level of distortion resulting from human activities, deviating only slightly from those normally associated with those developing in undisturbed conditions. Within the WFD, several indices based on biological communities (phytoplankton, macroalgae, seagrasses, macroinvertebrates and fish) as bio-indicators (Biological Quality Elements or BQEs) have been developed along the Atlantic and Mediterranean coasts for the evaluation of the ES of marine coastal waters (for a review see Martínez-

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Crego et al., 2010). According to many ecological studies, macroalgal communities, one of the BQEs proposed in the WFD, are considered useful bio-indicators for the assessment of water quality worldwide and a wide range of indexes use them for the assessment of water quality: CCO index [Cover Characteristic Opportunistic species (Gall et al., 2016)], CFR index [Calidad de Fondos Rocosos (Guinda et al., 2008; Juanes et al., 2008)], the RICQI index [Rocky Intertidal Community Quality Index (Díez et al., 2012)], the MarMAT index [Marine Macroalgae Assessment Tool (Neto et al., 2012) and the RSL [Reduced Species List (Wells et al., 2007)] for the North East Atlantic, and the CARLIT index [Cartography of littoral and upper-sublittoral rocky-shore communities (Ballesteros et al., 2007)] and the EEI index [Ecological Evaluation Index (Orfanidis et al., 2011; Taskin, 2015)] for Mediterranean coastal waters. In the Mediterranean Sea, the sensitivity of very shallow macroalgal communities to human disturbances is well known (Arévalo et al., 2007; Ballesteros et al., 2007; Orlando-Bonaca et al., 2008; Pinedo et al., 2007) and their distribution and status is assessed in the CARLIT index (Ballesteros et al., 2007) in order to calculate the ecological status of coastal waters. The communities are visually assessed and ranked according to their sensitivity to perturbation: Several *Cystoseira* species (Fucales, Phaeophyceae), which are particularly sensitive to water quality and other disturbances, are associated to the highest values of ecological status. In contrast, stress-resistant species (e.g. articulated Corallinales and Dictyotales), that are ubiquitous and tolerant, are associated to medium values. The lowest ES values are associated to very low structured communities dominated by opportunistic species such as green algae (e.g. *Ulva* spp. and *Cladophora* spp.) and cyanobacteria (Arévalo et al., 2007; Pinedo et al., 2007). The CARLIT methodology, developed in the Northwestern Mediterranean coast of Spain (Ballesteros et al., 2007) has been largely applied in other Mediterranean countries: France (Blanfuné et al., 2017), Italy (Asnaghi et al., 2009; Buia et al., 2007; Cecchi et al., 2009; Mangialajo et al., 2007; Sfriso and Facca, 2011), Malta (Blanfuné et al., 2011), Croatia (Nikolić et al., 2013), Tunisia (Omrane et al., 2010) and Albania (Blanfuné et al., 2016b). The CARLIT index has been widely used since: (i) it is a non-destructive method (no sample collection is needed); (ii) it potentially takes into consideration the entire rocky coastline of an area, although subsampling can be performed; (iii) it is time and cost-effective with almost no laboratory work needed; (iv) it is based on widely distributed communities that are relatively easy to identify and whose response to anthropogenic pressures is well-known (Ballesteros et al., 2007; Bermejo et al., 2013; Blanfuné et al., 2016b; Cavallo et al., 2016; Mangialajo et al., 2007; Nikolić et al., 2013; Torras et al., 2015). From a conservation point of view, the CARLIT index also provides valuable data concerning the distribution of shallow water Mediterranean algal forests, generally dominated by species of the genus *Cystoseira* C. Agardh and *Sargassum* C. Agardh (Fucales, Phaeophyceae), the main representatives of the order Fucales (Phaeophyceae, kingdom Stramenopiles) in several Mediterranean rocky-bottom communities (Blanfuné et al., 2016a; Cheminée et al., 2013; Hereu et al., 2008). These large brown seaweeds are ecosystem engineers as their canopy constitute highly structured and diverse communities (Thiriet et al., 2016), forming dense forest habitats that offer shelter, food and nursery to other organisms (Cheminée et al., 2013). Like kelp forests in oceanic environments (Schiel and Foster, 2015), fucoid forests represent one of the more productive coastal habitats in the Mediterranean Sea (Mangialajo et al., 2012), providing valuable ecosystem goods and services to many organisms and to human kind (Cheminée et al., 2013; Salomidi et al., 2012; Thiriet et al., 2016). However, most of Mediterranean fucoids species are highly threatened and are currently disappearing or in regression in many coastal areas due to a complex mix of local and global impacts (Arévalo et al., 2007; Hereu et al., 2008; Mangialajo et al., 2008; Mineur et al., 2015; Thibaut et al., 2016; Thibaut et al., 2014a,b; Thibaut et al., 2005). As a consequence, most Mediterranean fucoids are listed as endangered or threatened in the Annex II of the Barcelona Convention (1976, updated 2013) and their conservation and restoration is the object of several researches (reviewed by Gianni et al., 2013).

The application of CARLIT in the areas surveyed so far has provided valuable data on the ES of the water bodies, but also on the present distribution of shallow water forests dominated by fucoids. At present CARLIT index has been applied in most of the North-Western Mediterranean Sea and in part of the Adriatic Sea (Blanfuné et al., 2017 and references therein). The present study represents the first application of the CARLIT index in the Eastern-most part of the Mediterranean Sea (Levantine Sea, Lebanon) in order to i) test the applicability of CARLIT in this Basin, ii) assess the ES of Lebanese coastal waters, iii) calculate the relation between the CARLIT index and the anthropogenic pressures and iv) document and provide a baseline for the current distribution of fucoids forests and other valuable communities in Lebanon.

2. Material and methods

2.1. Study area

Lebanon has about 220 km of coastline which hosts 70% of the Lebanese population (Kouyoumjian and Hamzé, 2012). The continental shelf in the Lebanese Coastal Zone (LCZ) is narrow (Abboud-Abi Saab et al., 2012), 3–7 km wide, and the coastline is characterized by the presence of a few bays (Bay of Beirut, Bay of Jounieh, Bay of Shekka and Bay of Akkar), 4 commercial ports and over 15 fishing harbors, dozens of sea pipelines for petroleum imports, various industries, three power plants and fuel tank farms (El Asmar and Taki, 2014) (Fig. 1). Pebble beaches and rocky coasts are dominant, sandy beaches interesting only 20 percent of the coast (MOE/UNDP/ECODIT, 2011). Furthermore, the LCZ is suffering from many supplementary sources of pollution such as illegal sewage discharge, rivers (generally characterized by torrential regime and carrying pollutants from agricultural, industrial and urban activities) and uncontrolled urban development, especially involving coastal artificialization (MOE/UNDP/ECODIT, 2011). Very few studies on macroalgal communities presence, abundance and patterns of distribution have been performed along the Lebanese coast (Basson et al., 1976; Kanaan et al., 2015; Lakkis and Novel-Lakkis, 2000) and *Cystoseira* species have never been the object of a detailed study although they have been mentioned in few benthic inventories and underwater visual census surveys (Bitar and Bitar-Kouli, 1995; Ramos-Esplá et al., 2014).

