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Implementation of a new index to assess intertidal seaweed communities as bioindicators for the European Water Framework Directory

E. Ar Gall[a,*], M. Le Duff[a], P.-G. Sauriau[b], M.-N. de Casamajor[c], F. Gevaert[d], E. Poisson[e], P. Hacquebart[f], Y. Joncourt[f], A.-L. Barillé[g], R. Buchet[h], M. Bréret[b], L. Miossec[i]

[a] Lémar – UMR6539 and UMS 3113, IUEM, University of Brest – UBO-UEB, str. Dumont d'Urville, Teknopol Brest – Hirwazh, 29280 Plouzane, Brittany, France
[b] LIENSs, Université de la Rochelle, CNRS, 2 rue Olympe de gouges, 17000 La Rochelle, France
[c] IFREMER HGS/LRHA – UFR Côte Basque, 1 allée du Parc Montaury, 64600 Anglet, France
[d] Université Lille1, CNRS – UMR 8187 LOG, 62930 Wimereux, France
[e] Cellule de Suivi du Littoral Normand (CSLN), 53 rue de Prony, 76600 Le Havre, France
[f] GEMEL-Normandie, C.R.E.C., 54 rue du Docteur Charcot, 14530 Luc-sur-mer, France
[g] BIO-LITTORAL, 2, rue du Château de l'Eraudière, Immeuble Le Nevada, CS 80693, 44306 Nantes Cedex 3, Brittany, France
[h] Mer Molécules Santé – EA 2160, Faculté des Sciences et des Techniques, University of Nantes, B.P. 92208, 44322 Nantes Cedex 03, Brittany, France
[i] IFREMER, Département Dynamique de l'Environnement Côtier, Service Valorisation de l'Information pour la Gestion Intégrée et la Surveillance, rue de l'île d'Yeu, BP 21105, 44311 Nantes Cedex 03, Brittany, France

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ABSTRACT

An index CCO (cover, characteristic species, opportunistic species) has been developed for the implementation of the European Water Framework Directory (WFD) in coastal waters, using intertidal macroalgal communities as bio-indicator (Biological Quality Element). CCO is based on the calculation of three metrics corresponding to the global cover of macroalgal communities (metric 1), the number of characteristic species per topographic level/seaweed community (metric 2) and the cover of opportunistic species (metric 3). The final rating is obtained by pooling the scores of the three metrics. Results are given for 32 sites in 29 water bodies, grouped into four biogeographic regions along the Channel–Atlantic coasts of France. Over the six-year study, most of sites were sampled twice each (every three years). CCO index revealed that 25 coastal water bodies of both the Channel and the Bay of Biscay were in good or high ecological quality status (EQS), whereas only 4 of them were moderate and none in poor to bad status. However, significant differences have been found between sites and between geographic regions, water bodies located in Brittany obtaining the best EQS. No significant change occurred between the three-year sampling sets. A significant correlation has been established between a three-component anthropogenic pressure index and CCO ratings, showing the accuracy of CCO to evaluate the impact of anthropic activities on the structure and development of macroalgal communities as indicator of the ecological quality of coastal water bodies.

1. Introduction

In the prospect of a global climatic change, international agreements have been signed to protect biodiversity (United Nations, 1992), making necessary the evaluation of ecosystemic trends in both continental and marine areas (Thompson et al., 2002; Barange, 2003). Related to the development of public policies for the observation, the preservation and the recovery of natural environments (e.g. Habitats Directive 92/43/EEC, adopted in 1992 by the European Community), monitoring networks have been initiated to better know the putative impact of anthropic pressures on various biotopes (Mann, 2000). Since 2000, the European Union has included in the Water Framework Directory (WFD, 2000/60/EC; E.C., 2000) the investigation of biological communities (phytoplankton, macroalgae, seagrasses, macroinvertebrates and fish) as bio-indicators (biological quality elements or BQEs) to evaluate the ecological status of water bodies (e.g. Guinda et al., 2008; Borja et al., 2013). Seaweed communities have been first recognized as a quality element for the classification of coastal water bodies

* Corresponding author. Tel.: +33 298 49 87 92; fax: +33 298 49 87 72.
E-mail address: erargall@univ-brest.fr (E. Ar Gall).

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and indices have been then established for macroalgae to assess the quality of both coastal and transitional waters. Among these, some used in the North East Atlantic region are based on several metrics, like the CFR index in Spain (Calidad de Fondos Rocosos; Juanes et al., 2008; Guinda et al., 2008, 2014), MarMAT in Portugal (Marine Macroalgae Assessment Tool; Neto et al., 2012) or HPI in Germany (Helgoland Phytobenthic Index; Kuhlenkamp et al., 2011). Other WFD indices focus mainly on specific diversity, like the RSL (Reduced Species List) in the British Isles (Wells et al., 2007). Some integrate both faunistic and floristic metrics, like the subtidal seaweed indicator in France (Derrien-Courtel and Le Gal, 2011) and the RICQI index in Spain (Rocky Intertidal Communities Quality Index; Díez et al., 2012).

Ecological studies at the community scale may be carried out to assess coastal ecosystems (Crowe et al., 2000) and various tools have been developed to treat field data (e.g. Clarke, 1993; Dauer, 1993; Panayotidis et al., 2004; Rombouts et al., 2013). The global diversity approach requires both thorough field sampling and expertise in taxonomic identification (e.g. Guiry and Nic Dhonncha, 2002). Generally, the exhaustive overview of site diversity is not really targeted but reduced lists may give the opportunity to estimate the common specific richness (Wells et al., 2007; Ar Gall and Le Duff, 2013). However, functional grouping of organisms may be preferable than taxonomic one, in particular by reducing spatial and temporal community variability (Steneck and Watling, 1982). The Ecological Evaluation Index (EEI) is a biotic index based on the concept of morphological and functional groups (Littler and Littler, 1980, 1984), which has been adapted to the WFD and compared with several other indices (Shannon-Weaver index, Pielou evenness, Multi-Dimensional Scaling plot of Bray–Curtis similarity; Panayotidis et al., 2004). The EEI assigns marine benthic macrophytes to two different ecological groups, the late-successional or perennials (ESG I) and the opportunistic or annuals (ESG II) (Orfanidis et al., 2001, 2003). The distinction between characteristic and opportunistic species used in several indices is mainly based on that discrepancy (e.g. Neto et al., 2012).

