Assessment of the CARLIT methodology in the Mediterranean rocky water bodies

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The CARLIT method for the assessment of the ecological quality of European Mediterranean waters: Relevance, robustness and possible improvements

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A B S T R A C T

The application of the European Union (EU) Water Framework Directive (WFD) requires the assessment of the ecological status (ES) of coastal waters in order to detect environmental changes and implement management plans to prevent their further deterioration. The ES of a water body (WB) has to be assessed on the basis of the status of several biological indicators, referred to as biological quality elements (BQE), such as phytoplankton, macroalgae, seagrasses, macroinvertebrates and fish. We present the most extensive assessment ever undertaken of the ES of Mediterranean waters, by means of the CARLIT index, the most widely used index for the Mediterranean Sea. This index is based on the Ecological Quality Ratio (EQR) between a measured value of Ecological Quality (EQ) and a value corresponding to a reference site. This assessment is based on an extensive field study, covering the whole of the Mediterranean French coasts (including Corsica), 40 WBs and ~2 970 kilometres of shore (at a 1/2 500 scale). The original Ballesteros CARLIT method is compared to the Nikolić modified method, and we have undertaken the challenge of developing an alternative new simplified CARLIT method. This simplified method, which requires less expert judgement, is easier to implement by local authorities, and provides results similar overall to those of the original method. Previous attempts, if any, to correlate EQRs with anthropogenic stressors (through pressure indices) were mainly based upon land uses or on comprehensive lists of stressors, some spatially very sporadic, temporally highly variable, non-representative of the WB and with the impact poorly established on species and communities. To date, the LUSI (Land Uses Simplified Index) and the MA-LUSI-WB have been the most widely used pressure indices. Here, we propose a new pressure index (HAPI) taking into consideration the possible shortcomings of previous indices. It takes into account the actual pressures at community levels considered by the CARLIT method. It accounts well for the EQR values of the study area, as evidenced by the high correlation coefficient between EQRs and HAPI, better than that of the other pressure indices. The present study provides a comprehensive view of the ES of the French Mediterranean coasts. Surprisingly, the picture is far less cause for concern than expected, although this could result from an artefact due to the focus on superficial waters and habitats inherent to the CARLIT method. Where two successive assessments were performed (23 WBs, 2007–2010 vs 2012–2015), the results were similar, which stresses the robustness of the method and/or the relative stability over time of the overall ES of the WBs, and suggests that the successive assessments could be carried out at low frequency.

1. Introduction

The coastal shore is an area that is strongly influenced by anthropogenic pressures, e.g. the constant growth of the population and its socio-economic activities, including agriculture, fisheries and aquaculture, industry and tourism. Coastal marine ecosystems are heavily affected throughout the world. The impact on the

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environment is multiple and cumulative, including habitat destruction, overfishing, pollution, species introduction, sea-level rise and global warming. None of these pressures is isolated and their cumulative effects impact the coastal marine ecosystems and their ability to deliver ecological goods and ecosystem services (Worm et al., 2006; Halpern et al., 2008; Waycott et al., 2009).

Monitoring networks have been set up in order to better understand the putative impact of anthropogenic pressures on various biotopes (Mann, 2000). The European Union (EU) has introduced legislative measures to mitigate the impact on ecosystems of anthropogenic pressures. Since the early 1990s, the EU has adopted framework legislation to regulate the sustainable use of the environment, while protecting, and where necessary restoring, the good quality of the environment. In the framework legislation Birds and Habitats Directives (Council Directive 79/409/EEC, 1979 amended by Council Directive 2009/147/EC, 2009 and Council Directive 92/43/EEC, 1992), the EU established a list of rare and threatened species, and rare natural habitat types, which are protected in their own right (Member States), to designate a network of protected sites ('Natura 2000 sites'). While these Directives also took into account the marine realm, more recently the EU Marine Strategy Framework Directive, MSFD, (Council Directive 2008/56/EC, 2008) established a specific framework for conservation in the field of marine environmental policy. The application of the European Water Framework Directive, WFD (Council Directive 2000/60/EC, 2000) requires the assessment of the ecological status of coastal waters in order to detect environmental changes and implement management plans to prevent their further deterioration. This EU Directive recommends working on the basis of water bodies (WB). France has 11 523 surface WBs (rivers, lakes, transitional waters, and coastal waters) and 574 groundwater WBs. Of the 180 coastal WBs on French coastlines, only 47 are situated along the French Mediterranean coast: 33 between the Spanish border and the Italian border and 14 in Corsica (Ifremer, 2015). The ecological status of a WB has to be assessed on the basis of the status of several biological indicators referred to as Biological Quality Elements (BQE), such as phytoplankton, macroalgae, seagrasses, macroinvertebrates and fishes, and hydro-morphological and physico-chemical quality elements.

To assess the ecological status of coastal water bodies in the WFD, a wide range of biological indices using macrophytes as BQE has been developed along the Mediterranean coasts, such as CARLIT (CARtography LITtoral), CCO (Cover Characteristic species Opportunistic species), CFR (Calidad de Fondos Rocosos), EEI (Ecological Evaluation Index), E-MaQI (Expert-Macrophyte Quality Index), ICS (Index of Community Structure), MarMAT (Marine Macroalgae Assessment Tool), RICQI (Rocky Intertidal Community Quality Index), and RSL (Reduced Species List) (Panayotidis et al., 1999, 2004; Orfanidis et al., 2001, 2003, 2011; Simboura et al., 2005; Ballesteros et al., 2007; Buia et al., 2007; Mangialajo et al., 2007; Wells et al., 2007; Guinda et al., 2008, 2014a,b; Juanes et al., 2008; Orlando-Bonaca et al., 2008; Asnaghi et al., 2009; Azzopardi and Schembri, 2009; Iveša et al., 2009; Sfriso et al., 2009; Sfriso and Facca, 2011; Bermejo et al., 2012, 2013a,b; Díez et al., 2012; Neto et al., 2012; Nikolić et al., 2013; Ar Gall and Le Duff, 2014; Ferrigno et al., 2014; Ar Gall et al., 2016; Blanfuné et al., 2016). Most of them are based on sampling along transects or at a few stations along the coast (Mangialajo et al., 2007; Juanes et al., 2008; Asnaghi et al., 2009; Iveša et al., 2009; Bermejo et al., 2012; Neto et al., 2012; Nikolić et al., 2013; Guinda et al., 2014a,b). The CARLIT index (Ballesteros et al., 2007) is the only one to take into account the entire rocky coastline of a coastal WB. In addition, this index is the most widely used in the EU Mediterranean countries (Spain, France, Italy, Malta and Croatia) and in one non-EU country (Albania) (Ballesteros et al., 2007; Buia et al., 2007; Mangialajo et al., 2007; Omrane et al., 2010; Blanfuné et al., 2011; Sfriso and Facca, 2011; Bermejo et al., 2012, 2013a; Nikolić et al., 2013; Ferrigno et al., 2014; Blanfuné et al., 2016).