2.2. CARLIT application

The study was performed along 164 km of the Lebanese coast, which represent about 75% of the entire coastline. Sandy beaches and highly modified areas such as marinas were excluded, according to Ballesteros et al. (2007) and Bermejo et al. (2013). As Lebanon does not belong to the European Union, no coastal water bodies were previously defined in an institutional framework. Then, the Lebanese coast was divided into 12 stretches of coast (Fig. 2) taking into account their catchment basin and typology.

The category table proposed by Ballesteros et al. (2007) and subsequently modified (e.g. Asnaghi et al., 2009; Bermejo et al., 2013; Blanfuné et al., 2017; Nikolić et al., 2013) was adapted to the Lebanese coast, as reported in Table 1. The same range of sensitivity values was considered (from 20, very sensitive to 1, not sensitive) and the simplified version with only three classes of *Cystoseira* belts was adopted (Nikolić et al., 2013).

The list of geomorphological features and their categories (Table 2) used to describe the coastline sectors in the Lebanese coast, based on previous studies (Nikolić et al., 2013), consisted in coastline morphology (low coast/metric blocks), coastline slope (horizontal/subvertical), nature (natural/artificial) and type of the substrate (calcareous/sandstone) and degree of wave exposure (calm/exposed).

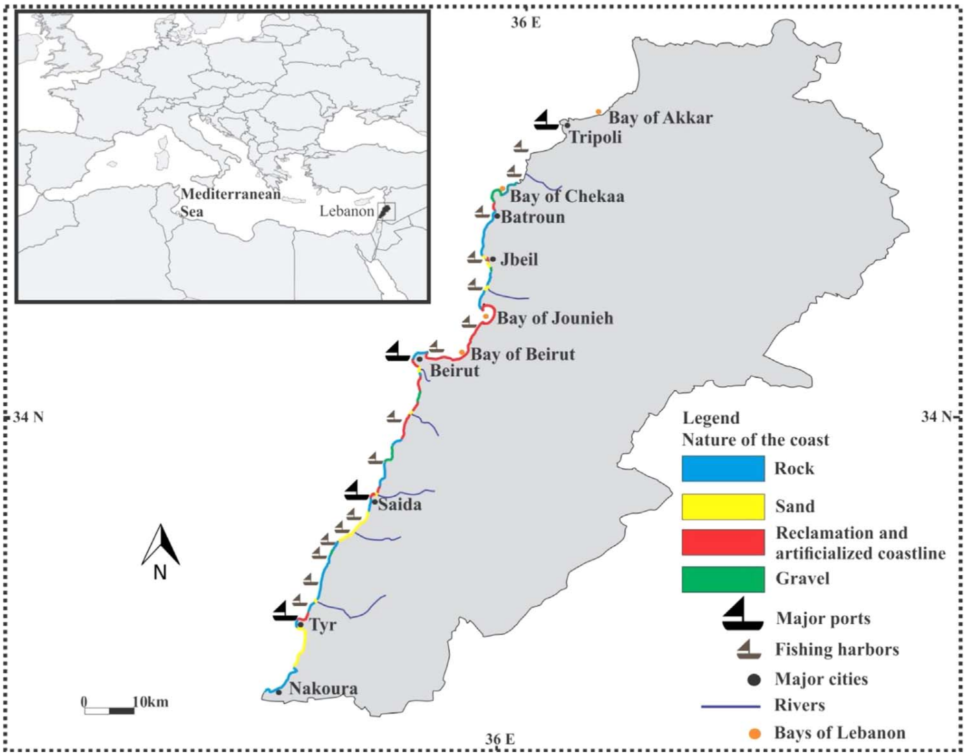

Fig. 1. Map of Lebanon, showing the location of the major cities, the 4 commercial and 15 fishing harbors, the main rivers, the 4 bays as much as distribution of rocky, sandy, gravel and reclamation and artificialized coastline in the study area.

The survey was conducted during April – May 2016, during the period of maximal development of macroalgal assemblages in the Lebanese coast. Each stretch of coast was previously divided into sectors of 50 m length using Quantum Geographical Information System (QGIS) software. The sampling consisted in a run of all the sectors, using a small boat, moving at low speed and proceeding as close as possible to the shoreline, in order to observe the shallow macroalgal communities. When hardly accessible by boat, some sectors were

