Environmental Quality of Catalan Coastal Waters Based on Macroalgae: The Interannual Variability of CARLIT Index and Its Ability to Detect Changes in Anthropogenic Pressures over Time

Xavier Torras, Susana Pinedo, María García, Boris Weitzmann, and Enric Ballesteros

Abstract CARLIT is a Water Framework Directive-compliant methodology permitting a rapid assessment of water quality using rocky-shore macroalgae as biological quality elements. Here we present the water quality assessment of 32 coastal water bodies of Catalonia (Northwestern Mediterranean) during a period of 14 years (1999–2012) applying CARLIT. The averaged ecological status of the water bodies ranges between high and poor and the Ecological Quality Ratio shows a significant negative relationship with a modified LUSI index, thus providing further evidence on the utility of CARLIT to detect anthropogenic pressures. The lowest interannual variability in water quality was found in water bodies having most of their shore covered by natural rocks, while the highest variability was observed in water bodies situated in semi-confined environments or located close to freshwater discharges. In spite of the multiple advantages of CARLIT as a monitoring methodology, it can show strong disagreements in water quality assessment with other methodologies using other biological quality elements (i.e., macroinvertebrates). These discrepancies mainly occur in water bodies with reduced extension of rocky shores, questioning the use of CARLIT in these situations.

Keywords CARLIT, Ecological status (ES), Macroalgae, Rocky-shore assemblages, Water Framework Directive (WFD)

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Contents

Abbreviations

BQE	Biological quality elements
CARLIT	Cartografia Litoral (Littoral Cartography)
CFR	Quality of Rocky Bottoms
EEIc	Ecological Evaluation Index continuous formula
EQ	Environmental quality
ES	Ecological status
LUSI	Land Uses Simplified Index
MA-LUSI-WB	Modified LUSI index
MEDOCC	MEDiterranean OCCidental
RSL	Reduced species list
WB	Water body
WFD	Water Framework Directive

1 Introduction

The main objective of the Water Framework Directive (WFD; European Commission 2000/60/EC) is to achieve the good ecological status (ES) in all the surface water bodies (WBs) by 2015 and to prevent its deterioration in the subsequent years. Different biological quality elements (BQE) have been proposed to assess the ecological status in coastal water bodies: phytoplankton, macrophytes (macroalgae and seagrasses), and macroinvertebrates.

Macroalgae have been frequently used to assess the environmental quality in the implementation of the WFD [1–11]. Species of the brown algal genus *Cystoseira* (Fucales, Cystoseiraceae) usually dominate the upper infralittoral levels from non-polluted environments in the Mediterranean Sea [12–18] but they are replaced by other species when nutrient or heavy metal concentrations increase [3, 4, 11, 16, 19–22]. In non-polluted Mediterranean environments, the upper infralittoral algal beds thriving in moderately exposed to highly exposed rocky shores are dominated whether by *Cystoseira mediterranea* or by *Cystoseira stricta* (*C. amentacea* v. *stricta*) [3, 4, 12, 23–26]. When pollution or the frequency of any other kind of disturbance increases, *Cystoseira* spp. populations are first replaced by beds of the red alga *Corallina elongata* and the mussel *Mytilus galloprovincialis* [11, 13, 21, 23, 25, 27, 28]. Green ephemeral algae (*Ulva* spp., *Cladophora* spp.) and cyanobacteria replace *Corallina* and *Mytilus* in highly disturbed environments and near freshwater discharges [11, 13, 25, 29–32].

Several methodologies based on macroalgae (EEIc [2], CARLIT [3], RSL [5], CFR [7]) have been developed to assess the ES of water bodies. CARLIT is based in the cartography of littoral and upper infralittoral rocky-shore assemblages and was developed to assess the water quality in the coast of Catalonia (Northwestern Mediterranean). Afterward, it has been officially used for the implementation of the WFD in most of the Mediterranean coasts of Spain, France, and Italy [33, 34]. CARLIT has been applied to the coast of Catalonia (Northwestern Mediterranean) during 14 years, continually from 1999 to 2012, and has provided enough data to explore its interannual variability and its possible utility to detect long-term changes in the environmental quality of coastal WBs.