The CARLIT method is based upon the mapping of mid-littoral and upper infralittoral species and communities of rocky shores that are considered as good descriptors of the environmental water quality. Evidence on the effects of industrial and wastewater discharges have been widely reported for shallow species, highlighting different sensitivity levels for different coastal assemblages (e.g. Bellan-Santini, 1968; Arnoux and Bellan-Santini, 1972; Bellan and Bellan-Santini, 1972; Belsher and Boudouresque, 1976; Belsher, 1977; Chryssovergis and Panayotidis, 1995; Soltan et al., 2001; Terlizzi et al., 2002). Long-lived macrophytes such as *Cystoseira* spp. (Fucales, Phaeophyceae) are evidence of long, relatively disturbance-free periods and good water quality, in contrast to some ephemeral or opportunistic species that respond quickly to any environmental disturbances, such as the articulated red algae of the genera *Corallina* Linnaeus and *Ellisolandia* K.R.Hind & G.W.Saunders (Corallinales, Rhodophyta) and the mussel *Mytilus galloprovincialis* Lamarck, 1819 (Mytiloida, Mollusca), that are indicative of medium water quality, and some species of green algae such as *Ulva* spp., *Cladophora* spp. that usually characterize waters of poor quality (e.g. Fernandez and Niell, 1982; Thomas, 1983; Janssens et al., 1993; Orfanidis et al., 2001; Panayotidis et al., 2004; Arévalo et al., 2007; Ballesteros et al., 2007; Mangialajo et al., 2007; Cecchi et al., 2009; Maggi et al., 2009; Falace et al., 2010; Sfriso and Facca, 2011; Nikolić et al., 2013).

The relevance of biological indices has to be validated by putting them in correlation with the anthropogenic pressures acting in the study area, in order to establish the link between the ecological status of the coastal WB and the biological quality elements (BQE) used. All existing indices have been more or less correlated with pressure indices such as the LUSI Index (Land Use Sustainability Index), but the link has been assessed empirically and not clearly established, or not dealt with at all (Orfanidis et al., 2001, 2003, 2011; Mangialajo et al., 2003, 2007; Panayotidis et al., 2004; Simboura et al., 2005; Ballesteros et al., 2007; Buia et al., 2007; Juanes et al., 2008; Orlando-Bonaca et al., 2008; Azzopardi and Schembri, 2009; Iveša et al., 2009; Omrane et al., 2010; Bermejo et al., 2012, 2013a,b; Díez et al., 2012; Neto et al., 2012; Nikolić et al., 2013; Ferrigno et al., 2014; Guinda et al., 2014a; Ar Gall et al., 2016). Moreover, parameters used to determine the correlation with biological indices were often not relevant pressures for the species and communities considered. A relevant link requires that the considered pressures would have an actual impact on species or communities of interest, and would be quantifiable at the scale of a WB and for all the water bodies considered.

The aims of this study are i) to assess the ecological status of the water bodies of the French Mediterranean coasts by means of the CARLIT method, the first assessment undertaken over such an extensive shoreline (~2 970 kilometres), ii) to calculate the relationship between the CARLIT index and different, already-existing anthropogenic pressure indices, iii) to propose and to test a new index of anthropogenic pressures (HAPI), better correlated with the CARLIT index than previous pressure indices, iv) to discuss changes in the CARLIT index scores between two successive surveys (2007–2010 vs 2012–2015), and v) to discuss possible improvements to the CARLIT index, requiring less expert judgement and making it easier to implement by local authorities.

2. Material and methods

2.1. Study area and coastal water bodies

The CARLIT method only applies to coastal water bodies dominated by rocky shores where macrophytes can be used as BQE.

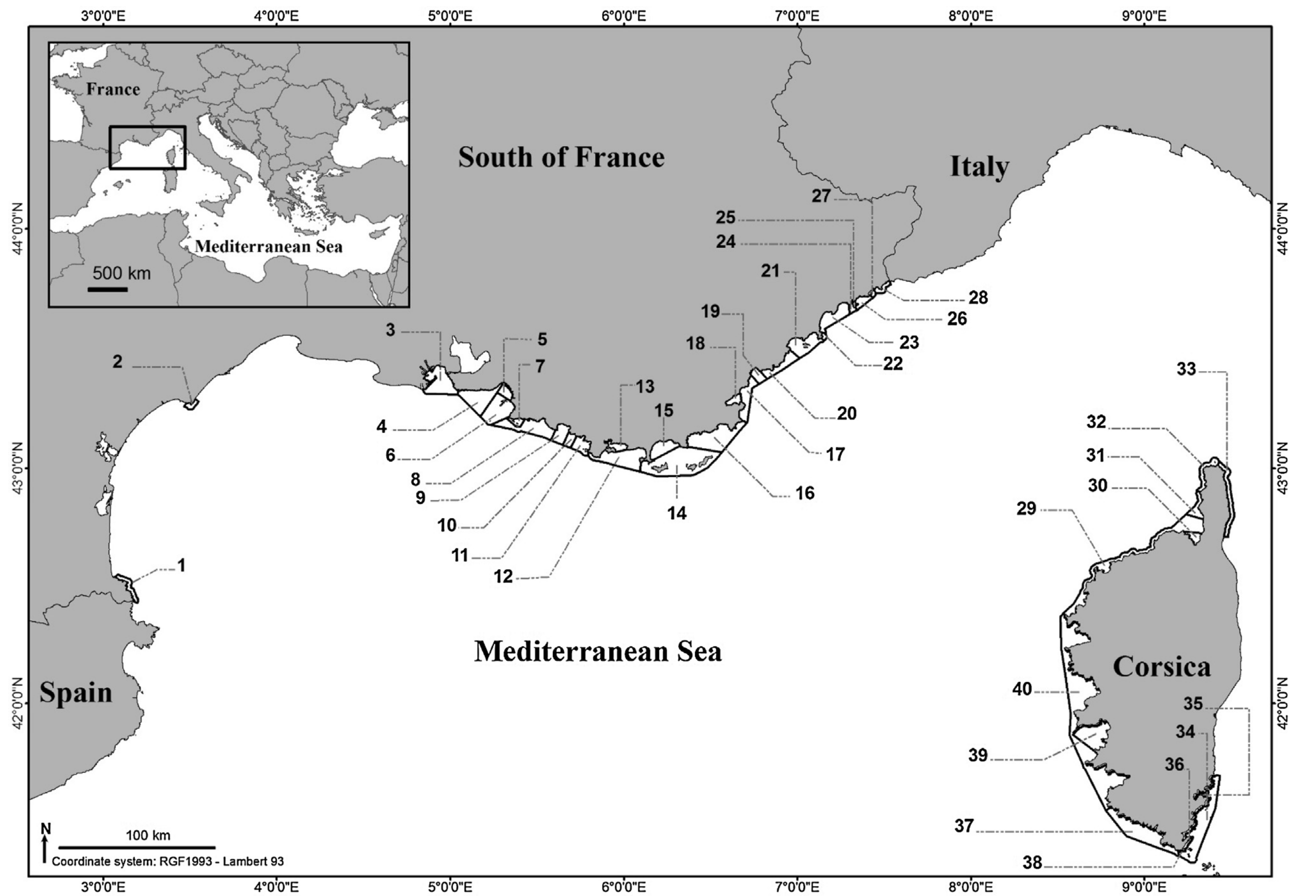

Fig. 1. Study area and coastal water bodies assessed. See Table 1 for the meaning of the numbers.