The procedure developed in this work has been inspired by the CFR index, which includes three complementary metrics (global cover of macroalgae, occurrence of characteristic species, total cover of opportunistic species), two of them giving a surface quantification of species occurrence (Juanes et al., 2008; Guinda et al., 2008). However, most of the indices cited above result from a global transect approach, i.e. over all topographic (bathymetric) levels of a rocky shore. Otherwise, the vertical zonation of seaweed communities on hard substrates in temperate areas is well documented and corresponds generally to the development of linear populations (belts) of dominating species (e.g. Stephenson and Stephenson, 1949; Floc'h, 1964, 1970; Lüning, 1990; Cabioc'h et al., 2014). Since both the global cover and the number of common species tend to vary with topographic levels and their corresponding macroalgal associations (Connan, 2004; Ar Gall and Le Duff, 2009, 2014), we developed a three-metric index based on both sampling and initial data treatment per level. It is called CCO for cover–characteristic species–opportunistic species. Results obtained along the Channel–Atlantic coasts of France are discussed regarding both biogeographical specificities, environmental traits and anthropic pressure features in the WFD water bodies.

2. Material and methods

2.1. Description of sampling areas

Both Atlantic and Channel coasts of France are under the influence of a temperate, oceanic climate which corresponds to relatively regular precipitations throughout the year and to moderate air temperature shifts (Peel et al., 2007). Seasonal oscillations of light amounts available at the sea surface are in the range 25–250 $W\,m^{-2}$, measured as average surface solar irradiances (Posselt et al., 2012). Corresponding water bodies are located in the warm temperate region of the Atlantic Ocean and more precisely in the Lusitanian Province, stretching from West Ireland to Senegal (Stephenson, 1948; Briggs, 1974). They are partially under the influence of the North Atlantic drift, which contributes to reduce yearly amplitudes of sea temperatures (Lüning, 1990). Even though temperature conditions are relatively stable at the day to month scale, seasonal variations determine potential modifications in the occurrence of macroscopic algal forms and may modify the cover of structuring Phaeophyceae. However, they do not necessarily impact the global structure and the stability of seaweed communities (Ar Gall and Le Duff, 2014).

The whole littoral between Dunkerque and Biarritz is under the influence of important semidiurnal tide amplitudes (megatidal and macrotidal regimes) corresponding to a major gradient of environmental conditions on the shore and a concomitant altitudinal gradient of adaptation mechanisms in marine organisms (Lüning, 1990). The distribution of intertidal macroalgae shows a latitudinal gradient which is associated with physical environment traits (sea surface temperature (SST), photosynthetically active radiation (PAR), wave height, tidal range and salinity) (Ramos et al., 2012, 2014). As previously mentioned (van den Hoek, 1975; Dinter, 2001), Brittany appears in these studies as a biogeographical transition area which separates the southern from the northern parts of the North East Atlantic coast. Therefore, four geographic regions have been determined for the implementation of the CCO index on the Atlantic–Channel coasts of France: Eastern Channel, Armorican Massif (including Brittany), Poitou-Charentes and Basque Country (Fig. 1 and Table 1). Local environmental specificities, including climate characteristics, hydrodynamics and substrate, have been taken into account and are detailed hereafter. They are conditioning variations in the macroalgal diversity which corresponds to discrepancies in both the occurrence and the abundance of common species. This statement made necessary the elaboration of lists of characteristic species differing from one zone to another.

2.1.1. Eastern Channel: Artois–Picardy, Eastern Normandy

The eastern part of the English Channel is characterized by tides with an average amplitude of 6.30 m and by strong tidal currents in the Dover Strait. These alternating and parallel currents, greater than 1.5 $m\,s^{-1}$, occur at mean spring tide (SHOM, 1988) and result in rather harsh living conditions for seaweeds. Furthermore, they increase the coastal water turbidity originating from the neighboring cretaceous cliffs and rocks, the ooze and terrigenous continental inputs and the sand deposited between rocky areas (Gevaert et al., 2002). Light attenuation of the photosynthetically active radiations (400–700 nm) in this chalky seawater thus ranges from 0.19 to 0.96 m^{-1} (Delebecq et al., 2013). Seawater surface temperature displayed great seasonal variations, with an annual temperature range from 5 °C in winter to 20 °C in summer. In Artois and Picardy, seaweeds communities are restricted to hard rocky Jurassic sandstone areas, which are separated by sandy areas. In Eastern Normandy, a large proportion of the coastline corresponds to limestone cliffs and terraces (hard-grounds) colonized by seaweeds. Cliffs are subjected to erosion by the sea water, giving rock falls which chalk gangue is continuously disaggregated and release flint pebbles. Limestone rock dissolution may result in the occurrence of milky suspensions limiting light penetration in the water column and potentially reducing the development of seaweeds. In addition, the effect of sand burial may regularly disturb their distribution in many sites. Eastern Normandy coastline is also under the influence of both the