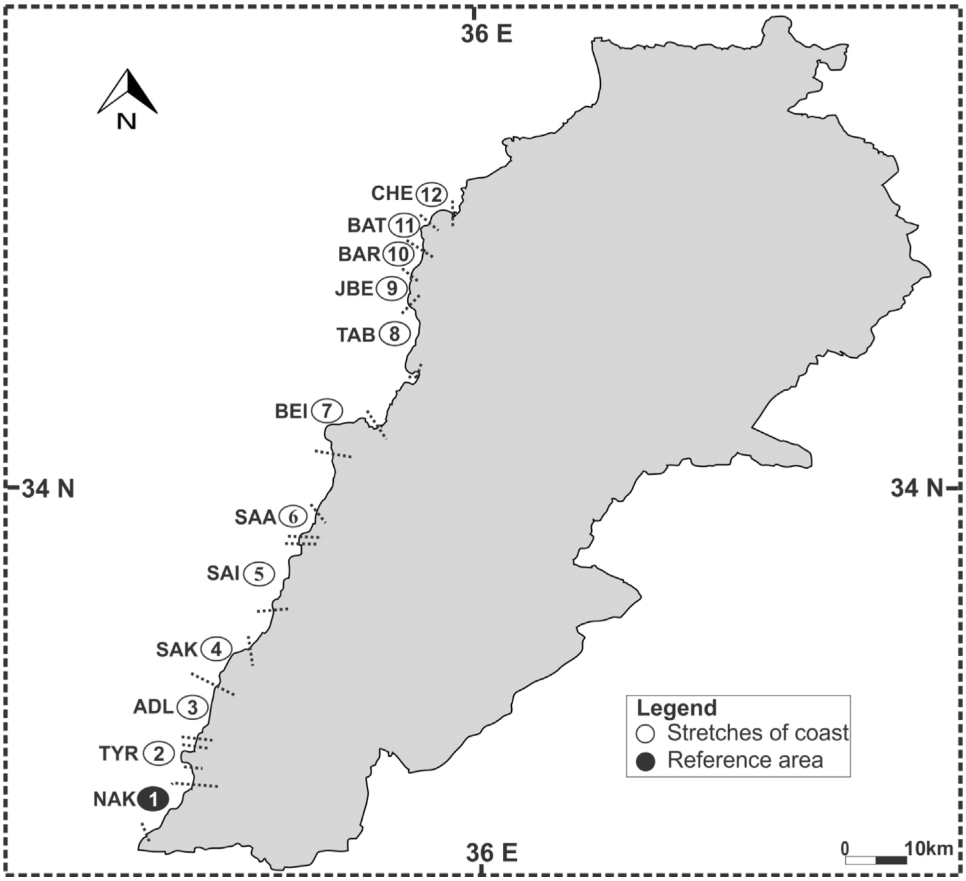

Fig. 2. Geographical distribution of the 12 stretches studied along the Lebanese coast. 1-NAK: Nakoura; 2-TYR: Tyr; 3-ADL: Adloun; 4-SAK: Saksakiyé; 5-SAI: Saida; 6-SAA: Saadiyet; 7-BEI: Beirut; 8-TAB: Tabarja; 9-BAR: Barbara; 10-JBE: Jbeil; 11-BAT: Batroun; 12-CHE: Ras-Chekaa.

Table 1
Summarized description and sensitivity levels of the main community categories taken into account for the application of CARLIT along the Lebanese coasts modified from Nikolić et al. (2013).

Category	Community description	Sensitivity level (SL.)	Acronym
Cystoseira amentacea 3	Continuous belts of *C. amentacea*	20	CYS3
Other sensitive *Cystoseira* species	Stands of other sensitive *Cystoseira* species (*Cystoseira rayssiae)*	20	CYSS
Cystoseira amentacea 2	Abundant patches of *C. amentacea*	15	CYS2
Sargassum spp.	Stands of *Sargassum vulgare*	14	SARG
Cystoseira compressa	Stands of *Cystoseira compressa*	12	CYSC
Cystoseira amentacea 1	Rare, scattered plants of *Cystoseira amentacea*[a]	10	CYS1
Ubiquitous photophilic algae	Stands of *Padina pavonica, Dictyota* spp., *Dictyopteris polypodioides, Halopteris scoparia, Taonia atomaria, Laurencia* complex	10	UPHO
Erect corallines	Stands of articulated Corallinales	8	ACOR
Tolerant photophilic algae	Community dominated by *Colpomenia sinuosa, Pterocladiella capillacea, Hypnea musciformis*	6	TPHO
Green algae	Stands of *Ulva* spp. and *Cladophora* spp.	3	VTPH
Cyanobacteria	Stands dominated by cyanobacteria	1	CYAN

[a] In the case of rare scattered plants of belt-forming *Cystoseira amentacea* (class 1), the dominant community is also recorded. (Sensitivity level: average value).

Table 2
Geomorphological feature data collected in the field for every sector.

Geomorphological features	Category
Coast morphology	Low continuous coast Metric blocks
Coastline slope	Horizontal (0–30°) Subvertical (30–60°)
Nature of the substrate	Natural Artificial
Substrate type	Calcareous (limestone) Sandstone
Wave exposure	Sheltered Exposed

Table 3
Ecological quality values under NW Mediterranean Reference Conditions (RC, Ballesteros et al., 2007).

Geomorphological situation	Coastal morphology	Coastline slope	EQ$_{rsi}$
1	Decimetric blocks	Artificial	12.1
2	Low coast	Artificial	11.9
3	High coast	Artificial	8
4	Decimetric blocks	Natural	12.2
5	Low coast	Natural	16.6
6	High coast	Natural	15.3

Table 4
Ecological quality values under Adriatic Reference Conditions (RC,).

Geomorphological situation	Coastal morphology	Coastline slope	EQ$_{rsi}$
1	High coast	Horizontal	20
2	High coast	Sub-vertical	17.55
3	High coast	Vertical	12.96
4	High coast	Overhanging	10.00
5	Low coast	Horizontal	19.02
6	Low coast	Sub-vertical	17.72
7	Low coast	Vertical	14.62
8	Low coast	Overhanging	9.66
9	Blocks	–	12.76

Table 5
Lebanese RC, corresponding to the Ecological Quality values (EQi) calculated for the four Geomorphological Relevant Situations (GRS) resulting from the BEST analysis, in the reference area (Nakoura).

GRS	Type of substrate	Slope	EQi
1	Natural	Horizontal	12.9
2	Natural	Subvertical	9.3
3	Artificial	Horizontal	8
4	Artificial	Subvertical	8

sampled by snorkeling or walking. In each sector, littoral/and upper littoral communities and geomorphological factors were visually recorded and noted directly into maps (scale 1:5000) previously prepared using aerial photographs taken from Google Earth$^{®}$. Subsequently, data were transferred into geo-referenced maps using (QGIS) software.

In order to propose adequate reference conditions (RC) for the Lebanese coastline, potential reference areas were selected according to the criteria proposed by the Mediterranean Geographical Intercalibration Group (Bermejo et al., 2013; Nikolić et al., 2013): i) population density lower than 1000 ind/km^2 in the next 15 km and/or more than 100 habitats/km^2 in the next 3 km within that area (winter population); ii) no more than 10% of artificial coastline; iii) no harbors (more than 100 boats) within 3 km; iv) no beach regeneration within 1 km; v) no industries within 3 km; vi) no fish farms within 1 km vii) no desalination plants within 1 km. Along the studied Lebanese coast, only the relatively undisturbed area of Nakoura (black dot, Fig. 2), fulfilled the criteria selected.

The Ecological Quality (EQ) value was calculated for each Geomorphological Relevant Situation (GRS) in every stretch of coast, following the classical formula:

$$EQ = \frac{\sum (li * SLi)}{\sum li}$$

EQ: Ecological quality value of a particular coastline sector

li: Length of the coastline with the community category “i”

SLi: Sensitivity level of the community category “i”

According to the WFD, the ES has to be expressed in terms of ecological quality ratios (EQRs). The EQR of a stretch of coast is expressed as the ratio between the obtained EQ (EQ$_{ssi}$) and the EQ of reference sites. The EQR, expressed as a value (Table 5) ranging from 0 (bad ES) to 1 (high ES), is calculated as follows:

$$EQR = \frac{\sum \frac{EQssi\ *\ li}{EQrsi}}{\sum li}$$

EQ$_{ssi}$: EQ in the study site for a situation i.

EQ$_{rsi}$: EQ in the reference sites for the situation i.

li: Coastal length in the study coast for a situation i.

The calculations of RC for the Lebanese coast were performed using the reference values calculated in the Lebanese proposed reference area, Nakoura (see results section), the Northwestern (NW) Mediterranean RC proposed in the first application of the CARLIT method (calculated in Corsica and Balearic Islands, Ballesteros et al., 2007, Table 3) and the Adriatic ones (calculated along Croatian coasts, Nikolić et al., 2013, Table 4). Class boundaries adopted are the same than previous studies (Ballesteros et al., 2007; Nikolić et al., 2013; Bermejo et al., 2013; Blanfuné et al., 2016a,b; Blanfuné et al., 2017): 0.75 for the high/good boundary, 0.6 for the good/moderate, 0.4 for the moderate/poor and 0.25 for the poor/bad.