Of the 47 French coastal water bodies, 40 are concerned by this study; the others, which are mainly fringed by sandy shores, are not considered here (Fig. 1).

A first assessment of the considered water bodies was conducted in 2007 and 2008 on the mainland and in 2009 and 2010 in Corsica. A second assessment was run in 2012 and 2015 (Table 1).

2.2. Calculation of the CARLIT index

The ecological status of coastal water bodies in the study area was assessed by means of the CARLIT method (Ballesteros et al., 2007). The CARLIT method is based upon the mapping of geomorphological characteristics obtained in the field (slope, morphology and natural/artificial substrate) and some mid-littoral and shallow subtidal species and communities of the rocky shoreline.

In the present study, three methods of calculation of the CARLIT Index have been applied to the same data set and coastal water bodies: the classical method described by Ballesteros et al. (2007), the Nikolić et al. (2013) method and an alternative simplified method proposed here.

In the classical method (hereafter: original CARLIT method), six relevant geomorphological situations were distinguished according to the coastline morphology and natural/artificial substrates (Table 2). The species and communities taken into account, according to a decreasing level of sensitivity (from 20, very sensitive, to 1, not sensitive) to disturbance, are listed in Table 3.

For each geomorphological situation, the length of the coast occupied by each species or community was measured and the ecological quality value (EQ) was calculated using the formula:

$$EQ_{ssi} = \sum(l_j * SL_j) / \sum l_j$$

Where i is the geomorphological situation; EQ_{ssi} is the ecological quality value of the geomorphological situation i; l_j is the length of the coastline with the species or community j, SL_j is the sensitivity level of the species or community j (Table 3) and $\sum l_j$ is the total length of the coastline occupied by the geomorphological situation i.

According to the WFD, the ecological status of a coastal WB has to be expressed in terms of ecological quality ratios (EQR). This ratio indicates the relationship between the value of the biological parameters (here, species and communities) recorded for a given coastal WB and the value for these parameters under the reference conditions applicable to this water body.

The EQR (Ecological Quality Ratio) of a geomorphological situation of a coast is calculated as the ratio between the EQs measured (EQ_{ssi}) and the EQ of reference sites corresponding to the same 'geomorphological situation' with species and communities of highest sensitivity level (EQ_{rsi}) (Table 2). Therefore, the EQR of a coast corresponding to a coastal WB is calculated according to the following formula:

$$EQR = \left(\sum[(EQ_{ssi}/EQ_{rsi}) * l_i]\right) / \sum l_i$$

Table 1
The 40 coastal water bodies assessed by the CARLIT method and the sampling dates for each area (nra = not re-assessed). Between square brackets, English translation of the water body (WB) name and further geographical information, where necessary.

No	Administrative name of the WB (in French) [English translation]	First assessment	Second assessment
1	FRDC01 – Frontière espagnole – Racou plage [Spanish border – Racou beach]	2007	2012
2	FRDC02c – Cap d'Agde	2007	2012
3	FRDC04 – Golfe de Fos	2007	2012
4	FRDC05 – Côte Bleue [between Couronne and Pointe de Corbières]	2007	2015
5	FRDC06a – Petite Rade de Marseille [between Pointe de Corbières and Pointe d'Endoume, not including Frioul Islands]	2007	2012
6	FRDC06b – Pointe d'Endoume – Cap Croisette et îles du Frioul [between Pointe d'Endoume and Cap Croisette, including Frioul Islands and Planier Island]	2007	2012
7	FRDC07a – Îles de Marseille hors Frioul [Riou Archipelago: Maïre, Tiboulen de Maïre, Jarre, Jarron, Plane, Petit Congloué, Grand Congloué and Riou Islands]	2007	2015
8	FRDC07b – Cap Croisette – Bec de l'Aigle	2007	2015
9	FRDC07c – Bec de l'Aigle – Pointe Fauconnière	2008	2015
10	FRDC07d – Pointe Fauconnière – Îlot Pierreplane	2008	2015
11	FRDC07e – Îlot Pierreplane – Pointe du Gaou	2007	nra
12	FRDC07f – Pointe du Gaou – Pointe Escampobariou	2008	2015
13	FRDC07 g – Cap Cépet – Cap de Carqueiranne	2007	2015
14	FRDC07 h – Brégançon – Îles du Soleil [From Escampobariou to Cap de l'Esterel, and from Cap de Brégançon to Cap Bénat, excluding the inner gulf of Giens and including Porquerolles Island, Port-Cros Archipelago and Le Levant Island]	2007	nra
15	FRDC07i – Cap de l'Esterel – Cap de Brégançon	2008	nra
16	FRDC07 j – Cap Bénat – Cap Camarat	2008	nra
17	FRDC08a – Cap Camarat – Pointe des Issambres	2008	nra
18	FRDC08b – Golfe de Saint-Tropez	2008	2015
19	FRDC08c – Fréjus – Saint-Raphaël – Ouest de Sainte-Maxime [From west of Sainte-Maxime to Saint-Raphaël]	2008	2012
20	FRDC08d – Ouest Fréjus – Pointe de la Galère	2007	2015
21	FRDC08e – Pointe de la Galère – Cap d'Antibes	2008	nra
22	FRDC09a – Cap d'Antibes – Sud Port d'Antibes [From Cap d'Antibes to the south of Antibes harbour]	2007	nra
23	FRDC09b – Port d'Antibes – Port de commerce de Nice [From Antibes harbour to the commercial port of Nice]	2007	2012
24	FRDC09c – Port de commerce de Nice – Cap Ferrat [From the commercial port of Nice to Cap Ferrat]	2007	nra
25	FRDC09d – Rade de Villefranche [Bay of Villefranche-sur-Mer]	2007	2012
26	FRDC10a – Cap Ferrat – Cap d'Ail	2007	nra
27	FRDC10b – Cap d'Ail – Monte Carlo [From Cap d'Ail to the eastward border of the Monaco Principality]	2008	2012
28	FRDC10c – Monte Carlo – Frontière italienne [From the eastward border of the Monaco Principality to the Italian border]	2008	nra
29	FREC01ab – Sud Nonza – Punta Palazzu [From south of Nonza to Punta Palazzu]	2010	nra
30	FREC01c – Golfe de Saint-Florent	2009	2012
31	FREC01d – Canari	2009	2015
32	FREC01e – Ouest du Cap Corse [western coast of Cap Corse]	2009	nra
33	FREC02ab – Est du Cap Corse [eastern coast of Cap Corse]	2009	2015
34	FREC03ad – Littoral sud est de la Corse [southeastern coast of Corsica]	2010	nra
35	FREC03b – Golfe de Porto-Vecchio	2009	2012
36	FREC03c – Golfe de Santa Amanza	2009	nra
37	FREC03eg – Littoral sud-ouest [southwestern coast of Corsica]	2009	nra
38	FREC03f – Goulet de Bonifacio [the cove of Bonifacio, mainly occupied by the commercial port and marina]	2009	2012
39	FREC04ac – Golfe d'Ajaccio	2009	nra
40	FREC04b – Punta Senetosa – Punta Palazzu	2010	nra