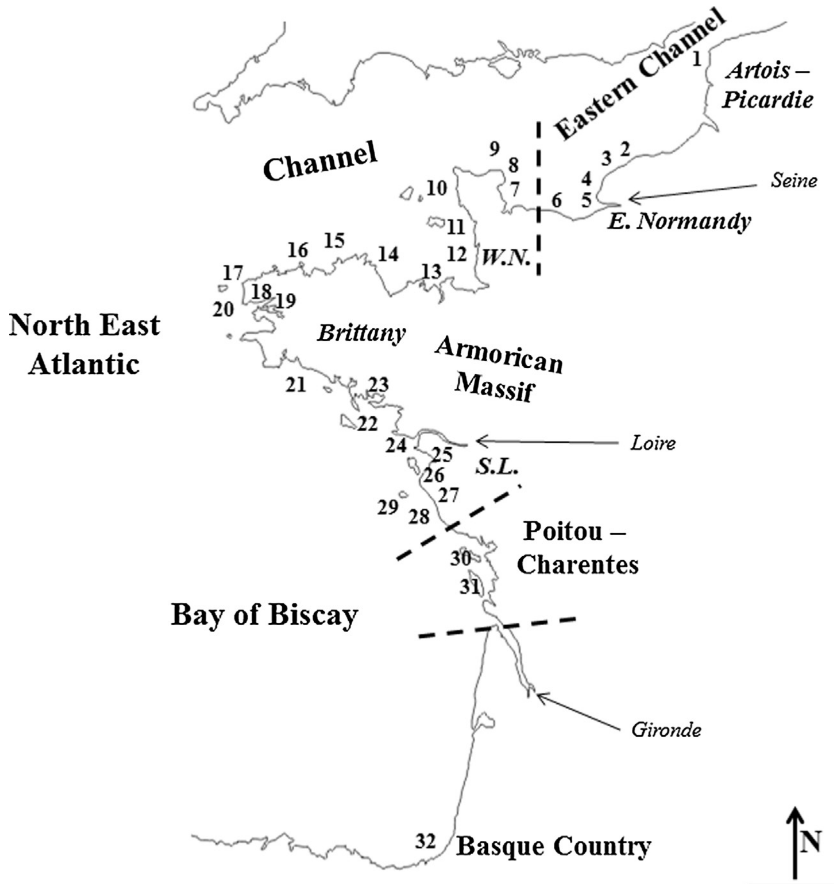

Fig. 1. Location of the 32 sampling sites along the Atlantic–Channel coasts of France and their distribution between four geographic regions. Scale bar: 100 km.

Table 1
Geographical distribution of sites and water bodies along the Atlantic and Channel coasts of France. Numbers refer to those indicated in Fig. 1.

Site number	Water body (FR)	Site	Sampling area	Geographic region
1	AC03	Audresselles	Artois–Picardie	Eastern Channel
2	HC18	Hautot	Eastern Normandy	Eastern Channel
3	HC17	Saint Valéry	Eastern Normandy	Eastern Channel
4	HC17	Bénouville	Eastern Normandy	Eastern Channel
5	HC16	Octeville	Eastern Normandy	Eastern Channel
6	HC13	Saint-Aubin	Eastern Normandy	Eastern Channel
7	HC10	Grandcamp	Western Normandy	Armorican Massif
8	HC09	Tatihou	Western Normandy	Armorican Massif
9	HC07	Cap Levi	Western Normandy	Armorican Massif
10	HC04	Dielette	Western Normandy	Armorican Massif
11	HC03	Pirou	Western Normandy	Armorican Massif
12	HC01	Chausey	Western Normandy	Armorican Massif
13	GC03	Saint-Briac	Brittany	Armorican Massif
14	GC07	Bréhat	Brittany	Armorican Massif
15	GC08	Malban	Brittany	Armorican Massif
16	GC11	Kallot	Brittany	Armorican Massif
17	GC13	Portsall	Brittany	Armorican Massif
18	GC18	Molène	Brittany	Armorican Massif
19	GC16	Delleg	Brittany	Armorican Massif
20	GC16	Karo	Brittany	Armorican Massif
21	GC28	Trégunc	Brittany	Armorican Massif
22	GC36	Quiberon	Brittany	Armorican Massif
23	GC39	Berchis	Brittany	Armorican Massif
24	GC45	Le Croisic	Brittany	Armorican Massif
25	GC46	Saint-Gildas	Sud-Loire	Armorican Massif
26	GC46	Herbaudière	Sud-Loire	Armorican Massif
27	GC47	Yeu Sud	Sud-Loire	Armorican Massif
28	GC48	Bouin Sud	Sud-Loire	Armorican Massif
29	GC50	Brétignolles	Sud-Loire	Armorican Massif
30	GC53	Loix (Ré)	Poitou-Charentes	Poitou-Charentes
31	FC01	Sabia (Oléron)	Poitou-Charentes	Poitou-Charentes
32	FC11	Abbadia	Basque Country	Basque Country

estuary plume streaming from the Seine northwards (Fig. 1) and numerous fresh water resurgences in terraces.

2.1.2. Armorican Massif: Western Normandy (Cotentin), Brittany, South-Loire (Vendée)

Brittany Peninsula constitutes the main part of the Armorican Massif, at the junction between the Channel and the Bay of Biscay in the North–East Atlantic (Fig. 1). That intermediate location favors the mixing between boreal seaweed species introduced through the British Iles and the North Sea and southern species which moved along the coasts of the Bay of Biscay (Cabioc'h et al., 2014). In Brittany, 47 seaweed species are therefore on the boundary of their distribution area, 26 at the northern limit and 21 at the southern one (determined from previous data in Dizerbo and Herpé, 2007). Rocky substrates represent about 50% of the total coast line, favoring the occurrence of wide seaweed covers (Lüning, 1990; Mann, 2000). Metamorphic and plutonic rocks, notably granites, largely dominate in the Armorican Massif. They form hard and rough substrates allowing a better fixation of both zygotes and spores, a solid anchoring of large thalli by their holdfast and eventually the development of sustainable macroalgal communities. Average amplitude of spring tides is in the range 7–10 m on the coasts of the Armorican Massif, and they are larger in the Channel (close to 10 m in Roscoff and to 12 m near Saint Michael's Mount) than on the Atlantic coasts (6–8 m; data from the S.H.O.M., Hydrographic and Oceanographic Service of the French Navy).

2.1.3. Poitou-Charentes

The Pertuis Charentais Sea is located north to the Gironde estuary, halfway between Western Brittany and the Basque Country (Fig. 1). This is a large macrotidal (ca. >6 m) embayment complex constituted by four islands (Ré and Oléron the largest, Aix and Madame the smallest) and three sounds (Pertuis Breton, Pertuis d'Antioche and Pertuis de Maumusson). Rocky outcrops dated from the Jurassic and Cretaceous periods are all calcareous. They are mainly located on the northern and western sides of these islands but co-occurred with large exposed sandy beaches and/or small sheltered muddy bays. The coastline of the mainland is indented by four small estuaries (Lay, Sèvre Niortaise, Charente and Seudre) and is thus dominated by large bare mudflats where scarce rocky shores are surrounded and embedded by muddy sediments. Turbidity of coastal waters thus appears as a main forcing driver of macroalgae distribution in the Pertuis Charentais, with values higher than 100 mg L^{-1} currently recorded in bays with sparse seaweed covers (Héral et al., 1982) and reduced macroalgal diversity (Bréret, 2008).