2 Material and Methods

The sampling surveys consisted in a run of the entire coast with a small boat kept as close as possible to the shoreline [3]. Littoral and upper sublittoral assemblages were identified (Table 1) and directly annotated in a graphic display (aerial photographs, nautical charts, or ortho-photographs at a scale of 1:5000). Highly human-modified WBs such as the inner part of harbors and marinas were not sampled, as they do not reflect the environmental quality of the adjacent coast. The final result of each survey was a partition of the rocky shoreline in several sectors – at least 50 m long – characterized by an assemblage category (corresponding to a single assemblage or a combination of assemblages). The sectors harboring *Cystoseira* species were assigned to *Cystoseira* categories taking into account also the coverage in a semiquantitative scale [3]. When more than one species were present in a sector (i.e., *Corallina elongata* and *Mytilus galloprovincialis*), the assignment was given to the most visually abundant one, but scoring the presence of both species (i.e., Coelo+Mgal or Mgal+Coelo; Table 1). Each category was assigned to a sensitivity level (SL) regarding their vulnerability to any environmental stress based on literature and expert judgment (Table 1; [3]).

The environmental quality (EQ) assessment of a WB was calculated as

$$\mathrm{EQ} = \frac{\sum \mathrm{l}_i {*} \mathrm{SL}_i}{\sum \mathrm{l}_i} \quad (1)$$

where l_i is the length of the coastline occupied by the community category *i* and SL_i is the sensitivity level of the assemblage category *i*.

The Ecological Quality Ratio (EQR) is defined as the ratio between the EQ calculated in the study region and the EQ calculated at reference sites [35]. Reference sites were located in Corsica and in the Balearic Islands [3]. In the reference sites the abundance and relative cover of each category of assemblages depend on

Table 1 Summarized description and sensitivity levels of the main assemblage categories distinguished in the Catalan coast

Category	Description	Sensitivity level
Cymed continuous	Continuous belt of *C. mediterranea*	19–20
Cymed dense	Abundant patches of dense stands of *C. mediterranea*	15
Cymed rare	Abundant scattered plants of *C. mediterranea*	10–12
Other Cy spp.	Populations of *Cystoseira* spp. in sheltered environments	15
Cymed+Cycom	*C. compressa* and *C. mediterranea* populations in exposed or sheltered environments	12–15
Cycom	*C. compressa* populations in exposed or sheltered environments	12
Coelo	Belt of *Corallina elongata*, devoid of *Cystoseira*	8
T	Buildups of *Lithophyllum byssoides* (Trottoir)	20
Mgal	Mussel (*Mytilus galloprovincialis*) beds, without *Cystoseira*	6
Green algae	Belts of *Ulva* and *Cladophora* species	3
Cyano	Communities dominated by cyanobacteria and *Derbesia tenuissima*	1
Photophilic algae	Communities dominated by *Padina*/*Dictyota*/*Dictyopteris*/*Halopteris*	10

Table 2 Environmental quality (EQ) values calculated for the six geomorphological relevant situations in reference sites

Geomorphological relevant situation (i)	Coastal morphology	N/A	EQ_i
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

coastline geomorphology and on the kind of substrate (artificial versus natural) [3]. Thus, different geomorphological situations potentially influencing the establishment and the abundance of the littoral and upper sublittoral assemblages were defined (Table 2).

The EQR of a sector of coast is calculated as

$$\mathrm{EQR} = \frac{\sum \frac{\mathrm{EQss}_i * \mathrm{l}_i}{\mathrm{EQrs}_i}}{\sum \mathrm{l}_i} \quad (2)$$

where i is the situation, EQss_i is the EQ in the study site for the situation i, EQrs_i is the EQ in the reference sites for the situation i, and l_i is the coastal length in the study coast for the situation i. The EQR values range from 0 (bad ES) to 1 (high ES). Five ESs (high, good, moderate, poor, and bad) are considered. According to

Table 3 Correspondence between ecological quality ratio (EQR) intervals and ecological status (ES)

EQR	ES
>0.75–1	High
>0.60–0.75	Good
>0.40–0.60	Moderate
>0.25–0.40	Poor
0–0.25	Bad

the normative definitions of the ecological classes in the WFD and the expert judgment, a correspondence between the EQRs and ESs was obtained ([3] Table 3).