Where i is the geomorphological situation; EQ_{ssi} is the EQ at the study site for the geomorphological situation i; EQ_{rsi} is the EQ at the reference sites for the geomorphological situation i; l_i is the coastal length occupied by the geomorphological situation i ($l_i = \sum l_j$) and $\sum l_i$ is the total length of the coastline of the coastal WB ($\sum li = \sum\sum l_j$).

The EQR is expressed as a numerical value between 0 and 1. The ecological status of a coastal WB is defined as follows:

EQR	Ecological status
1 to >0.75	High
0.75 to >0.60	Good
0.60 to >0.40	Moderate
0.40 to >0.25	Poor
0.25 to 0.0	Bad

Nikolić et al. (2013) developed a slightly modified CARLIT index for the eastern Adriatic Sea (hereafter: Nikolić method). The equations and the rationale are the same as described by Ballesteros et al. (2007). The differences lie in the relevant geomorphological situations (Table 4), in some species and communities, and in their sensitivity levels (Table 5).

Table 2
Geomorphological situations with their ecological quality values calculated under reference conditions (EQ_{rsi}). 'Low coast' means a cliff lower than 15 m; 'high coast' means a cliff higher than 15 m (from Ballesteros et al., 2007; Ballesteros pers. comm.).

Geomorphological situation (i)	Coastal morphology	Substrate	EQ_{rsi}
1	Decimetric blocks	Artificial	12.1
2	Low coast	Artificial	11.9
3	High coast	Artificial	8.0
4	Decimetric blocks	Natural	12.2
5	Low coast	Natural	16.6
6	High coast	Natural	15.3

In the present study, we propose another, alternative and simplified CARLIT index (hereafter: simplified CARLIT method). The relevant geomorphological situations identified by Ballesteros et al.

Table 3
Species and communities taken into account in the CARLIT Index (classical method), with their 'sensitivity level' (SL) according to Ballesteros et al. (2007), with their description in the study area.

Species and communities	Description in the study area	SL
Cystoseira mediterranea/amentacea 5	Continuous stands of *C. mediterranea* or *C. amentacea*	20
Cystoseira crinita	Stands of *C. crinita*	20
Cystoseira balearica	Stands of *C. brachycarpa*[a]	20
Other shallow *Cystoseira* species	Stands of *C. foeniculacea*, *C. barbata*, *C. spinosa* var. *tenuior*, C. *compressa* subsp. *pustulata*[b]	20
Posidonia reefs	Barrier and fringing reefs of *Posidonia oceanica* (Magnoliophyta)	20
Cymodocea nodosa	*Cymodocea nodosa* (Magnoliophyta) meadows	20
Zostera noltii	*Zostera noltei* (Magnoliophyta) meadows[c]	20
Lithophyllum byssoides rims	Bioconstructions of *L. byssoides* (Rhodophyta)	20
Cystoseira mediterranea/amentacea 4	Almost continuous stands of *C. amentacea* or *C. mediterranea*	19
Cystoseira mediterranea/amentacea 3	Abundant patches of dense stands of *C. amentacea* or *C. mediterranea*	15
Cystoseira mediterranea/amentacea 2	Abundant scattered plants of *C. amentacea* or *C. mediterranea*	12
Cystoseira compressa	Stands of *C. compressa* subsp. *compressa*	12
Cystoseira mediterranea/amentacea 1	Rare scattered plants of *C. amentacea* or *C. mediterranea*	10
Corallina elongata	Stands of articulated Corallinales without *Cystoseira* species[d]	8
Haliptilon virgatum	Stands of epiphytic articulated Corallinales without *Cystoseira*[e]	8
Mytilus galloprovincialis	*M. galloprovincialis* (mussel) beds without *Cystoseira*	6
Encrusting corallines	Communities of *Lithophyllum incrustans*, *Neogoniolithon brassica-florida* and other encrusting corallines (Rhodophyta)	6
Green algae	Stands of *Ulva* spp. and/or *Cladophora* spp. (Chlorobionta)	3
Blue green algae	Communities dominated by Cyanobacteria[f]	1

[a] *C. balearica* is a heterotypic synonym of *C. brachycarpa*.
[b] *C. spinosa* var. *tenuior* was not observed during the survey.
[c] *Zostera noltei* is the correct name for *Z. noltii*.
[d] Several species of articulated Corallinales, not distinguishable in the field, can occur in the Mediterranean Sea, e.g. *Ellisolandia elongata* (synonym: *C. elongata*), *Corallina caespitosa* and *C. officinalis*.
[e] *Haliptilon virgatum* is an epiphytic species not distinguishable in the field, if not collected, from other epiphytic articulated Corallinales such as *Jania* spp.
[f] Ballesteros et al. (2007) added the Chlorobionta *Derbesia tenuissima*; this species is not easy to see and impossible to identify in the field; we therefore did not consider it.

Table 4
Geomorphological situations with their ecological quality values calculated under reference conditions (EQ_{rsi}), from Nikolić et al. (2013). 'Low coast' means a cliff lower than 15 m; 'high coast' means a cliff higher than 15 m (from Ballesteros et al., 2007; Ballesteros pers. comm.).