2.1.4. Basque Country

The water body "Basque coast" is a 35 km southern rock enclave in the conjunction of the Pyrenees and the Atlantic Ocean, with coastal substrates represented mainly by boulders and flysch facies (Alexandre et al., 2003). Environmental conditions are also characterized by a large input of fresh water due to heavy rainfall and a rather long river system (Winckel et al., 2004) and relatively high surface temperatures, with averages of 12 °C in February and 22 °C in August (Valencia et al., 2004). These conditions do not favor the development of macroalgal taxa having an affinity for cold temperate waters like many fucoids and kelps, whereas they facilitate the extension of southern red algae (Gorostiaga et al., 2004). Hydrodynamics features are characterized by energetic waves, the strongest of the French coastline with an average height of 1.8 m for a period of 9.6 s (Alexandre et al., 2003). However, the tidal range is low (mesotidal type, 1.85–3.85 m) with resulting currents between 0.025 and 0.075 m s^{-1} only (Idier and Pedreros, 2005; Augris et al., 2009).

2.2. Sampling: frequency and communities

Field sampling has been carried out on intertidal rocky shores between 2007 and 2012, usually every three years for each site, once a year from February to July during great amplitude tide periods. Thirty-two sites have been studied, corresponding to 29 coastal water bodies (Fig. 1 and Table 1).

Dominant, canopy-forming seaweeds, i.e. Fucales and Rhodophyceae in the intertidal zone and Laminariales in the subtidal zone, grow out linear populations (belts) at given topographic levels which correspond to different average emersion periods and constitute distinctive habitats (Cabioc'h et al., 2014; Ar Gall and Le Duff, 2014). The vertical zonation of macroalgal species is also interacting with hydrodynamism (swell, waves, currents), with macroalgal communities extending in sheltered areas whereas they tend to be restricted to pools in exposed shores (Floc'h, 1964; Lüning, 1990). To get a global overview of the shore vegetation, all seaweed communities occurring at successive vertical levels corresponding to linear populations (belts) of dominating species were sampled each time on each site. The number of communities varied from 2 (a few sites in Normandy and in the Basque Country) to 6 (eight sites in Brittany).

Communities were named by the corresponding dominating species structuring linear populations (belts) constituting protective habitats or canopies. In both the Channel and the Bay of Biscay, six potential communities distributed from the top (below the level of the black, crustose Lichen *Verrucaria maura* Wahlenberg) to the bottom of the shore (on the intertidal–subtidal fringe): *Pelvetia canaliculata* (Linnaeus) Decaisne et Thuret (emerged 75–85% of time), *Fucus spiralis* Linnaeus (emerged 65–75% of time), *Ascophyllum nodosum* (Linnaeus) Le Jolis/*Fucus vesiculosus* Linnaeus (emerged 40–65% of time), *Fucus serratus* Linnaeus/Rhodophyceae (emerged 25–40% of time), *Himanthalia elongata* (Linnaeus) S.F. Gray/*Bifurcaria bifurcata* R. Ross/Rhodophyceae (0–25% of time) and the upper part of the *Laminaria digitata* (Hudson) J.V. Lamouroux belt (0–15% of time), on the fringe of the subtidal zone. In the Basque Country, two different communities only were identified on the rocky shores: *Corallina spp.*/*Caulacanthus ustulatus* (Turner) Kützing in the upper intertidal zone and *Stypocaulon scoparium* (Linnaeus) Kützing/*Gelidium spp.* in the lower intertidal zone.

Sites or bathymetric levels with more than 50% of soft (sand, mud), unstable (gravels, small boulders) or splitting (friable limestone) substrates were not sampled. However, hard substrates potentially covered by 1–2 cm sand/silt could be kept at lower levels when erect macroalgal thalli emerge above the soft layer. Even though sand/silt deposition due to high turbidity reduces the development of large Phaeophyceae (Wells et al., 2007), total specific richness is often improved by the occurrence of a reduced soft layer over a rocky basis, mainly related to the multiplication of small red macroalgae (e.g. lowest level at Bréhat (Table 1, Fig. 1); details not shown). In addition, only sites with at least two macroalgal communities were taken into consideration.

2.3. Evaluation of specific covers

For each community occurring in each site, three 1.65 m × 1.65 m sampling surfaces or spots were precisely located using satellite positioning (GPS – Global Positioning System, handheld Garmin device) and field photographs. The spots were evenly spaced within the community and were permanent. At each sampling session, they were materialized on the rocky substrate by a removable frame comprising 5 × 5 squares named A1 to E5, each 33 cm × 33 cm in size and a bit more than 0.1 m^2 in surface. Before each session, three squares were previously determined randomly for each spot, then placed on the field using the frame and sampled. The surface sampled per community, i.e. 9 squares and ca. 1 m^2,

Table 2
Scale giving the scores of seaweed communities in points for metric 1 in a sampling site. Each score corresponds to the total cover of all macrophytes occurring in the area available for colonization which determines the rank of the corresponding community.

% cover	Rank 1	Rank 2	Rank 3	Rank 4	Ranks 5 & 6
[0–2.5[	0	0	0	0	0
[2.5–5[	2	2	1	1	1
[5–10[	4	3	2	2	2
[10–25[	5	5	3	3	3
[25–50[	6	6	5	4	3
[50–75[	7	7	6	5	4
[75–100]	9	8	7	6	5

was therefore comparable to minimal areas previously used for similar assemblages (Boudouresque, 1974; Connan, 2004). The sampled surface per site corresponded to 27–54 squares and was in the range 3–6 m^2, depending on the number of macroalgal communities. In each sampling square (33 cm × 33 cm), only opportunistic species and characteristic species corresponding to a reduced list adapted to the geographical area were identified in the field. The surface covered by individuals of a given taxon was estimated in each square using percentage intervals, i.e. [0–5[, [5–25[, [25–50[, [50–75[and [75–100], as previously adapted for seaweeds from terrestrial phyto-sociology (L'Hardy-Halos et al., 1973; Connan, 2004). When they were too long to stay arisen at low tide, erect individuals were set up by hand, in order to mimic their contribution to the canopy during immersion, and the covered surface was estimated from the vertical projection of the frond onto the substrate.