CARLIT methodology was applied to the whole Catalan coast, which extends for more than 400 lineal km, yearly from 1999 to 2012. Sampling was always performed during spring (from May to June) in coincidence with the highest development of littoral assemblages [14]. Although the Catalan coast is divided into 34 coastal WBs defined according to anthropogenic pressures and typology, the CARLIT index was calculated for 32 WBs since two WBs (C33 and C34) are completely devoid of rocky shores.

The information obtained on the surveys was transcribed into a GIS system and the yearly ES for the different WBs was calculated. There is not a minimum percentage of rocky coast or natural rocky coast to be considered for the calculation of the CARLIT index on a WB [3], and therefore, despite the existence of several WBs with a low percentage of natural rocky coasts (Fig. 1), EQRs were calculated for all WBs where some sector of rocky shore was present.

A Nonmetric Multidimensional Scaling (NMDS) ordination was performed to visualize the similarities of the 32 WBs according to the EQR values. A modified version of the Land Uses Simplified Index (LUSI) [36] was used to analyze the relationship of anthropogenic pressures and CARLIT results. LUSI is based on a combination of factors that reflect the continental influence in the coastal WBs: (1) land uses (urban, industrial, and agricultural), (2) the vicinity and the typology of a river, and finally (3) the shape of the coast (concave, convex, or straight). The scores were calculated taking into account 1.5 km inland between the limits of each WB on a Corine Land Cover map based on 2006 data. Two new factors were added to the original LUSI based on (1) the density of population and (2) the artificialization of the coastline at each WB. The density of population was estimated as the logarithm of the total population in the littoral municipalities divided by the length of each WB. The artificialization of the coastline was calculated as the relative length, from 0 to 1, of artificial structures in the total rocky coastline sampled at each WB. The modified LUSI index (MA-LUSI-WB) was thus calculated as

$$\mathrm{MA-LUSI-WB} = \mathrm{LUSI} + \log\left(\frac{\text{Inhabitants}}{\text{Coastline length}}\right) + \left(\frac{\text{Length artificial}}{\text{Total rocky length}}\right) \quad (3)$$

The relationship between the scores of MA-LUSI-WB and the mean EQR value at each WB was obtained by means of Pearson correlation analysis.

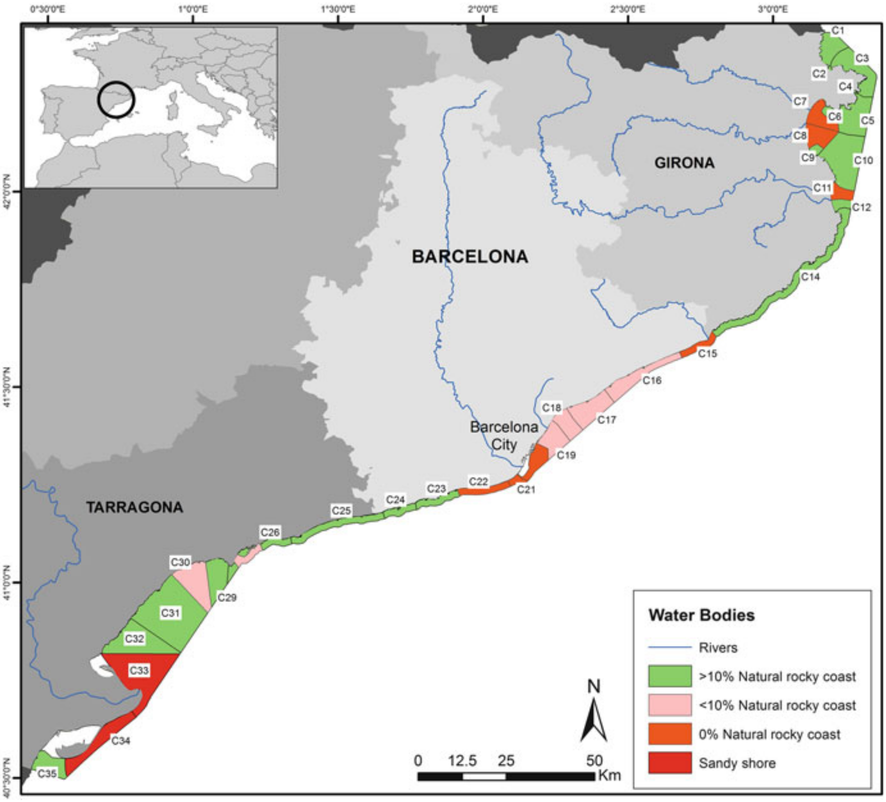

Fig. 1 The 34 coastal water bodies of Catalonia (Northwestern Mediterranean) delimited according to its typology and anthropogenic pressures. Completely sandy shores, water bodies without natural rocky coast or with a percentage lower than 10% of natural rocky coast are shown on a red scale