Geomorphological situation (i)	Coastal morphology	Coastline slope	EQ_{rsi}
1	High coast	Horizontal	20.00
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

(2007) according to the coastline morphology and natural/artificial substrates, were not modified, except that only the last three relevant geomorphological situations were taken into account on the basis of the principle that any artificial substrate will tend to be colonized as a natural substrate over time (Table 2), although increased herbivory hinders the colonisation by *Cystoseira* spp. (Gianni, 2016). Likewise, some modifications were made regarding the communities mapped. The species and communities taken into account according to a decreasing level of sensitivity (from 20, very sensitive, to 1, not sensitive) are listed in Table 6. In contrast to Ballesteros et al. (2007), *Cymodocea nodosa* meadows, *Zostera noltei* meadows, *Posidonia oceanica* reefs and *Lithophyllum byssoides* rims are no longer taken into account for the calculation. Except for these changes, the calculation method is still the same.

2.3. Calculation of the anthropogenic pressure indices

2.3.1. The land uses simplified index (LUSI)

The LUSI index was designed as a basis for analysing the relationship between the CARLIT results and the anthropogenic pressures. This index is based on a combination of factors that reflect continental influences in the coastal water bodies: (i) land uses (urban, industrial, and agricultural), (ii) the vicinity and the typology of rivers, and finally (iii) the shape of the coast (concave, convex or straight). The LUSI uses publicly available data. The calculation method of LUSI is described in Flo et al. (2011):

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

The scores were calculated taking into account a 1.5 km inland strip, within the limits of each coastal WB, on a Corine Land Cover map based on 2006 data (Corine Land Cover, 2006).

2.3.2. The MA-LUSI-WB index

Torras et al. (2016) added two new descriptors to the calculation of the LUSI index: the population pressure and the artificialization rate of the rocky shore. The population pressure was estimated as the logarithm of the total population in the littoral municipalities divided by the length of the coastline. The artificialization rate was calculated as the ratio of the total length of artificial structures divided by the length of rocky shores.

The MA-LUSI-WB index of a coastal WB was calculated as follows:

$$MA-LUSI-WB = LUSI + \log(\frac{\text{Inhabitants}}{\text{Coastline length}}) + \frac{\text{Length of artificial structures}}{\text{Length of rockycoastline}}$$

2.3.3. The cumulative human impacts index

The Cumulative Human Impacts Index (CHII) was proposed by Holon et al., 2015. It is based upon a cumulative impact model, which takes into account 10 different pressures: man-made coastline, boat anchoring, aquaculture, urban effluents, industrial

Table 5
Species and communities taken into account for the calculation of the CARLIT Index, and their 'sensitivity level' (SL), according to Nikolić et al. (2013), with the description adapted to the study area.

Species and communities	Description in the study area	(SL)
Cystoseira spicata 3	Continuous stands of *C. amentacea* or *C.mediterranea*[a]	20
Cystoseira crinitophylla	Stands of *C. crinitophylla*	20
Cystoseira crinita	Stands of *C. crinita*	20
Cystoseira corniculata	Stands of *C. corniculata*	20
Cystoseira foeniculacea	Stands of *C. foeniculacea*	20
Coralline rims	Bioconstructions of *Lithophyllum byssoides*[b]	20
Cystoseira barbata	Stands of *C. barbata* without other *Cystoseira* species	16
Cystoseira spicata 2	Abundant patches of *C. amentacea*[a]	15
Cystoseira compressa	Stands of *C. compressa* without other *Cystoseira* species	12
Cystoseira spicata 1	Rare scattered plants of *C. amentacea* [a]	10
Photophilic algae	Communities dominated by *Padina* spp., *Dictyota* spp., *Dictyopteris* spp., *Taonia* spp. and *Halopteris* spp. (Phaeophyceae)	10
Corallina elongata	Community dominated by articulated Corallinales[c]	8
Mytilus	*M. galloprovincialis* (mussel) beds without *Cystoseira*	6
Ulva spp. and *Enteromorpha* spp.	Stands of *Ulva* spp. and *Cladophora* spp. (Chlorobionta)[d]	3
Cyanobacteria	Communities dominated by Cyanobacteria	1

[a] *Cystoseira spicata* and *C. amentacea* var. *spicata* are considered here as heterotypic synonyms of *C. amentacea*.
[b] We restricted this community type to bioconstructions of *L. byssoides*.
[c] Several species of articulated Corallinales, not distinguishable in the field, can occur in the Mediterranean Sea, e.g. *Ellisolandia elongata* (synonym: *C. elongata*), *C. caespitosa* and *C. officinalis*.
[d] The genus *Enteromorpha* is no longer distinguished from the genus *Ulva*, to which *Enteromorpha* species belong.

Table 6
Species and communities taken into account for the calculation of the new simplified CARLIT Index, and their 'sensitivity level' (SL).

Species and communities	Description in the study area	SL
Cystoseira amentacea/C. mediterranea 3	Continuous or almost continuous stands of *C. amentacea* or *C. mediterranea*	20
Other shallow *Cystoseira* spp.	Populations of *C. barbata, C. brachycarpa, C. crinita, C. foeniculacea*, *C. jabukae* (other than *C. amentacea, C. compressa, C. mediterranea*)	20
Cystoseira amentacea/C. mediterranea 2	Abundant patches of dense stands of *C. amentacea* or *C. mediterranea*	15
Cystoseira compressa	Continuous or almost continuous stands of *C. compressa* subsp. *compressa*	12
Cystoseira amentacea/C. mediterranea 1	Scattered plants of *C. amentacea* or *C. mediterranea*	10
Other soft macroalgae	Communities of non-perennial macroalgae without *Cystoseira* species, *Ulva* spp. and/or *Cladophora* spp. (including algal turf)	10
Articulated corallines	Stands of articulated *Corallina* spp. without *Cystoseira* species (e.g. *Corallina caespitosa*, *C. officinalis* and *Ellisolandia elongata*)	8
Encrusting corallines	Stands of *Lithophyllum incrustans*, *Neogoniolithon brassica-florida* and other encrusting corallines (Rhodophyta)	6
Mytilus galloprovincialis	*Mytilus galloprovincialis* (mussel) stands without *Cystoseira* species	6
Green macroalgae	Stands of *Ulva* spp. and/or *Cladophora* spp. (Chlorobionta)	3
Cyanobacteria	Communities dominated by Cyanobacteria (other than *Rivularia* sp.)	1

Table 7
Pressure score (PS) assigned to each pressure i.

PS	Urban area (% watershed)	Industrial area (% watershed)	Agricultural area (% watershed)	Coastal artificialization (% shore length)	Fish farms (%shore length)	Freshwater (%shore length)
1	0–10	0–10	0–5	0–5	0 –1	0–5
2	11–35	11–25	6–15	6–25	2–15	6–25
3	36–75	26–75	16–30	26–75	16 – 40	26–75
4	>75	>75	>30	>75	>40	>75

effluents, urbanisation, agriculture, coastline erosion, coastal population and fishing.