2.3. Data analysis

In order to define which geomorphological features mostly influenced the distribution of macroalgal communities, a BEST analysis (Clarke and Gorley, 2006) was applied by combining each geomorphological feature and community category in the surveyed stretches of coast. The number of output geomorphological variables in the BEST analyses was limited to two. A non-metric multidimensional scaling (nMDS) was performed on the biological data, after calculation of the Bray-Curtis similarity matrix, separately for the two selected geomorphological features and for each stretch of coast. In order to better investigate multivariate patterns among stretches and macroalgal assemblages along the Lebanese coast, a Factorial Correspondence Analysis (FCA) was performed on biological data, independently on the GRS. PRIMER 6 software package (Clarke and Gorley, 2006) and XLStat were used for statistical analyses.

2.4. Relationship of CARLIT index with anthropogenic pressures

The Land Use Simplified Index (LUSI; Flo et al., 2011), the Modified LUSI index (MA-LUSI-WB; Torras et al., 2015) and the Human Activities and Pressures Index (HAPI; Blanfuné et al., 2017), were used to analyze the relation between the CARLIT assessment of Ecological Status and the anthropogenic pressures. For each stretch of the surveyed coastline, land use category (urban, agricultural, industrial, population and artificial land) was assessed within 1500 m from the considered coastline using institutional (Lebanese Ministry of Environment) and QGIS data as follows:

$$\text{LUSI} = (\text{Urban score} + \text{Agricultural score} + \text{Industrial score} + \text{Typology score}) \times \text{Confinement}$$

Where Urban, Agricultural and Industrial represent the individual scores of the three land uses, typology represents the presence of sewage outfalls, commercial harbors, aquaculture or freshwater input and the Confinement represents a correction number depending on the shape of the coast (high for concave, low for convex). In our study the confinement correction number was not applied as it was assumed that the Lebanese coast is homogeneous and can generally be approximated to a line (confinement correction number = 1).

The MA-LUSI-WB index of the considered area was calculated by adding i) the number of inhabitants and ii) the percentage of artificialized coast, to the LUSI index results for each surveyed stretch of coast (Torras et al., 2015). It is expressed by the formula:

$$\text{MA} - \text{LUSI} - \text{WB} = \text{LUSI} + \log\left(\frac{\text{Inhabitants}}{\text{Coastline length}}\right) + \left(\frac{\text{Length of artificial structure}}{\text{Length of rocky coastline}}\right)$$

The HAPI index was applied according to Blanfuné et al. (2017): five land use pressures (urban, industrial, agriculture, artificialization and freshwater) were given a score (Ps_i) and a linear correlation was performed to define the coefficient of correlation (r) between the pressures factors and the EQRs results for each stretch of coast (the EQR based on the Lebanese RC calculated in Nakoura were applied). Finally, the result was divided by an annual seawater turnover score (TS = 0.8) that is the same for the whole Lebanese coastal zone, characterized by torrential rivers uniquely. The HAPI index is given by the following formula:

$$\text{HAPI} = \sum \frac{\text{Psi}^{*}\ \text{ri}}{\text{TS}}$$

The linear correlation between LUSI and MA-LUSI pressures index and the CARLIT index results in each stretch of coast was performed. No correlation was assessed with the HAPI index, which already includes the ES values in the calculations.

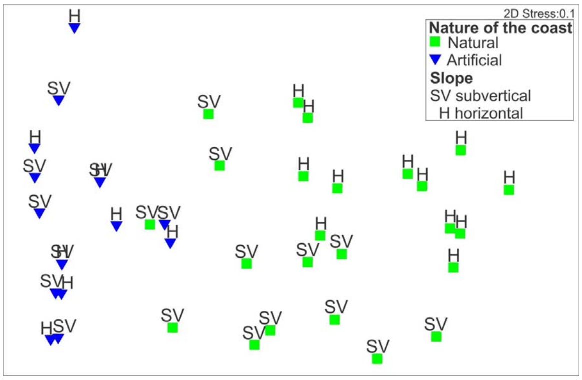

Fig. 3. Non-metric multi-dimensional scaling (nMDS) analysis on the community categories, in function of the 4 Geomorphological Relevant Situations, independently on the stretch of coast.

3. Results

The surveyed stretches of coast (Fig. 2) represent about 75% of the entire coastline (164 km at a scale of 1:5000). The BEST analysis applied on the combination of the geomorphological features selected, showed the highest correlation between macroalgal community categories (r = 0.380) and the couple of geomorphological features "nature of substrate" (natural/artificial) and "slope" (horizontal/subvertical). Consequently, four different "Geomorphological Relevant Situations" (GRS) were obtained from the combination of these two most relevant geomorphological features (Table 5). The MDS performed on the community categories in function of the four GRS shows a clear segregation of points (Fig. 3), independently of the studied stretch of coast. On the basis of the 4 GRS obtained by the BEST analyses, corresponding EQ values were calculated on the unique possible reference area (Nakoura), as reported in Table 5.

The assessment of the ES using the Lebanese RC proposed in this study (calculated in NAK), ranged from 0.16 in Beirut and 0.64 in ADL (Table 6, Fig. 4), with an average value of 0.44. The ES values calculated using the NW Mediterranean (Ballesteros et al., 2007) and Adriatic (Nikolić et al., 2013) RC are significantly and strongly correlated with the Lebanese results (respectively $R^2 = 0.93$ for Lebanese versus Adriatic-based values, $R^2 = 0.96$ for Lebanese versus North-West Mediterranean-based values, Fig. 5), even if these ES values are consistently lower than the Lebanese ones. A very high correlation is found between the ES values calculated with Adriatic versus NW Mediterranean-based values ($R^2 = 0.99$, Fig. 5).

Concerning the classification in ES classes (Fig. 4), the use of Lebanese RC calculated in NAK allowed the classification of 3 stretches of coast in the good ES class (ADL, BAR, CHE), 5 in the moderate (BAT, SAK, TYR, SAA, TAB), 2 in the poor (SAI, JBE) and one in the bad class (BEI). Based on the NW Mediterranean RC, 2 stretches were classified in good, 4 in moderate, 3 in poor and 3 in bad ES classes, while based on the Adriatic values 1 site was classified in good, 3 in moderate, 5 in poor and 3 in bad ES classes. Class agreement among the results of the three calculations was relatively low, with 4 matches out of 11 between the results based on Lebanese versus NW Mediterranean RC (1 good, 2 moderate and 1 bad), and no matches between results based on Lebanese versus Adriatic RC. On the contrary, 9 out of 12 matches were

Table 6
Ecological quality and human pressures. EQR and ES CARLIT values calculated in the 12 stretches of the Lebanese surveyed coastline, under the three different reference conditions (RC) considered (Lebanese, this study, North-West Mediterranean, Ballesteros et al., 2007, and Adriatic,). Values of LUSI index are according to Flo et al. (2011), MA-LUSI according to Torras et al. (2015) and HAPI according to Blanfuné et al. (2017) corresponding to the 12 stretches of the Lebanese coastline.