3 Results

Water bodies are ordinated in the MDS plot following a gradient of water quality, with the WBs having the highest EQR (C14, C10) situated at the right side of the plot and those having the worst water quality situated at the left side (C21, C22) (Fig. 2). The EQR values and the ES at each WB change over time (Table 4). The lowest variability is found in WB C14 with only 5% of variability in the 14-year period. The highest variability is found in WB C21 with 82%. The SD oscillates between 0.01 (C14) and 0.13 (C02 and C21) (Table 5). The values of EQR usually range between rather restricted intervals in most water bodies, as summarized in Fig. 3. The highest values are obtained in the northern shores, medium values in the southern shores, and the lowest values in the central sector of the coast. Seven WBs

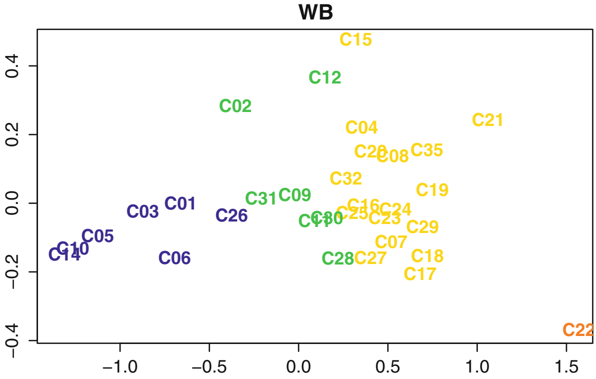

Fig. 2 Nonmetric Multidimensional Scaling (NMDS) ordination of water bodies based on Kruskal-Wallis mapping for yearly EQR data

register a high averaged ES; of these, both high and good ES have been assessed for WBs C01, C03, C06, and C26, while WBs C05, C10, and C14 have always been rated high. Good averaged ES has been assessed at seven WBs. Moderate averaged ES has been obtained at seventeen WBs, mainly in Barcelona coastline, where good or poor ES has also been obtained during some surveys. Finally, one WB (C22) sampled only from 2005 to 2010 has been evaluated with a poor averaged ES. A significant negative relationship between MA-LUSI-WB scores and EQR mean values was obtained ($R^2 = 0.5033$; $p < 0.001$) (Fig. 4).

4 Discussion

After sampling the Catalan coast using CARLIT for 14 years, we feel confident to reinforce some its advantages when compared with other WFD-compliant methodologies based on macroalgae [1, 2, 5–8]. First, CARLIT is a nondestructive methodology. Second, there is almost no laboratory work, therefore saving time and money. Third, sampling is fast, being possible to survey a coast length of 400 km in no more than 6 weeks, minimizing the seasonal variability on the composition and development of the assemblages. And, fourth, it takes into account the totality of the coast, avoiding the misclassification of a WB due to special features of the sampling stations chosen to evaluate the WB. Moreover, the ES assessment of the WBs agrees with the intensity of the anthropogenic pressures as previously reported [18, 37–39]. The good negative relationship between the averaged EQR values and the modified LUSI index used here (Fig. 4) provides new evidence on the utility of CARLIT to detect anthropogenic pressures.

Our data shows a low to high interannual variability in the values of the CARLIT index for the same WB. One of the factors that may explain this variability is the subjectivity of the observers as reported in other studies [40, 41]. This is especially critical in CARLIT where the assignment of a category to a sector of coastline depends on the identification skills of the observer. However, this is not a cause of

Table 4 EQRs and ESs for the 32 water bodies assessed in Catalan coastal waters from 1999 to 2012 with CARLIT methodology