2.4. Global plant cover (metric 1)

All bathymetric (topographic) levels of the intertidal zone were concerned. The score of each community in points was obtained using a scale (Table 2) which takes into account both the rank of the community and the macrophyte cover. The rank was determined from the surface (on bedrock or stable boulders) available for colonization by macrophytes, at the corresponding topographic level, and was established relative to other communities at various levels of the shore. The macrophyte cover expressed in percentage included all seaweeds and lichens developing on the available area. Table 2 attributed a score for a covering interval at a given surface rank. Then, points obtained for all communities were cumulated in order to get a global value for the site out of 40. Since the ranking table has been established for a maximum number of six levels (communities) in the intertidal zone, a rule of three was applied to get the score out of 40 when the number of levels was below six. For example, if four communities occur on a shore, their score will be calculated for a total of 9 + 8 + 7 + 6 = 30 points (cf. maximal scores per community in Table 2). A score of y out of 30 will give a score of $(y/30) \times 40$ out of 40. When more than 50% of the substrate surface was unconsolidated (sand, mud, gravels, small boulders) or friable (stratified limestone), the corresponding level was not considered as representative. However, either a high turbidity in the water column or a 1–2 cm sand layer over the rocky substrate was not seen as disqualifying, since Rhodophyceae often replace dominating Phaeophyceae in those cases. When occurring, the sixth surface rank community (i.e. with the less extended surface) shared the same grid as the fifth one.

2.5. Number of characteristic species (metric 2)

Lists of characteristic species have been established for each topographic level, corresponding to macroalgal communities defined as above. *P. canaliculata* (Pc) and *F. spiralis* (Fspi) levels shared a single list, since they exhibit reduced macrophyte diversity. The relative importance of each community in the calculation of the metric was approached using an adapted index table, with a given number of characteristic species per shore level. A global list of characteristic species is given in Table 3a for all Channel–Atlantic sites, but different lists have been designed for each geographic region (Eastern Channel, Armorican Massif and Poitou-Charentes), depending on their flora. The Basque Country was treated apart due to the occurrence of only two belts and the lack of dominance by either Fucales or Laminariales (Table 3b). Corresponding numbers of characteristic species are given in Table 4a, whereas a grid to calculate the scores of metric 2 is shown in Table 4b. Only characteristic species exhibiting a minimal cover of 2.5% per bathymetric level were taken into account. For species with a heteromorphic life-cycle, surfaces covered by each generation were added (e.g. *Mastocarpus stellatus* (Stackhouse) Guiry/*Petrocelis cruenta*). The rating was calculated for five levels (common level for *P. canaliculata* and *F. spiralis*) and when one level (or more) lacked on the site, a rule of three was applied to get the score out of 30 for the metric.

2.6. Cover by opportunist species (metric 3)

Whatever the geographic area and the topographic level, this metric took into account the cover by Ectocarpales (Ectocarpaceae: *Ectocarpus spp.*, *Pylaiella spp.*, *Hincksia spp.*) in Phaeophyceae, by the Chlorophyceae *Ulva (Enteromorpha) compressa* Linnaeus, *Ulva (Enteromorpha) ramulosa* (Smith) Hooker and foliose *Ulva spp.*, by the Rhodophyceae *Ceramium spp.*, *Polysiphonia spp.* (excluding both *P. lanosa* and *P. elongata*) and *Boergeseniella spp.*, and by colonial microalgae (particularly epiphytic and epilithic Diatoms). Covers obtained per level were reported to the grid shown in Table 5 to get scores. These values were then added per site to reach a maximum score of 30 for five levels (including *P. canaliculata* + *F. spiralis*), when covers by opportunists were below 5% in each community. When one was lacking, the total rating was obtained by adding the values of occurring communities and applying to the result a rule of three. In the calculation, the same weight was given to each community (or group of communities for *P. canaliculata* + *F. spiralis*).

2.7. Determination of the qualitative status (boundaries)

The ecological quality status (EQS) of a given site for the quality element "intertidal macroalgae" was obtained by adding the three metrics calculated as above (global plant covering (0–40), number of characteristic species (0–30) and cover by opportunist species (0–30)) to get a maximum rating of 100. Boundaries of the ecological status were established following results of the European Intercalibration Exercise (JRC, 2013) and are given in Table 6, together with the Ecological Quality Ratio (EQR) corresponding to the EQS values divided by the theoretical maximum of 100, as defined for other indices used in the coastal water bodies of the North East Atlantic.

2.8. Evaluation of anthropogenic pressures

Anthropogenic pressures were estimated following a semi-quantitative scale established during the inter-calibration process of macroalgae in the North East Atlantic by the Geographical Inter-calibration Group (JRC, 2013). That scale includes three components: urban discharge (wastewater estimated in human equivalents and distance between effluent release and site), industrial pollution (estimated in human equivalents and from the distance between industrial facilities and site) and diffuse pressure (eutrophication and diffuse pollution, shore attendance, artificial infrastructures; expert evaluation). A score between 0 and 4 is given

Table 3
Global lists of characteristic, macrophyte taxa occurring per belt/topographic level:.

(a) On the coasts of the geographic regions Eastern Channel (1), Armorican Massif (2) and Poitou-Charentes (3)