2.3.4. The human activities and pressures index (HAPI)

To identify the pressures likely to have a real impact on the species and communities taken into account in the CARLIT method, we propose here a new pressure index. Several criteria have to be considered. To be considered, a pressure must concern the surface waters, must have an obvious impact on the communities mapped and be persistent. Furthermore, data on pressures must be available and representative at a coastal WB scale. Pressures observed at a single point or at a scale of a few kilometres cannot be considered because they are not representative at the scale of a coastal WB. Thus, we listed three metrics of continental pressures (urban, industrial and agricultural areas) and four metrics of marine pressures.

For the continental pressures, the three considered metrics were expressed as the percentage of land area covered (data from Corine Land Cover, 2006) and were considered at the scale of the watershed of the coastal WB (in contrast with the LUSI index, which takes into account a 1.5 km strip, whatever the coastal relief): (i) urbanisation (Corine Land Cover codes, CLC codes, 111, 112, 141 and 142) (hereafter 'Urban area'), (ii) industry (CLC codes 121–124 and 131–133) (hereafter 'Industrial area'), (iii) agricultural activities (CLC codes 211–213, 221–223, 231 and 241–244) (hereafter 'Agricultural area').

The other areas without such pressures (e.g. forests) are considered as natural areas.

For the 4 marine pressures, we measured: (i) the artificialization of the coast (field data, expressed as the percentage of the artificialized coastline of the WB), (ii) fish farms (field data and Medtrix, 2015 (database IMPACT), expressed as the length of coastline of

Table 8
Absolute values of the correlation coefficient (r) between pressures *i* and the EQR data, from correlation matrix of the PCA.

Pressure	Urban area	Industrial area	Agricultural area	Coastal artificialization	Fish farms	Freshwater
R	|0.14|	|0.31|	|0.06|	|0.68|	|0.15|	|0.40|

Table 9
Turnover score (TS) assigned to the annual seawater turnover rate of a WB j.

Seawater turnover rate	TS
>1 400	1.33
100 to 1400	1
<00	0.80

rocky coasts potentially impacted, in metres), (iii) sewage outfalls (field data and Medtrix, 2015 (database IMPACT), expressed as the length of coastline of rocky coasts potentially impacted, in metres) and (iv) rivers (field data and CARMEN, 2015a,b expressed as the length of coastline of rocky coasts potentially impacted, in metres). Data from IMPACT are derived from modelling results (Holon et al., 2015). For the calculation of the pressure index, the 'sewage outfalls' and 'rivers' pressures were summed into a single pressure named 'Freshwater'.

A semi-quantitative scale, between 1 and 4, was assigned for each pressure (Table 7). Each selected metric was correlated with the EQRs measured by the CARLIT method for each coastal WB. A Principal Component Analysis (PCA) was performed, using the software R® (R Core Team, 2013) to define the links between pressures and EQRs. An indication of the nature, strength and relevance of correlation is given to determine the prevailing trends in the data set. The correlation coefficients of these selected pressures were used to weight their influence in the calculation of the pressure index (Table 8).

Finally, the pressure index of a WB was weighted according to the annual seawater turnover. The annual seawater turnover of a coastal WB can be derived from modelling (Ganzin et al., 2009). It represents the flow of water entering the water mass relative to the total volume of the WB, which accounts for the remanence of pollutants. We have distinguished three levels of annual seawater turnover rate and we assigned them three turnover scores (Table 9).

The proposed pressure index (*Human Activities Pressures Index*; HAPI) for a coastal WB *j* is as follows:

$$\mathbf{HAPI}_j = \sum(\mathbf{PS}_i * \mathbf{r}_i)/\mathbf{TS}_j$$

Table 10
Comparison of EQR values and ecological status of the 40 WBs (for number and administrative names, see Table 1 and Fig. 1), according to the three CARLIT indices (Ballesteros et al., 2007, Nikolić et al., 2013 and this study). EQR and ES column: first assessment (left) and second assessment (right).

Water bodies (WBs)	Original CARLIT index			Nikolić index			Simplified CARLIT index		
	EQR	ES		EQR	ES		EQR	ES	
1 – FRDC01	0.52/0.58	Moderate	Moderate	0.50/0.53	Moderate	Moderate	0.47/0.56	Moderate	Moderate
2 – FRDC02c	0.32/0.43	Poor	Moderate	0.29/0.39	Poor	Poor	0.32/0.43	Poor	Moderate
3 – FRDC04	0.43/0.45	Moderate	Moderate	0.40/0.41	Moderate	Moderate	0.46/0.45	Moderate	Moderate
4 – FRDC05	0.63/0.61	Good	Good	0.58/0.61	Moderate	Good	0.64/0.56	Good	Moderate
5 – FRDC06a	0.36/0.43	Poor	Moderate	0.40/0.40	Moderate	Moderate	0.40/0.43	Moderate	Moderate
6 – FRDC06b	0.55/0.64	Moderate	Good	0.55/0.59	Moderate	Moderate	0.47/0.54	Moderate	Moderate
7 – FRDC07a	0.80/0.80	High	High	0.74/0.71	Good	Good	0.64/0.55	Good	Moderate
8 – FRDC07b	0.95/0.85	High	High	0.84/0.76	High	High	0.76/0.64	High	Good
9 – FRDC07c	0.66/0.57	Good	Moderate	0.60/0.59	Moderate	Moderate	0.61/0.57	Good	Moderate
10 – FRDC07d	1.00/0.90	High	High	0.94/0.82	High	High	1.00/0.85	High	High
11 – FRDC07e	0.76	High		0.76	High		0.77	High	
12 – FRDC07f	0.93/0.94	High	High	0.84/0.84	High	High	0.93/0.93	High	High
13 – FRDC07g	0.68/0.64	Good	Good	0.64/0.62	Good	Good	0.70/0.65	Good	Good
14 – FRDC07h	1.00	High		0.96	High		1.00	High	
15 – FRDC07i	0.64	Good		0.62	Good		0.65	Good	
16 – FRDC07j	1.00	High		0.94	High		1.00	High	
17 – FRDC08a	0.98	High		0.87	High		0.98	High	
18 – FRDC08b	0.66/0.61	Good	Good	0.55/0.45	Moderate	Moderate	0.57/0.49	Moderate	Moderate
19 – FRDC08c	0.54/0.55	Moderate	Moderate	0.51/0.49	Moderate	Moderate	0.55/0.55	Moderate	Moderate
20 – FRDC08d	1.00/0.93	High	High	0.99/0.83	High	High	1.00/0.92	High	High
21 – FRDC08e	0.82	High		0.75	Good		0.82	High	
22 – FRDC09a	1.00	High		0.88	High		1.00	High	
23 – FRDC09b	0.49/0.49	Moderate	Moderate	0.43/0.43	Moderate	Moderate	0.49/0.49	Moderate	Moderate
24 – FRDC09c	1.00	High		0.92	High		1.00	High	
25 – FRDC09d	0.36/0.43	Poor	Moderate	0.31/0.42	Poor	Moderate	0.36/0.44	Poor	Moderate
26 – FRDC10a	0.81	High		0.71	Good		0.81	High	
27 – FRDC10b	0.49/0.50	Moderate	Moderate	0.44/0.49	Moderate	Moderate	0.49/0.50	Moderate	Moderate
28 – FRDC10c	0.72	Good		0.65	Good		0.72	Good	
29 – FREC01ab	0.87	High		0.90	High		0.86	High	
30 – FREC01c	0.58/0.69	Moderate	Good	0.61/0.91	Good	High	0.57/0.72	Moderate	Good
31 – FREC01d	0.84/0.80	High	High	0.91/0.82	High	High	0.91/0.79	High	High
32 – FREC01e	0.83	High		0.88	High		0.79	High	
33 – FREC02ab	0.61/0.84	Good	High	0.79/0.85	High	High	0.60/0.85	Good	High
34 – FREC03ad	0.80	High		0.87	High		0.82	High	
35 – FREC03b	0.42/0.41	Moderate	Moderate	0.46/0.47	Moderate	Moderate	0.45/0.45	Moderate	Moderate
36 – FREC03c	0.94	High		0.79	High		0.84	High	
37 – FREC03eg	0.94	High		0.96	High		0.97	High	
38 – FREC03f	0.60/0.57	Moderate	Moderate	0.78/0.73	High	Good	0.58/0.58	Moderate	Moderate
39 – FREC04ac	0.96	High		0.96	High		0.96	High	
40 – FREC04b	0.88	High		0.89	High		0.90	High	