	WB	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
EQR															
Girona	C01	0.82	0.68	0.75	0.81	0.93	0.83	0.85	0.75	0.70	0.74	0.77	0.90	0.89	0.95
	C02	0.73	0.50	0.50	0.70	0.75	0.92	0.71	0.84	0.60	0.69	0.82	0.85	0.53	0.73
	C03	0.81	0.72	0.76	0.82	0.87	0.88	0.68	0.87	0.83	0.89	0.95	0.96	0.96	0.99
	C04	0.51	0.49	0.59	0.55	0.40	0.68	0.43	0.55	0.54	0.57	0.64	0.73	0.59	0.72
	C05	0.94	0.80	0.91	0.86	0.94	0.95	0.88	0.98	0.91	0.92	0.98	0.98	0.96	0.98
	C06	0.68	0.64	0.78	0.70	0.80	0.82	0.90	0.95	0.71	0.75	0.98	0.86	0.85	0.88
	C07*	0.43	0.50	0.62	0.65	0.58	0.38	0.55	0.55	0.49	0.56	0.54	0.55	0.52	0.50
	C08*	0.43	0.36	0.59	0.51	0.67	0.59	0.59	0.45	0.67	0.67	0.56	0.47	0.48	0.59
	C09	0.57	0.55	0.68	0.56	0.64	0.66	0.65	0.67	0.65	0.71	0.75	0.66	0.80	0.74
	C10	0.99	0.94	0.96	0.93	0.97	0.96	0.86	1.00	0.97	0.97	0.99	0.98	0.96	1.00
	C11*	0.67	0.67	0.67	0.67	0.60	0.58	0.51	0.67	0.67	0.67	0.67	0.63	0.65	0.65
	C12	0.56	0.55	0.60	0.47		0.58	0.27	0.68	0.58	0.61	0.61	0.77	0.75	0.69
	C14	0.99	0.94	0.98	0.98	0.98	0.98	0.98	0.99	0.99	0.99	0.99	0.99	0.99	0.98
Barcelona	C15*	0.22	0.31	0.36	0.49	0.51	0.46	0.60	0.46	0.53	0.47	0.41	0.64	0.54	0.63
	C16**	0.54	0.56	0.48	0.55	0.56	0.56	0.59	0.58	0.64	0.54	0.57	0.60	0.55	0.59
	C17**	0.45	0.49	0.50	0.54	0.66	0.48	0.54	0.41	0.51	0.49	0.46	0.38	0.55	0.53
	C18**	0.56	0.51	0.47	0.45	0.51	0.57	0.48	0.45	0.46	0.59	0.31	0.46	0.45	0.47
	C19**	0.46	0.49	0.52	0.41	0.33	0.57	0.46	0.41	0.52	0.47	0.49	0.50	0.52	0.52
	C20*	0.34	0.50	0.56	0.44	0.52	0.63	0.57	0.62	0.59	0.59	0.63	0.55	0.58	0.56
	C21*					0.10	0.40	0.39	0.51	0.55	0.39	0.50	0.40	0.51	0.49
	C22*							0.25	0.24	0.23	0.26	0.33	0.31		
	C23	0.54	0.52	0.54	0.53	0.57	0.49	0.53	0.51	0.52	0.58	0.58	0.55	0.50	0.51
	C24	0.53	0.49	0.50	0.48	0.52	0.51	0.49	0.47	0.52	0.56	0.57	0.51	0.51	0.52
Tarragona	C25	0.61	0.57	0.57	0.54	0.63	0.59	0.57	0.55	0.58	0.63	0.62	0.58	0.59	0.57
	C26	0.72	0.59	0.72	0.73	0.70	0.75	0.72	0.68	0.78	0.78	0.75	0.85	0.81	0.93
	C27**	0.64	0.57	0.61	0.64	0.65	0.66	0.46	0.47	0.57	0.55	0.59	0.51	0.56	0.55