Stretches	Name	Length (m)	Lebanese RC (calculated in NAK)		NW Mediterranean RC (Ballesteros et al., 2007)		AdriaticRC (Nikolić et al., 2013)		LUSI	MA-LUSI	HAPI[a]
			EQR	ES	EQR	ES	EQR	ES			
NAK[*]	Nakoura	9500	1	High	0.69	Good	0.61	Good	1	1.3	–
ADL	Adloun	14300	0.64	Good	0.61	Good	0.54	Moderate	3.0	3.1	1.9
BAR	Barbara	6600	0.61	Good	0.57	Moderate	0.50	Moderate	2.2	1.3	2.0
CHE	Chekaa	5500	0.60	Good	0.48	Moderate	0.42	Moderate	3.3	2.5	3.0
BAT	Batroun	6950	0.53	Moderate	0.42	Moderate	0.37	Poor	7.0	6.8	2.0
SAK	Saksakiyé	8500	0.49	Moderate	0.38	Poor	0.33	Poor	5.1	5.7	4.7
TYR	Tyr	5450	0.47	Moderate	0.41	Moderate	0.38	Poor	3.7	4.7	2.6
SAA	Saadiyet	2900	0.42	Moderate	0.32	Poor	0.28	Poor	5.0	4.7	3.0
TAB	Tabarja	8950	0.41	Moderate	0.31	Poor	0.27	Poor	6.0	5.1	3.0
SAI	Saida	5050	0.28	Poor	0.20	Bad	0.15	Bad	8.7	10.5	3.8
JBE	Jbeil	5650	0.27	Poor	0.21	Bad	0.18	Bad	13.0	14.1	4.0
BEI	Beirut	8750	0.16	Bad	0.12	Bad	0.13	Bad	26.0	27.6	5.9

[*] Reference area.
[a] EQR values under Lebanese RC.

recorded when comparing results based on North-Western Mediterranean and Adriatic RC.

The pressure indexes LUSI, MA-LUSI and HAPI calculated in the 12 studied stretches of coast (Table 6) showed maximal values, corresponding to highest human impacts, in BEI area (LUSI: 26.0, MA-LUSI: 27.6 and HAPI: 5.9) and the lowest, corresponding to low human pressure, in NAK (LUSI:1, MA-LUSI:1.30, HAPI not calculated, as the EQR value calculated in the reference area is 1).

The ranking of human pressures scores is not always matching the ES ranking, but the linear correlation performed between the ES calculated with the three different RC and LUSI and MA-LUSI pressure indexes (Fig. 6), always highlighted significant strong relationships (Lebanese reference values: $n = 11$; ES/LUSI $r = 0.85$, $p < 0.05$; ES/MA-LUSI, $r = 0.87$, $p < 0.05$; NW Mediterranean reference values: $n = 12$; ES/LUSI $r = 0.79$, $p < 0.05$; ES/MA-LUSI, $r = 0.79$, $p < 0.05$; Adriatic reference values: $n = 12$; ES/LUSI $r = 0.76$, $p < 0.05$; ES/MA-LUSI, $r = 0.76$, $p < 0.05$). A more detailed analyses of the ES and the relationships with the major pressure typologies (urban, industrial, agricultural, coastal artificialization, freshwater inputs), shows a high negative correlation with the urban pressure (Table 7), followed by artificialization of the coastline, freshwater inputs (including rivers and sewage outfalls) and industrial pressure. The correlations with agricultural pressure and rivers were, on the contrary, not significant.

The cartographic approach of the CARLIT method provides interesting insights on the distribution and conservation status of target communities. Large brown algae (*Cystoseira* and *Sargassum* species) covered the 31.8% of the surveyed Lebanese coastline (see detailed distribution of these target species in Fig. 7). Other less sensitive photophilic algae, such as species belonging to the orders Dictyotales and Sphacelariales or to the *Laurencia* complex group represented the dominant community in 25.9% of the coastline, while erect Corallinales represented the dominant communities in 19.0% of the coast. Green algae and Cyanobacteria, usually found in highly disturbed coasts, covered 23.1% of the surveyed coastline (respectively 18.7% and 4.3%).

The Factorial Correspondence Analyses (FCA) performed on the community categories shows a good association of the sites and the dominant categories (80% of total variance represented by the first two axes, $p < 0.05$, Fig. 8). Cyanobacteria-dominated communities are associated to BEI area, characterized by a bad ES; Green algae, Tolerant Photophilic algae and Erect Corallinales are associated to stretches of coast with a moderate [e.g. Tabarja (TAB), Saadiyet (SAA), Saksakiyé (SAK) and TYR] to poor [e.g. Saida (SAI) and Jbeil (JBE)] ES; Ubiquitous Photophilic algae (UPHO) and *Cystoseira* communities are associated to stretches of coast characterized by good ES [e.g. Chekaa (CHE), Barbara (BAR), Adloun (ADL), Batroun (BAT) and to the reference area (Nakoura; NAK)].

4. Discussion

The present application of the CARLIT (CARtography of LITtoral rocky-shore communities) index (Ballesteros et al., 2007) along

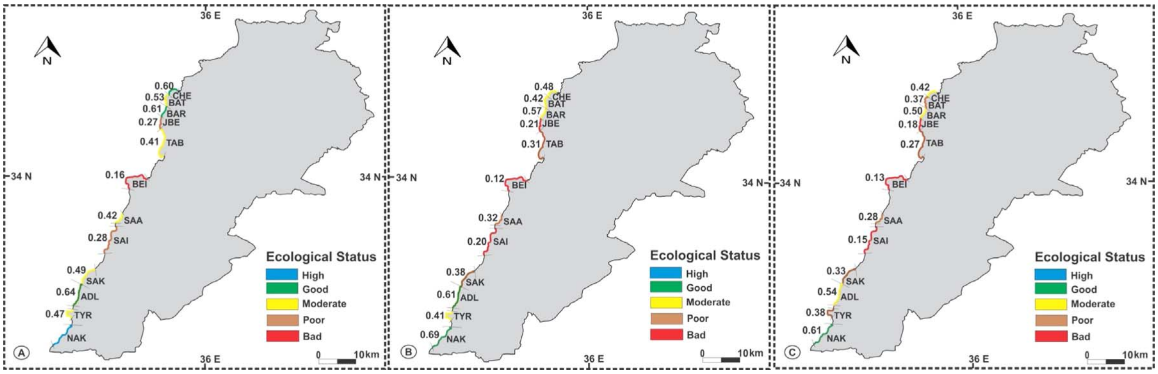

Fig. 4. Ecological quality Ratio (EQR) and Ecological status (ES) of the 12 studied stretches of coasts. EQR values calculated under the: A) Lebanese RC (calculated in Nakoura, assuming its ES as high), B) NW Mediterranean RC (Ballesteros et al., 2007) and C) Adriatic RC (Nikolić et al., 2013).