Pelvetia canaliculata + Fucus spiralis	*Ascophyllum nodosum/Fucus vesiculosus*	*Fucus serratus*	*Himanthalia elongata/Bifurcaria bifurcata*	*Laminaria digitata*
Ascophyllum nodosum[1,2,3]	*Ascophyllum nodosum*[1,2,3]	*Calliblepharis jubata*[3]	*Asparagopsis armata*[2]	*Calliblepharis jubata*[2,3]
Catenella caespitosa[1,2,3]	*Catenella caespitosa*[3]	*Chondrus crispus*[1,2,3]	*Bifurcaria bifurcata*[2]	*Chondracanthus acicularis*[1,2,3]
Cladophora rupestris[3]	*Cladophora rupestris*[1,2,3]	*Cladophora rupestris*[1,2,3]	*Calliblepharis jubata*[2,3]	*Chondria coerulescens*[3]
Fucus spiralis[1,2,3]	*Corallina spp.*[1,2,3]	*Corallina spp.*[1,2,3]	*Callithamnion tetricum*[3]	*Chondrus crispus*[1,2,3]
Hildenbrandia rubra[1,2,3]	*Fucus serratus*[1,2,3]	*Cryptopleura ramosa*[1,2]	*Chondracanthus acicularis*[1,2,3]	*Corallina spp.*[1,2,3]
Lichina pygmaea[2]	*Fucus vesiculosus*[1,2,3]	*Fucus serratus*[1,2,3]	*Chondrus crispus*[1,2,3]	*Cryptopleura ramosa*[1,2,3]
Pelvetia canaliculata[1,2,3]	*Gelidium pusillum*[1,2,3]	*Gelidium pusillum*[1,2]	*Cladophora rupestris*[1,2,3]	*Cystoclonium purpureum*[1,2]
Porphyra spp.[1]	*Gelidium spinosum*[1,2]	*Gelidium spinosum*[1,2,3]	*Corallina spp.*[1,2,3]	*Dictyopteris polypodioides*[3]
Rhodothamniella floridula[3]	*Lithophyllum incrustans*[1,2,3]	*Lithophyllum incrustans*[1,2,3]	*Cryptopleura ramosa*[1,2,3]	*Dictyota dichotoma*[3]
Verrucaria maura[1,2]	*Lithothamnion lenormandii*[1,2,3]	*Lithothamnion lenormandii*[1,2,3]	*Cystoclonium purpureum*[1,2]	*Gelidium spinosum*[3]
	Lomentaria articulata[1,2]	*Lomentaria articulata*[1,2]	*Gelidium spinosum*[1,2,3]	*Gracilaria bursa-pastoris*[3]
	Mastocarpus stellatus[1,2]	*Mastocarpus stellatus*[1,2]	*Himanthalia elongata*[2]	*Gymnogongrus crenulatus*[3]
	Osmundea pinnatifida[3]	*Osmundea pinnatifida*[1,2,3]	*Laurencia obtusa/hybrida*[1,2,3]	*Himanthalia elongata*[2]
	Plumaria plumosa[1,2]	*Palmaria palmata*[1,2]	*Lithophyllum incrustans*[1,2,3]	*Laminaria digitata*[1,2]
	Ralfsia verrucosa[3]	*Plumaria plumosa*[1,2]	*Lithothamnion lenormandii*[3]	*Laurencia obtusa/hybrida*[1,2,3]
	Rhodothamniella floridula[1,2,3]	*Ralfsia verrucosa*[3]	*Lomentaria articulata*[1,2,3]	*Lithophyllum incrustans*[1,2,3]
		Rhodothamniella floridula[1,2,3]	*Mastocarpus stellatus*[1,2]	*Lomentaria articulata*[1,2]
			Osmundea pinnatifida[1,2,3]	*Mastocarpus stellatus*[1,2]
			Palmaria palmata[1,2]	*Osmundea pinnatifida*[1,2,3]
			Plocamium cartilagineum[1,2]	*Palmaria palmata*[1,2]
			Rhodothamniella floridula[1,2,3]	*Plocamium cartilagineum*[1,2,3]
				Saccharina latissima[1,2,3]
				Saccorhiza polyschides[2,3]
10 taxa	16 taxa	17 taxa	21 taxa	23 taxa

(b) On the coasts of the Basque Country (France)

Corallina spp./Caulacanthus ustulatus	*Stypocaulon scoparium/Gelidium spp.*
Caulacanthus ustulatus	*Asparagopsis/Falkenbergia*
Chondracanthus acicularis	*Caulacanthus ustulatus*
Chondria coerulescens	*Chondria coerulescens*
Colpomenia peregrina	*Codium adaerens*
Corallina spp.	*Colpomenia peregrina*
Lithophyllum incrustans	*Corallina spp.*
Phymatolithon lenormandii	*Dictyota dichotoma*
	Gelidium spp (corneum/latifolium)
	Halurus equisetifolius
	Jania rubens
	Lithophyllum incrustans
	Stypocaulon scoparium
7 taxa	12 taxa

Table 4
Evaluation of metric 2.

(a) Number of characteristic taxa taken into account in each zone per belt/bathymetric level for the calculation of metric 2

	Pelvetia + Fucus spiralis	*Ascophyllum/F. vesiculosus*	*Fucus serratus*	*Himanthalia/Bifurcaria*	*Laminaria digitata*
Eastern Channel	7	13	15	15	14
Armorican Massif	7	13	15	19	17
Poitou-Charentes	7	12	11	14	17
Basque Country	*Corallina spp./Caulacauthus* 7	(higher intertidal)	*Stypocaulon scoparium/Gelidium spp.*	12	(lower intertidal)

(b) Grid based on the proportion of characteristic species of each list covering at least 2.5% of the quadrates and corresponding scores

Percentage of characteristic species	Score per community
>50	30
[35–50]	20
[20–35]	10
[5–20]	5
0	0

for both urban and industrial pollutions, between 0 and 3 for diffuse pollution, giving a global evaluation between 0 and 11, 0 for very few/not impacted sites, 11 for extremely perturbed areas.

2.9. Statistics

Statistical analysis was performed with the Statistica 10 software. After checking the homoscedasticity of variances, the differences between data were tested by either ANOVA or Kruskal–Wallis' test. When data showed significant differences ($p < 0.05$), an a posteriori test was used to rank values, either Fisher's least significant difference test (LSD) after ANOVA or a box-and-whisker diagram after Kruskal–Wallis. Correlations among data were calculated using Spearman's correlation coefficient (rs).

3. Results

3.1. Ratings and EQS for sites and water bodies

CCO ratings for the sub-BQE "intertidal macroalgae" (BQE "macroalgae–seagrasses") are displayed in Tables 7 and 8. Table 7 exhibits detailed values for the 2010–2012 campaign, with scores for metrics 1, 2 and 3 which may explain discrepancies in total CCO ratings, linking them to differences in global cover, number of characteristic species and/or extension of opportunists. Scores were in the range 21.18–40 for metric 1, 2.5–28 for metric 2 and 15–30 for metric 3, with averages at 32.41 ± 4.40, 17.72 ± 7.15 and 22.06 ± 4.76, respectively. Metric 2 appeared therefore more discriminating with lowest scores (Table 7) corresponding to moderate or hardly good EQS (Table 8). Metric 1 was not significantly correlated either to metric 2 or to metric 3 (Spearman, $p > 0.05$) and metrics 2 and 3 were only weakly correlated (Spearman, rs = 0.4775), in agreement with the relative complementarity between metrics. For highest graded sites, like Portsall and Molène with EQRs above 0.90, all CCO components yielded very good scores. At the opposite, at Octeville, low values have been noted for all three metrics (Table 7), with a medium macroalgal cover (metric 1), very few characteristic species (metric 2) and rather high opportunistic occurrence (metric 3), in agreement with a global degradation of macroalgal communities, with the lowest EQR of the sampling set at 0.45. Intermediate ranking generally depended on the modest score of either one single metric, like in Pirou (metric 2) or in Abbadia (metric 3), or two metrics, like in Saint-Aubin and Octeville. A parallel may be drawn between the rating of several sites and their relative substrate instability. For example, few characteristic species were recorded in seaweed communities of Hautot, Octeville, Saint Aubin and Pirou (Normandy), resulting in low scores for metric 2 which can partially account for a moderate EQS in Hautot, Octeville and Pirou. The occurrence of a very good macrophyte global cover (metric 1) in Saint-Aubin allowed that site to reach a hardly good status.