	C28	0.59	0.62	0.62	0.62	0.69	0.63	0.62	0.44	0.62	0.59	0.71	0.60	0.66	0.68
	C29	0.47	0.45	0.52	0.53	0.53	0.51	0.49	0.40	0.50	0.49	0.52	0.47	0.50	0.43
	C30**	0.67	0.60	0.63	0.60	0.64	0.62	0.66	0.62	0.60	0.67	0.63	0.64	0.58	0.61
	C31	0.63	0.59	0.57	0.60	0.74	0.73	0.74	0.76	0.75	0.71	0.69	0.79	0.74	0.74
	C32	0.52	0.47	0.47	0.52	0.58	0.58	0.63	0.60	0.63	0.57	0.59	0.70	0.67	0.61
	C35	0.54	0.30	0.59	0.63	0.54	0.49	0.53	0.44	0.52	0.51	0.54	0.54	0.55	0.57
ES															
Girona	C01	H	G	H	H	H	H	H	H	G	G	H	H	H	H
	C02	G	M	M	G	H	H	G	H	G	G	H	H	M	G
	C03	H	G	H	H	H	H	G	H	H	H	H	H	H	H
	C04	M	M	M	M	M	G	M	M	M	M	G	G	M	G
	C05	H	H	H	H	H	H	H	H	H	H	H	H	H	H
	C06	G	G	H	G	H	H	H	H	G	H	H	H	H	H
	C07*	M	M	G	G	M	P	M	M	M	M	M	M	M	M
	C08*	M	P	M	M	G	M	M	M	G	G	M	M	M	M
	C09	M	M	G	M	G	G	G	G	G	G	H	G	H	G
	C10	H	H	H	H	H	H	H	H	H	H	H	H	H	H
	C11*	G	G	G	G	G	M	M	G	G	G	G	G	G	G
	C12	M	M	G	M		M	P	G	M	G	G	H	H	G
	C14	H	H	H	H	H	H	H	H	H	H	H	H	H	H
Barcelona	C15*	B	P	P	M	M	M	G	M	M	M	M	G	M	G
	C16**	M	M	M	M	M	M	M	M	G	M	M	G	M	M
	C17**	M	M	M	M	G	M	M	M	M	M	M	P	M	M
	C18**	M	M	M	M	M	M	M	M	M	M	P	M	M	M
	C19**	M	M	M	M	P	M	M	M	M	M	M	M	M	M
	C20*	P	M	M	M	M	G	M	G	M	M	G	M	M	M
	C21*					B	M	P	M	M	P	M	M	M	M
	C22*							P	B	B	P	P	P		
	C23	M	M	M	M	M	M	M	M	M	M	M	M	M	M
	C24	M	M	M	M	M	M	M	M	M	M	M	M	M	M

(continued)

Table 4 (continued)

	WB	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Tarragona	C25	G	M	M	M	G	M	M	M	M	G	G	M	M	M
	C26	G	M	G	G	G	H	G	G	H	H	H	H	H	H
	C27**	G	M	G	G	G	G	M	M	M	M	M	M	M	M
	C28	M	G	G	G	G	G	G	M	G	M	G	G	G	G
	C29	M	M	M	M	M	M	M	M	M	M	M	M	M	M
	C30**	G	G	G	G	G	G	G	G	G	G	G	G	M	G
	C31	G	M	M	G	G	G	G	H	H	G	G	H	G	G
	C32	M	M	M	M	M	M	G	G	G	M	M	G	G	G
	C35	M	P	M	G	M	M	M	M	M	M	M	M	M	M

Water bodies without natural rocky sectors are indicated with a single asterisk, while those with less than 10% of natural rocky coast are indicated with a double asterisk

H high ES, *G* good ES, *M* moderate ES, *P* poor ES, *B* bad ES

Table 5 Mean and standard deviation (SD) of EQRs assessed with CARLIT methodology from 1999 to 2012, ES (mean value), and MA-LUSI-WB scores for the different water bodies