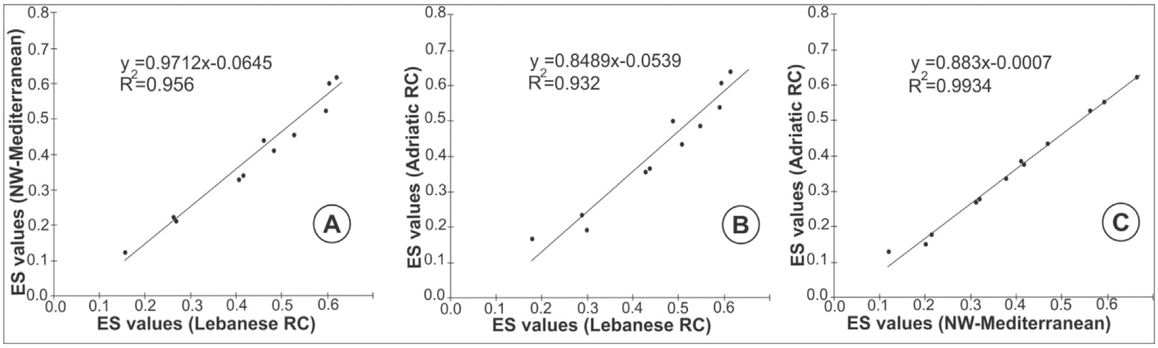

Fig. 5. Relation between the EQR values calculated under the three considered CARLIT RC: A) Lebanese RC, calculated in Nakoura, B) NW Mediterranean RC (Ballesteros et al., 2007) and C) Adriatic RC (Nikolić et al., 2013).

Lebanese coasts represents the first assessment in the Levantine Sea of the Ecological Status (ES) of rocky shores, following the principles of the WFD 200/60/EU. The Lebanese coastline is currently subjected to several, often uncontrolled, human impacts, such as a fast urban development (MOE/UNDP/ECODIT, 2011), sewage outfalls (Abboud-Abi Saab et al., 2012), industries (e.g. asbestos mines and factories producing phosphate fertilizers), overfishing by the use of illegal methods (Lteif, 2015) and an increasing spread of invasive lessepsian species (Bitar et al., 2017). Therefore, coastal ecosystems have suffered, in the recent decades (MOE/UNDP/ECODIT, 2011), important changes in species diversity and abundance and it is worth noting that deep water activities related to the oil and gas drillings have recently started. In counterpart, the awareness on the importance of reaching and maintaining a good ES is rising and poses a major challenge for setting up institutional monitoring programs. The Lebanese coastline is mostly characterized by rocky shores (70%, Kouyoumjian and Hamzé, 2012), making the indexes based on macroalgal communities very adequate for the assessment of the ES. The CARLIT index was chosen because it is a fast, non-destructive and simple method that does not require further analyses in the laboratory, allowing wide scale studies: in the present study, 164 km of the Lebanese coastline were assessed.

The analysis of macroalgal community categories in function of the geomorphology of the coast revealed that coastal slope (e.g. horizontal/subvertical/vertical) and the nature of the substrate (natural/artificial) were the most relevant geomorphological features inducing changes in macroalgal assemblages. Nikolić et al., 2013 and Lasinio et al. (2017) proved that, in absence of anthropogenic pressures, the coastline slope could be the most relevant geomorphological feature in determining the distribution of shallow macroalgal communities such as *Cystoseira* species of the infralittoral fringe. The same studies (Ballesteros et al., 2007; Lasinio et al., 2017; Nikolić et al., 2013) also proved that the nature of the substrate (artificial versus natural) is a major source of variation for macrolagal communities. Such result is in agreement with a large amount of scientific literature on this topic, highlighting differences between artificial and natural substrates due to several interacting abiotic factors (i.e. reduced heterogeneity, unnaturally high anthropogenic disturbances) and biotic factors (i.e. increased herbivory and invasions) (Bulleri and Chapman, 2010; Ferrario et al., 2016; Firth et al., 2014), rather than to the physical features of each substrate. This generally results in less complex and less performant macroalgal assemblages on artificial substrates (i.e. Perkol-Finkel et al., 2006). Indeed, it is worth noting that in the Mediterranean Sea, *Cystoseira* species are rarely observed on artificial substrates (Gianni, 2016; Thibaut et al., 2014b), and likely it occurs only when other ecological requirements of

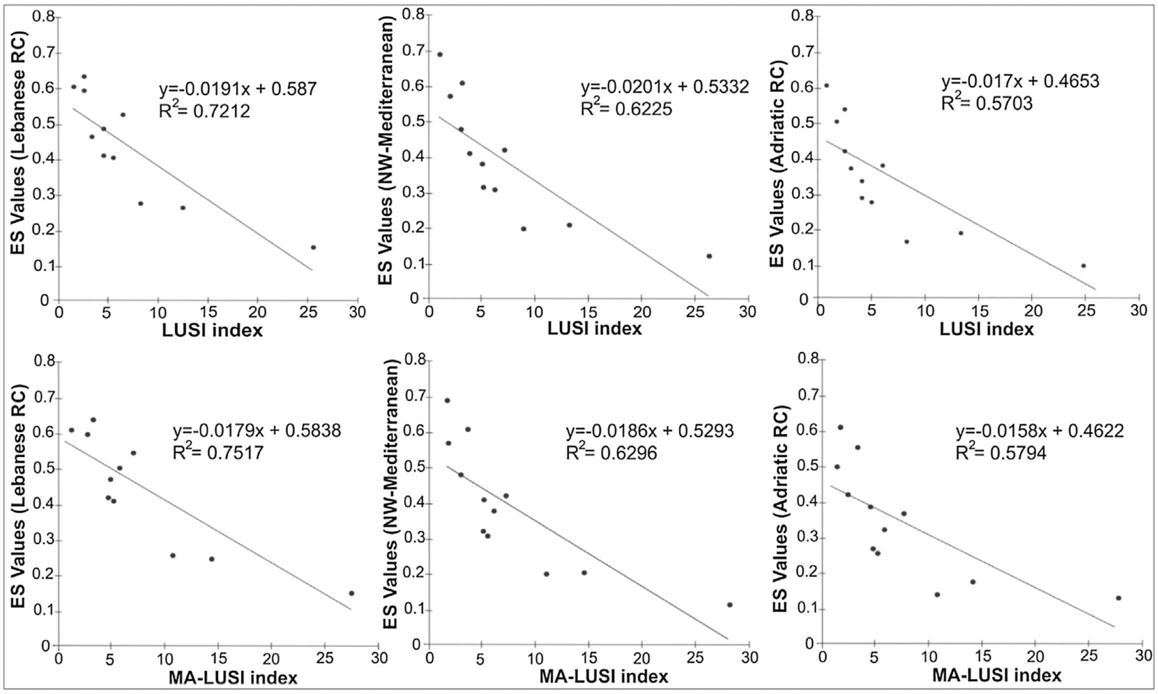

Fig. 6. Relation between the EQR values obtained by the three CARLIT RC (Lebanese, NW Mediterranean and Adriatic) and corresponding LUSI and MA-LUSI indexes of human pressures.