Table 11
Percentage of the shore length occupied by the species and communities taken into account for the calculation of the CARLIT index over 23 water bodies assessed in 2007–2010 and in 2012–2015.

Species and communities	First assessment (2007–2010)	Second assessment (2012–2015)
C. amentacea and *C. mediterranea* (3, 2 and 1)	38.0	39.5
Other shallow *Cystoseira* spp.	0.1	1.2
Cystoseira compressa	2.2	3.0
Other soft macroalgae	3.9	6.4
Articulated corallines	20.5	26.8
Encrusting corallines	12.5	7.3
Mytilus galloprovincialis (mussels)	6.9	2.8
Green macroalgae	3.1	3.1
Cyanobacteria	4.9	3.0
Lithophyllum byssoides rim	7.9	6.9

Table 12
Correlation between the EQR values, according to each CARLIT index, and the four anthropogenic pressures indices. * significant ($p < 0.05$).

	EQR Original CARLIT index	EQR Nikolić index	EQR Simplified CARLIT index
LUSI Index	−0.33*	−0.05*	−0.25
MA-LUSI-WB	−0.39*	−0.57*	−0.33*
CHII	−0.07	−0.06	+0.07
HAPI	−0.79*	−0.86*	−0.74*

Table 13
Comparison of the ecological status of coastal water bodies in different Mediterranean regions, based upon the CARLIT method sensu lato. Percentage of coastal water bodies falling within each category (High through Bad) and the total number of WB analysed.

Study area	High	Good	Moderate	Poor	Bad	Total	Reference
Alboran Sea (Andalusia, Spain)**	55	30	10	5	0	20	Bermejo et al., 2013a,b
Catalonia (Spain)	16	27	46	12	0	33	Ballesteros et al., 2007
Catalonia (Spain)	22	22	53	3	0	32	Torras et al., 2016
France (Ballesteros original method)*	55	18	28	0	0	40	This study
France (Nikolić method)*	50	20	28	3	0	40	This study
France (Simplified method)*	50	13	38	0	0	40	This study
Liguria (Italy)**	33	33	25	8	0	12	Asnaghi et al., 2009
Genova-Portofino area (Liguria, Italy)**	33	33	33	0	0	3	Mangialajo et al., 2007
Capo Carbonara MPA (Sardinia, Italy)**	100	0	0	0	0	2	Ferrigno et al., 2014
Malta	78	11	11	0	0	9	Blanfuné et al., 2011
Eastern Adriatic Sea (Croatia)**	67	0	0	17	17	6	Nikolić et al., 2013
District of Vlora (Albania)	40	0	20	20	20	5	Blanfuné et al., 2016

* Last Ecological status obtained for each coastal water bodies.
** Not water bodies but site.

where PS_i: Pressure score assigned to the pressure i (Table 7), r_i: absolute value of the correlation coefficient between the pressure i and EQR data (Table 8), TS_j: Turnover score assigned to the seawater turnover rate of the WB j, The HAPI pressure index can vary from 1.31 (minimum pressure) to 8.70 (maximum pressure).

Each pressure index (LUSI, LUSI modified, Cumulative impact and HAPI) was correlated with the EQR of each WB.

3. Results

3.1. Ecological assessment

The 40 coastal WBs surveyed represent ~2 970 km of coastline of rocky shores (measured at 1/2 500 scale).

For the first assessment of the 40 WBs, the three CARLIT indices gave very similar results (Table 10): only three WBs changed their ES between the original CARLIT method and the proposed simplified method (WB #5 from Poor to Moderate, WB #7 from High to Good and WB #18 from Good to Moderate). When the WBs were assessed twice (23 WBs), 7 and 8 WBs changed their ES (original and simplified CARLIT method, respectively) (Table 10).

Whatever the method, a significant correlation between the first and the second assessment was observed ($r = 0.93$ for the original CARLIT index, $r = 0.89$ for the Nikolić index and $r = 0.89$ for the simplified CARLIT index, $p < 0.001$), indicating both robustness (reproducibility) and the absence of trend.

Whatever the assessment (first or second), there is a significant correlation between the results of the three methods ($r = 0.92$ between the original and Nikolić indices, $r = 0.95$ between the original and the simplified CARLIT index and $r = 0.93$ between the simplified and the Nikolić indices, $p < 0.001$).

Considering the 23 WBs assessed twice, species and communities exhibited a relative stability between the two assessments ($r = 0.97$, $p < 0.001$). Only few changes in percentages of fast growing species or communities were recorded (mainly mussels, articulated corallines, encrusting corallines and other soft macroalgae) (Table 11), and 7 and 8 WBs changed their ES (mostly upgrade of one class) (original and simplified CARLIT indices, respectively) (Table 10).

3.2. Response of CARLIT indices to anthropogenic pressures

Values of each anthropogenic pressure index have been calculated for the 40 water bodies (Table S1 in the online version at DOI: http://dx.doi.org/10.1016/j.ecolind.2016.07.049).