	WB	Total length (Km)	Evaluated (%)	Artificial (%)	Natural (%)	Mean (EQR)	SD (EQR)	Mean (ES)	MA-LUSI-WB
Girona									
	C01	48.9	92	5	95	0.81	0.08	H	2.55
	C02	4.0	78	9	91	0.71	0.13	G	2.59
	C03	89.4	98		100	0.86	0.09	H	1.50
	C04	2.7	75	28	72	0.57	0.10	M	2.80
	C05	32.4	89		100	0.93	0.05	H	0.75
	C06	10.6	89	4	96	0.81	0.10	H	2.04
	C07	13.5	17	100		0.53	0.07	M	7.48
	C08	7.9	6	100		0.55	0.10	M	7.25
	C09	11.1	79	34	66	0.66	0.07	G	4.09
	C10	31.5	98	1	99	0.96	0.04	H	1.01
	C11	6.0	12	100		0.64	0.05	G	6.06
	C12	5.2	29	6	94	0.59	0.13	G	5.06
	C14	179.8	88	4	96	0.98	0.01	H	1.04
Barcelona									
	C15	11.6	2	100		0.47	0.12	M	4.51
	C16	27.0	22	91	9	0.57	0.04	M	4.60
	C17	13.4	18	94	6	0.50	0.07	M	4.47
	C18	5.9	8	72	28	0.48	0.07	M	5.03
	C19	14.7	67	97	3	0.48	0.06	M	5.52
	C20	13.4	86	100		0.55	0.08	M	5.57
	C21	4.0	15	100		0.42	0.13	M	7.61
	C22	15.1	2	100		0.27	0.04	P	6.14
	C23	19.4	77	39	61	0.53	0.03	M	2.39
	C24	15.7	56	60	40	0.51	0.03	M	3.19
Tarragona									
	C25	35.5	28	83	17	0.59	0.03	M	3.18
	C26	12.2	56		100	0.75	0.08	H	2.74
	C27	14.2	68	94	6	0.57	0.06	M	5.48
	C28	3.0	96		100	0.62	0.06	G	1.50
	C29	10.0	35	26	74	0.49	0.04	M	4.59
	C30	15.5	28	99	1	0.63	0.03	G	2.56
	C31	23.2	49	38	62	0.70	0.07	G	1.38
	C32	26.4	90	7	93	0.58	0.07	M	1.07
	C35	9.4	54	44	56	0.52	0.08	M	4.44

H high ES, *G* good ES, *M* moderate ES, *P* poor ES, *B* bad ES

great concern here because all surveys have been performed by the same pool of observers. Another factor that can account for interannual differences is the period of the year when the survey is made, but as stated above, surveys were always performed in May to June, dismissing this possibility.

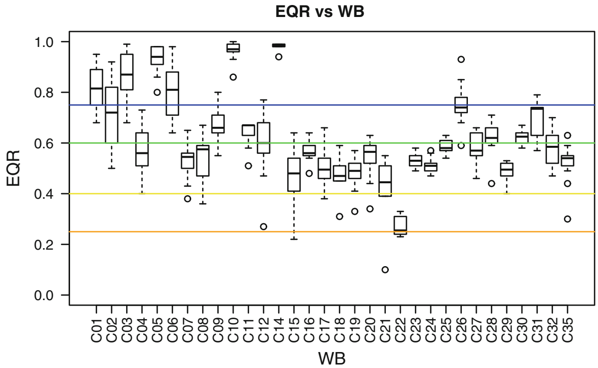

Fig. 3 Box plot showing the average (*black line*), SE value (*box*), SD value (*vertical line*), and outlier values (*circles*) of the EQRs at the Catalan water bodies sampled during a period of 14 years (1999–2012). *Horizontal lines* show boundaries between the different ecological statuses (ESs). *Blue line*, limit between high and good ESs; *green line*, limit between good and moderate ESs; *yellow line*, limit between moderate and poor ESs; *orange line*: limit between poor and bad ESs

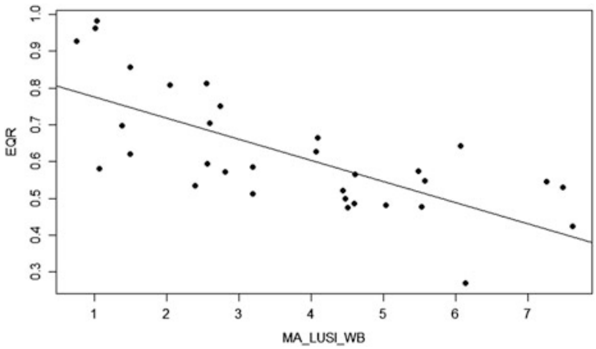

Fig. 4 Relationship between the EQR mean values obtained by CARLIT and the anthropogenic pressures measured according to MA-LUSI-WB index (see Table 2)

Another factor that can account for an interannual shift in the EQR could be a sudden change in coastal geomorphology due to a natural disaster or to a human-induced coastal modification. It is not usual that a human-induced coastal modification encompasses a sector big enough to have an incidence on a WB as a whole. However, we report here one case that fits into this situation. The coastline of the sector C21 was completely modified due to an enlargement of the Barcelona harbor and a deviation of the Llobregat river mouth. The building up of new rocky substrata (breakwaters and quays) changed a big sector of the coast from sandy to rocky and from assemblages dominated by microbes (2003) – typical of bad ecological quality – to assemblages dominated by ephemeral algae (2004) and later to a turf of *Corallina elongata* accompanied by populations of *Mytilus* *galloprovincialis* (year 2005 and beyond), assemblages that indicate a moderate water quality [3].