Table 7
CARLIT calculations.

	Pressure	Urban	Industrial	Agriculture	Artificialization	Freshwater (rivers)	Freshwater (rivers and sewage outfalls)
Lebanese RC	r	−0.819	−0.577	0.123	−0.750	−0.170	−0.720
	p-value	0.002	**0.043**	0.745	**0.007**	0.613	**0.012**
NW Mediterranean RC	r	−0.851	−0.610	0.102	−0.743	−0.169	−0.669
	p-value	**0.000**	**0.035**	0.750	**0.005**	0.599	**0.010**
Adriatic RC	r	−0.838	−0.584	0.113	−0.709	−0.153	−0.698
	p-value	**0.001**	**0.040**	0.720	**0.004**	0.698	**0.012**

Values of the correlation coefficient (r) from correlation matrix between the land uses pressures and EQR data for all the stretches of coast according to the three CARLIT methods (Significant correlation at $p < 0.05$).

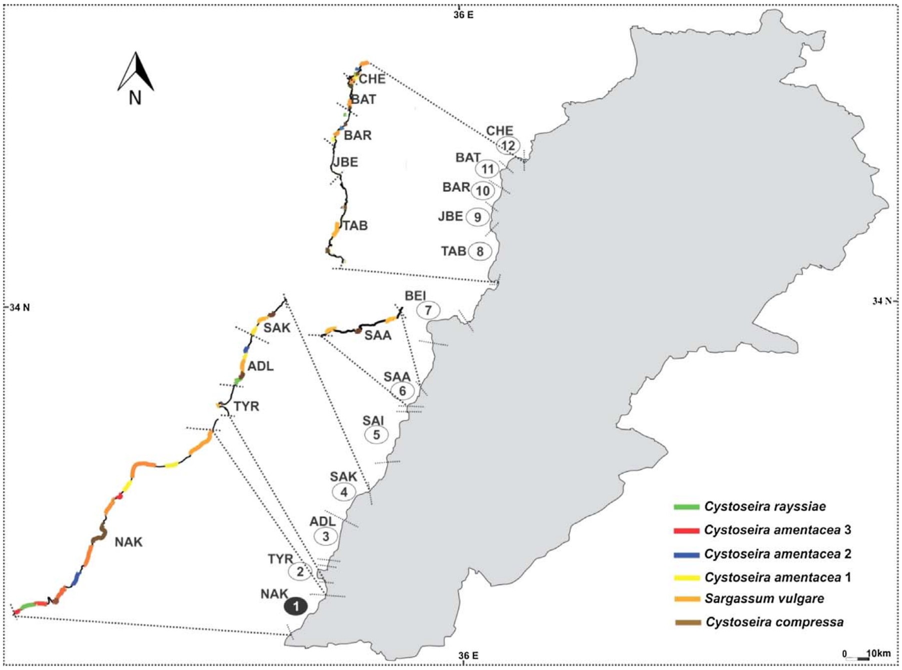

Fig. 7. The distribution of fucoids (*Cystoseira* and *Sargassum* species) along the Lebanese surveyed coastline.

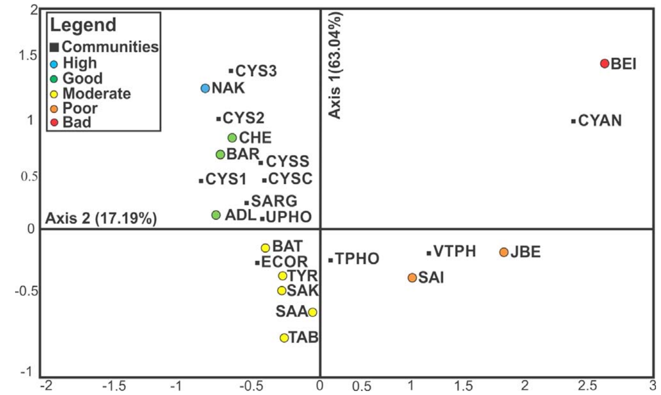

Fig. 8. Ordination of surveyed coastline stretches (n = 12) and community types derived from Factorial Correspondence Analysis (for abbreviations, see Tables 1 and 6).

the species, such as good water quality, are guaranteed. This is in agreement with the results of the present study, in which no fucoids were recorded on artificial substrates.