Correlations between the three CARLIT indices and the different pressure indices were not significant with the CHII, slightly correlated with LUSI and MA-LUSI-WB, and strongly correlated with the HAPI (Table 12).

4. Discussion

The present data constitute the most extensive assessment ever undertaken of the ecological status of Mediterranean waters, based upon the CARLIT index, the most widely used index for the Mediterranean Sea (Table 13). This assessment encompasses 40 coastal water bodies and ~2 970 kilometres of shore (at 1/2 500 scale).

The simplified CARLIT index, proposed here, does not significantly save field time, and provides less accurate mapping of the communities (Enric Ballesteros pers. comm.), but is easier to implement and requires less expert judgement than the original method (Ballesteros et al., 2007). As highlighted by Dauvin et al. (2010), the benthic indicators have to be transferred in the simplest possible form to local authorities, such as marine protected areas (MPAs). In addition, the simplified index provides results similar overall to those of the original method; when changes occur, they consist in a slight lowering of the EQR; this is due to the removal of *Lithophyllum byssoides* rims (e.g. WB #7 where *L. byssoides* rims are very abundant). These rims were indicative of a long period of good ES in the past, but are currently undergoing submersion and collapse because of the sea level rise (Verlaque, 2010; Faivre et al., 2013; Thibaut et al., 2013). This trend is expected to increase in the next few years, and it is thus difficult to separate the impact of sea level rise from that of the water quality, obviously resulting in a bias in future assessments.

Two successive assessments were performed (2007–2010 vs 2012–2015). The results were very similar and, when there was a change in EQR, the simplified CARLIT index does not evidence a unidirectional trend. Cavallo et al. (2016) already stressed the robustness of the CARLIT method. In addition to robustness, the significant high correlation between the two assessments, whatever the method, evidences the stability of the overall ES of the coastal water bodies. Consequently, as suggested by Cavallo et al. (2016), successive assessments could be carried out at low frequency.

The existing EQRs were mainly based upon the expert knowledge of the sensitivity of species and communities to a set of anthropogenic stressors. Most of these EQRs have not been correlated with definite pressures, or have been empirically linked to ill-defined pressures. Interesting attempts have been made to link EQRs and pressures (e.g. Mangialajo et al., 2007; Orlando-Bonaca et al., 2008; Iveša et al., 2009; Díez et al., 2012; Neto et al., 2012; Bermejo et al., 2012, 2013a,b; Nikolić et al., 2013; Guinda et al., 2014a; Ar Gall et al., 2016). However, some of the stressors were often tackled on the basis of scattered measurements, were spatially and/or temporally very variable, were not representative of all the WBs and/or their impact upon species and communities was far from being established. Stressors such as turbidity, dissolved organic nitrogen, phosphate, Chlorophyll-*a*, saturated O_2, faecal bacterial indices, etc., may prove to be irrelevant in the framework of the WFD, at least in some WBs, for one or several of the above-mentioned reasons. This is illustrated by general indices, such as CHII (Holon et al., 2015); although very comprehensive and useful in contexts other than that of the WFD, it is totally uncorrelated with the CARLIT index. To date, the LUSI and the MA-LUSI-WB were the best and most widely used pressure indices, the former being the recommended pressure index in the context of the Mediterranean Geographical Intercalibration Group (Buché, 2012). The main shortcoming of the LUSI index is that it is only based upon the land and river estuaries (Flo et al., 2011). The MA-LUSI-WB (Torras et al., 2016) improves on the LUSI index by adding the length of artificial structures along the shore. Here, we have proposed a new pressure index (HAPI), taking into account the possible shortcomings of previous indices; this pressure index accounts better for the EQR values than the previous indices, as evidenced by the high correlation coefficient between EQR and HAPI.

Data collected in the framework of CARLIT method provide a mapping of species or communities present on the rocky shores and ultimately the ecological status of one water body at a given time. The link between the CARLIT index and HAPI index provides an understanding of the link between the ecological status and anthropogenic pressures of a water body. The HAPI index could be used to define switching thresholds between ecological statuses and quantify the ‘maximum load’ for each pressure in each water body. Identification of pressures impacting the communities and determining the switching threshold will allow managers to act at the source of the pressure and prevent or limit the deterioration or improve the ecological quality of water bodies, which is one of the objectives of the WFD.

The CARLIT index, especially when coupled with a pressure index, constitutes a powerful tool in the framework of the WFD. However, in the context of the MSFD policy (Council Directive, 2008), it must be completed by new indicators taking into account the whole water column and the ecosystem functioning, such as the Ecosystem-Based Quality Indices (EBQI) (Personnic et al., 2014; Ruitton et al., 2014; Rastorgueff et al., 2015).

The Mediterranean Sea is often regarded as a sea that is highly impacted by a variety of human-induced stressors, e.g. artificialization of the coast, discharges from sewage outfalls and rivers, fish farms (e.g. Pergent-Martini et al., 2006; Halpern et al., 2008; Lejeusne et al., 2010; Meinesz et al., 2013; Micheli et al., 2013; Giakoumi et al., 2015; Holon et al., 2015). The present study significantly increases the available number of coastal water bodies assessed with the CARLIT method and now provides a comprehensive view along thousands of kilometres of shore. Surprisingly, the picture is far less a cause for concern than initially expected, at least in the western Mediterranean basin (Table 13). This can be related to the recent improvement of the water quality (Pinedo et al., 2013) as a result of the European water policy. There is also a possibility that the situation of the Mediterranean WB, better than expected, may be an artefact due to the focus on superficial waters and habitats inherent to the CARLIT method. If so, this artefact should be corrected by the complementary indices developed in the framework of the MSFD. Overall, as stressed by Enric Ballesteros (pers. comm.), the problems of the Mediterranean Sea are more related to habitat loss, overfishing, invasive species, etc., which do not per se affect the water quality at a water body level (although they can affect it at a more local scale).

5. Conclusion

As a result of the present study, undertaken at a geographical scale never previously attempted, a comprehensive picture of a broad range of WBs is now available. The pertinence of the method, and of its improvement proposed here, has been confirmed, through several pressure indices, one of them (HAPI) being an original proposal. In fact, considering the complexity of the Integrated Coastal Zone Management (ICZM), no single index can account for such a diversity of issues: the ecological quality of a WB as a whole, status of the ecosystems, natural and human-induced pressures, etc. The future of the ICZM requires a combination of indices, each one providing information regarding a given problem, parameter and/or ecosystem, at a given scale.

Future developments of the relationship between WB quality and ecological indicators on the one hand, and between CARLIT indices and stressors, could take advantage of the use of mathematical methods and models such as those developed in the framework of other scientific fields (e.g. Ocampo-Duque et al., 2006; Zhao et al., 2006; Muttil and Chau, 2007; Wang et al., 2014).

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