Other factors that can lead to changes in ES assessment are natural variabilities or changes in human pressures. Natural variability is inevitably associated to ecological systems and we contend here that this should be the major cause of variability in our data, mainly in those WBs where there is not a significant trend of change during the surveyed period. The highest interannual variability corresponds to WBs situated inside little bays (C02, C04) or to WBs located southward of river mouths (C08, C12, C15, and C21). Differences in river discharges associated to rainy periods [42–44] can modify the assemblages close to the inflows. Unexpected strong storms [45–47], differences in nutrients by upwelling processes and river discharges [43, 48, 49], salinity changes [50, 51], temperature variability [50, 52], and hydroclimatic variability [53–55], among other factors, have also been reported as major drivers for Mediterranean marine ecosystems and may be also affecting the interannual variability on the composition and development of upper infralittoral assemblages on rocky shores, and thus, they may be shaping the assessment of the water quality using CARLIT.

Changes in human pressures should revert into changes on indexes based on biological indicators if these indexes are appropriate, irrespectively of the natural variability intrinsically associated to natural assemblages. We have observed an increase in the ES of three WBs that are probably related to an improvement in the water quality at the level of the whole basin. In C09 and C12 the ES has shifted from moderate to good or high, and in C15 it has changed from bad-poor to moderate-high. These three WBs are placed just south of the mouth of three rivers (Fluvià, Ter, and Tordera) whose water quality may have improved [56]. Because the general coastal water circulation in Catalonia is moving southward [57], an improvement on the water quality from these rivers may also imply an increase on the CARLIT values of the coastal water body situated south of the water mouth.

Another example that could be related to water improvement is the shifting from bad to moderate in WB C21. In this WB the water treatment was highly improved, and from 2006 there is a special treatment to reduce nutrient loading [58]. However, and as stated above, the improvement from bad to moderate ES seems to be related to the succession patterns of the assemblages since hard bottoms evaluated in this WB were build up in 2003.

The values of ES obtained with the CARLIT methodology show sometimes striking differences with the ES obtained using other BQEs such as macro-invertebrate assemblages thriving in fine sands (MEDOCC; [56]). For instance, most WBs from Barcelona are rated as moderate and most WBs from Tarragona are rated between moderate and good, using CARLIT; however, they are rated from good to high using the MEDOCC methodology [56]. These differences mainly occur in shores where rocky substrates at the littoral level are mainly artificial and are surrounded by large sandy beaches. Assemblages developing in these artificial substrates are usually dominated by stress-resistant species (*Corallina elongata* and *Mytilus galloprovincialis*) and in some cases by opportunists (green algae and cyanobacteria). *Cystoseira mediterranea* is never encountered in these littoral rocks surrounded by sand. In fact, *C. mediterranea* has been observed growing in artificial breakwaters (authors' pers. obs.) but only when placed around rocky shores with widespread populations of *C. mediterranea* nearby. This is partially to be explained by the low dispersion of *C. mediterranea* zygotes [59], which impairs colonization on sites that are far away from well-developed populations. Another factor that seems to account for the lack of colonization by *C. mediterranea* in these environments is the inhibition of *Cystoseira* recruits by *C. elongata* turfs and *M. galloprovincialis* populations. There is no chance for *Cystoseira* colonization if these stress-resistance space occupiers are not removed [60], a problem that is not only faced by artificial structures but also by degraded natural rocks. Moreover artificial structures are always close to zones with a high human pressure like harbors, whose environmental conditions and water quality do not represent WBs as a whole. For instance, *C. mediterranea* is present on natural rocks in WB C16, but it is completely absent on breakwaters that make up the 90% of the rocky shore in this WB. Thus, results obtained using CARLIT methodology in WBs with a low percentage of rocky shores, mainly when they are not natural, have to be questioned.

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