Table 8 gives a comparison between CCO results of two sampling sets, 2007–2009 and 2010–2012, which correspond to data collected along the Atlantic and Channel coasts of France over a six year period corresponding to a WFD management cycle. Site ratings ranged between 47 and 94 (EQR 0.47–0.94) in 2009 and between 46 and 93 in 2012 (EQR 0.46–0.93). Distribution of EQS was as follows in 2009: over 26 sites (24 water bodies), 4 sites or 15.4% of total (4 water bodies) were moderate, 14 or 53.8% (12) good, 8 or 30.8% (8) high. Water body FRHC17 was moderate, with an average EQR 0.58 calculated from two constitutive sites (Saint Valéry and Bénouville), whereas FRGC16 was high, with an average EQR of 0.82, also calculated from two constitutive sites (Delleg and Karo, in the Bay of Brest). In 2012, distribution of EQS was as follows: over 32 sites (29 water bodies), 3 sites or 12.1% (3 water bodies) were moderate, 19 or 57.6% (17) good, 10 or 30.3% (9) high. Water body FRHC17 reached a good status in the 2012 round, with an average EQR of 0.70. Water body FRGC16 remained high with an average 0.87 and FRGC46 was good at 0.73. One may notice a slight increase in the number of sites and water bodies reaching a good ecological state (good or high status). This global, apparent stability however co-occurs with contrasted evolutions at the site (water body) scale. Among sites sampled twice within the six year period (2007–2012), 7 had a reduced CCO rating in 2012, including 5 with a strong decrease. Nevertheless, only one water body (FRGC39, Berchis) changed EQS, shifting from high to good. At the opposite, ratings increased for 15 sites, sometimes markedly, leading to a change from moderate to good for 2 water bodies (FRHC04 (Dielette) and FRHC17 (St Valéry-en-Caux)) and from good to high for 3 water bodies (FRGC03 (St Briac), FRGC16 (Karo) and FRGC36 (Quiberon)). When sites have been sampled twice, an average rating has been calculated over a six year period, as recommended by EC (EC, 2000), and expressed as EQR in Table 8. On a total of 26 sites of that type, 8 showed a high EQS (only in Brittany) (8 water bodies), 14 a good EQS (14 water bodies) and 4 were moderate (only in Normandy) (3 water bodies). The highest ratings (over 90 points/100 and EQR 0.90) have been obtained for two Breton sites, Portsall (FRGC13, average 0.94) and Molène (FRGC18, 0.91 in 2012 but average 0.87), which we consider as reference sites for intertidal macroalgae.

Compensation in scoring using rules of three was essential to overtake the intrinsic discrepancies between sites linked to the number of vegetated topographic levels corresponding to macroalgal communities (Table 7). Indeed, the total rating (68.2 points) obtained in Abbadia (Basque Country) underlines the fact that the CCO procedure is compatible with a reduced number of macroalgal communities, illustrating also the necessity of adapted lists of characteristic species per level and per geographical zone. However, a reduced number of sampled levels may amplify the impact of environmental instability, noticeably in the presence of surrounding soft substrates. For example, only two communities (levels) were sampled in 2009 in five sites of Normandy, which all obtained borderline ecological evaluations by CCO. In several of these sites however, one or two levels more could have been sampled if 50–100 m lateral deviations from the middle transect line would have been accepted. We therefore recommend some flexibility in defining the limits of the sampling area.

Table 5
Grid giving the score for each bathymetric level/belt based on the cover of opportunistic taxa.

Value	Cover of opportunistic taxa
6	<5%
4	5–25%
2	25–50%
1	50–75%
0	75–100%

Table 6
Rating and EQR boundaries determining each ecological quality status (EQS) for the CCO evaluation of coastal water bodies.

rating boundaries	EQR boundaries	Status
80–100	0.80–1	High
60–79	0.60–0.79	Good
40–59	0.40–0.59	Moderate
20–39	0.20–0.39	Poor
0–19	0–0.19	Bad

Table 7
CCO ratings of sites and corresponding water bodies obtained in 2012 on the Atlantic–Channel coasts of France (sampling in 2010, 2011 and 2012).

Site name	Water body (FR)	Sampled levels Number	Metric 1 Global covering/40 points	Metric 2 Characteristic species/30 points	Metric 3 Opportunistic species/30 points	Total score/100 points	EQR
Audresselles	AC03	5	34.29	13	17	64.29	0.65
Hautot	HC18	3	33.33	3.33	20	56.66	0.57
Saint Valéry	HC17	3	35	10	20	68.33	0.68
Bénouville	HC17	4	34.37	20	20	74.65	0.75
Octeville	HC16	2	28.23	2.5	15	45.73	0.45
Saint-Aubin	HC13	2	40	5	15	60	0.60
Grandcamp	HC10	3	30	11.67	20	61.67	0.62
Tatihou	HC09	2	28.23	15	25	68.23	0.68
Cap Levi	HC07	4	22.67	18.33	23.33	64.33	0.64
Dielette	HC04	2	21.18	12.5	30	63.68	0.64
Pirou	HC03	2	28.23	7.5	20	55.73	0.56
Chausey	HC01	4	28	16.67	30	74.67	0.75
Saint-Briac	GC03	6	37	19	24	80	0.80
Bréhat	GC07	5	40	27.5	20	87.5	0.88
Malban	GC08	6	33	24	26	83	0.83
Kallot	GC11	6	35	24	22	81	0.81
Portsall	GC13	6	35	28	30	93	0.93
Molène	GC18	6	35	26	30	91	0.91
Delleg	GC16	6	36	24	26	86	0.86
Karo	GC16	5	29.7	27.5	25	82.2	0.82
Trégunc	GC28	6	29	26	28	83	0.83
Quiberon	GC36	5	34.28	22.5	27.5	84.28	0.84
Larmor-Baden (Berchis)	GC39	5	34.3	22.5	20	76.8	0.77
Le Croisic	GC45	6	33	19	26	78	0.78
Saint-Gildas	GC46	5	38	17	18	73	0.73
Herbaudière	GC46	5	34.28	16.25	22.5	73.03	0.73
Yeu Sud	GC47	5	30.86	17.5	20	68.36	0.68
Bouin Sud	GC48	3	38.33	8.33	20	66.66	0.67
Brétignolles	GC50	2	35.29	12.5	15	62.79	0.63
Loix (Ré)	GC53	4	38.67	21.25	17.5	77.42	0.77
Sabia (Oléron)	FC01	5	37.71	18	20	75.71	0.76
Abbadia	FC11	2	28.2	25	15	68.2	0.68

Table 8
Evolution of scores (as EQR) obtained for the CCO between 2009 (sampling in 2007, 2008 and 2009) and 2012 (sampling in 2010, 2011 and 2012) on the Atlantic–Channel coasts of France. When sites have been sampled only one year, both average EQR and global EQS correspond to that year. Average EQR and global EQS are the same for sites and water bodies, except for HC17 and GC16.