In order to provide appropriate Ecological Quality Ratio (EQR) calculations for the Levantine Sea, characterized by more oligotrophic waters and lower species diversity than other Mediterranean areas (Martin et al., 2006), a search for potential reference sites was performed accordingly to the criteria applied in the framework of the MEDGIG (Mediterranean Geographical Intercalibration Group) for the implementation of the WFD 2000/60EU. Ideally several reference sites should be selected in order to avoid biases due to the geographic position of the reference sites versus the studied sites, but unluckily this was not possible in Lebanon, as only one site included in the cartography (Nakoura) was compliant with the MEDGIG RC criteria. Based on the Lebanese RC, the results showed that, excluding the reference site Nakoura covering 10.9% of the surveyed coast, 29.9% of the coast was assessed as belonging to the good, 37.1% to the moderate, 12.1% to the poor and 9.9% to the bad ES. This result is particularly relevant when considering the principle of the WFD to reach and maintain a good ES. A comparison with the values calculated in the Northwestern Mediterranean (Ballesteros et al., 2007) and Adriatic reference sites (Nikolić et al., 2013) allowed to highlight relatively good correlations of EQRs, but some mismatches in the ES classes' agreement. This is due to the strict boundaries (no error assessment is allowed in classes attribution) and it highlights that appropriate reference conditions have to be chosen according to the area of study (Borja et al., 2012; Gaspar et al., 2012; Van Hoey et al., 2010). The extreme southern part of Lebanon (from NAK to SAK) is characterized by a good to moderate ES and it includes the most "pristine" zone, where the RC were calculated (NAK) and a good ES stretch (ADL). Agricultural discharges, polluted river runoff (e.g. Qasmiyé river) and solid wastes, in addition to illegal domestic/urban outfalls (Abboud-Abi Saab et al., 2008) are most likely responsible of the moderate ES range of some stretches in the southern part of Lebanon (SAK, TYR). The southern and central zones of Lebanon, from SAI to BEI, are characterized by a moderate to bad ES. SAI has been affected by a thermal plant oil spill in 2006 (Khalaf et al., 2006) concerning about 140 km of coastline (from SAI, to JBE), likely responsible, together with urban and industrial influence, of the poor ES. The capital Beirut is the largest town of the Lebanese coastline. In Beirut water body the coastline urbanization is remarkable (> 450.000 inhabitants), the level of several pollutants in the sediments coming from industrial and urban wastewater sewages is high (Abi-Ghanem et al., 2016), it is affected by the runoff of the heavily polluted Beirut river (Abboud-Abi Saab et al., 2012), by an intense maritime traffic (and consequent pollution from ships) and by large seafront dumpsites, altogether being the causes of the observed bad ES range. The northern zone (from TAB to CHE) is characterized by a good to moderate ES range, except for JBE, characterized by a poor ES, as it is heavily affected by urban and touristic activities (Byblos is a highly frequented cultural heritage destination), as well as intensive agricultural practices. In the same zone, several pollutants (oils and other noxious and hazardous substances) are accumulated in storage tanks with regular rejects in the seawater. Other stretches of the northern Lebanese coastline are characterized by a moderate ES (e.g. TAB and BAT) due to industrial activities [e.g. thermal and chemical discharges (Fakhri et al., 2008) and polluted river runoff (e.g. Naher Ibrahim; Abboud-Abi Saab et al., 2008)]. BAR and CHE are characterized by a good ES. Rocky shallow communities, generally dominated by macroalgae, are known to be affected by several anthropogenic impacts (Crowe et al., 2000; Milazzo et al., 2004). The results of the present study shows that C-ARLIT-EQR results are well correlated to human pressure indicators (LUSI, MA-LUSI), in agreement with previous studies (Bermejo et al., 2013; Blanfuné et al., 2017; Nikolić et al., 2013; Torras et al., 2015). The present study allowed to show how urbanization, including artificialization of the coastline and sewage, are mostly affecting the very shallow communities, together with industrial impacts, as observed in other Mediterranean areas (Arévalo et al., 2007; Cavallo et al., 2016; Mangialajo et al., 2007; Pinedo et al., 2013). As a result, canopy-forming dominated assemblages tend to be lost as predicted (Benedetti-Cecchi et al., 2001; Mangialajo et al., 2008; Mineur et al., 2015; Thibaut et al., 2005) and to be replaced by less complex communities, characterized by stress tolerant, ubiquitous, opportunistic and ephemeral macroalgal species (Airoldi et al., 2014).

The CARLIT methodology also allows to perform a detailed cartography of the communities along the coastline. Such an assessment had never been performed before along the Lebanese coastline (and to our knowledge in neither part of the Levantine Sea). In the Mediterranean Sea, the highest complexity of shallow macroalgal assemblages is represented by fucoid (*Cystoseira* and *Sargassum*) forests, generally considered locally threatened (Airoldi and Beck, 2007; Mineur et al., 2015; Strain et al., 2014). The application of the CARLIT method on the Lebanese coast provides an accurate description of the distribution and abundance of *Cystoseira* and *Sargassum* shallow forests. Four species of fucoids have been recorded in the present study: *Cystoseira amentacea*, *Cystoseira compressa*, *Cystoseira rayssiae* and *Sargassum vulgare*. It is worth noting that *Cystoseira rayssiae*, endemic from the Levantine Sea (Ramon, 2000) has been recorded here for the first time along Lebanese coasts. *Cystoseira rayssiae* has been recorded in 4 stretches (NAK, ADL, BAR, CHE), covering 2% of the coast. *Cystoseira amentacea* has been recorded, in different abundance classes in 5 stretches (NAK, ADL, SAK, BAR, CHE), covering 9% of the coast. Most of the *Cystoseira amentacea* presence was recorded as isolated individuals, showing potentially suffering forests. Patches were abundant in 4 stretches (ADL, SAK, BAR, CHE), while continuous belts were recorded uniquely in NAK, the only site complying with the European criteria of a pristine area for the measure of RC. According to this study, *C. amentacea* was absent close to coastal artificialized areas (harbors and land reclamation zones) and severely polluted areas by urban and industrial sewage, as also reported in other studies (Thibaut et al., 2005). *Cystoseira compressa* and *Sargassum vulgare* were more abundant, present in all the stretches except SAI, BEI and JBE covering respectively 4% and 17% of the coast, being absent uniquely in harbors and highly impacted areas. This is due to the fact that these species are less sensitive than most *Cystoseira* species (Mangialajo et al., 2012; Thibaut et al., 2005) and they have a higher recovery potential, due to their reproductive strategy (Guern, 1962; Steneck et al., 2002) involving drift of fertile portion of the ramifications and better dispersal. Since no long-term data series for benthic macrophytes are available for the Lebanese coastal waters, the present study represents the first assessment of the present state of macroalgal assemblages along the Lebanese coastline, allowing a baseline for monitoring their evolution in the future. This is highly important since loss of algal forests has already been recorded in several areas of the Mediterranean Sea (Airoldi and Beck, 2007; Mineur et al., 2015; Thibaut et al., 2005) where historical data were present, but it is widely accepted that this loss may have happened without being noticed, due to the lack of past or even recent distribution data. For these reason, conservation and, when appropriate, restoration of marine forests should be seriously considered in several coastal zones (Gianni et al., 2013; Perkol-Finkel and Airoldi, 2010). The present study highlights that fucoid forests are still present in several Lebanese coasts and monitoring and conservation of such assemblages should be a priority in the framework of coastal zone management (Gianni et al., 2013). This is particularly important considering that the Lebanese coastline is under multiple stressors and about 32% of the surveyed coastline is already highly modified and artificialized. In addition, the entire Levant Basin is experiencing changes in marine assemblages at a very fast rate, due to the high impact of anthropogenic activities and the rise of seawater temperature (Doney et al., 2011), often associated with a continuous income of invasive species from the Suez Channel (Bitar et al., 2017; Galil et al., 2015). It is therefore of paramount importance to perform large scale assessment of marine assemblages in this Basin, in order to understand the magnitude of such changes and provide baselines for future assessments. The successful application of CARLIT method for the first time in a country of the Levantine Sea gives important insights on the ecological state of its coastal waters, and on the evolution of priority assemblages as marine forests of large brown seaweeds. Several advances have been performed in the evaluation of water masses at the European level (Birk et al., 2012; Hering et al., 2010), resulting in a potential recent improvement of the water quality (Borja et al., 2010; Pinedo et al., 2013). To go beyond this approach it would be important to include in these studies non-EU countries, such as Lebanon, in order to improve the ecological status at the Mediterranean level.

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