Water body (FR) Site	EQR2009	EQS 2009	EQR2012	EQS 2012	AverageEQR	GlobalEQS
AC03 – Audresselles	0.65	Good	0.64	Good	0.65	Good
HC18 – Hautot	0.47	Moderate	0.57	Moderate	0.52	Moderate
HC17 – Saint Valéry	0.50	Moderate	0.68	Good	0.59	Moderate
HC17 – Bénouville	0.65	Good	0.75	Good	0.70	Good
HC16 – Octeville	0.52	Moderate	0.46	Moderate	0.49	Moderate
HC13 – Saint-Aubin	0.60	Good	0.60	Good	0.60	Good
HC10 – Grandcamp	0.68	Good	0.62	Good	0.65	Good
HC09 – Tatihou	0.65	Good	0.68	Good	0.67	Good
HC07 – Cap Levi	0.64	Good	0.64	Good	0.64	Good
HC04 – Dielette	0.55	Moderate	0.64	Good	0.59	Moderate
HC03 – Pirou	n.d.	n.d.	0.56	Moderate	0.56	Moderate
HC01 – Chausey	0.63	Good	0.75	Good	0.69	Good
GC03 – Saint-Briac	0.77	Good	0.80	High	0.79	Good
GC07 – Bréhat	0.86	High	0.88	High	0.87	High
GC08 – Malban	0.80	High	0.83	High	0.82	High
GC11 – Kallot	0.85	High	0.81	High	0.83	High
GC13 – Portsall	0.94	High	0.93	High	0.94	High
GC18 – Molène	0.83	High	0.91	High	0.87	High
GC16 – Delleg	0.88	High	0.86	High	0.87	High
GC16 – Karo	0.75	Good	0.82	High	0.79	Good
GC28 – Trégunc	0.81	High	0.83	High	0.82	High
GC36 – Quiberon	0.75	Good	0.84	High	0.80	High
GC39 – Berchis	0.82	High	0.77	Good	0.79	Good
GC45 – Le Croisic	0.78	Good	0.78	Good	0.78	Good
GC46 – Saint-Gildas	n.d.	n.d.	0.73	Good	0.73	Good
GC46 – Herbaudière	n.d.	n.d.	0.73	Good	0.73	Good
GC47 – Yeu Sud	n.d.	n.d.	0.68	Good	0.68	Good
GC48 – Bouin Sud	n.d.	n.d.	0.67	Good	0.67	Good
GC50 – Brétignolles	n.d.	n.d.	0.63	Good	0.63	Good
GC53 – Loix (Ré)	0.70	Good	0.77	Good	0.74	Good
FC01 – Sabia (Oléron)	0.68	Good	0.76	Good	0.72	Good
FC11 – Abbadia	0.76	Good	0.68	Good	0.72	Good

Table 9
Evolution of EQRs obtained by the CCO index in geographic regions of the Channel–Atlantic coasts of France and on the whole sampling coast. Letters refer to LSD post hoc results after separate ANOVAs at the region level for 2009, 2012 and 2009 + 2012 sets.

Geographic region	EQR 2009	EQR 2012	Average EQR
Whole sampling coast	0.71 ± 0.12	0.73 ± 0.11	0.72 ± 0.12
Eastern Channel	0.57 ± 0.08^{b}	0.62 ± 0.10^{b}	0.59 ± 0.09^{b}
Armorican Massif	0.76 ± 0.09^{a}	0.76 ± 0.10^{a}	0.76 ± 0.10^{a}
Poitou-Charentes	0.69 ± 0.01^{ab}	0.77 ± 0.01^{ab}	0.73 ± 0.04^{ab}
Basque Country	0.76^{ab}	0.68^{ab}	0.72 ± 0.06^{b}
ANOVA	$F = 6.4712$, $p = 0.0026$	$F = 3.2675$, $p = 0.0359$	$F = 9.4746$, $p < 0.0000$

3.2. Comparative study of geographic areas

Average CCO ratings are given in Table 9 for geographical regions and the whole sampling coast. Results show no significant variation of EQR on the whole sampling coast between 2009 and 2012 (ANOVA, $F = 0.285$, $p = 0.5957$), underlining the overall stability of macroalgal communities (average EQR = 0.72 ± 0.12). Data obtained in intertidal seaweed communities by the CCO evaluation suggest that water bodies are little affected by human activities, since most of the EQS are above the good status threshold except Eastern Channel in 2009 and on the whole six year sampling period. A significant difference has been demonstrated between geographic areas, with lower ratings in Eastern Channel and higher ratings in the Armorican Massif (Table 9). With 8 sites over 12 at a high ecological status in 2009 and 10 in 2012, the Armorican Massif reached an average EQR of 0.76 ± 0.10 over the six year sampling period. Eastern Channel exhibited a global moderate status, related to low ratings of three sites in 2009 and two in 2012 (Table 8). Considering the long rocky coastline of the Armorican Massif and the fact that most sampling sites (23 over 32) were located in that region, ratings of its constitutive sampling areas have been compared. Significant differences have been found in 2009, 2012 and 2009 + 2012 between Brittany, with high EQRs of 0.82 ± 0.06, 0.84 ± 0.05 and 0.83 ± 0.05, respectively, and both Western Normandy at $0.63–0.65 \pm 0.06$ and South Loire at 0.69 ± 0.04 (ANOVAs per period: 2009, $F = 21.30$, $p < 0.0000$; 2012, $F = 32.15$, $p < 0.0000$; 2009 + 2012, $F = 9.48$, $p < 0.0000$; plus LSD post hoc analysis). That result is in agreement with the large seaweed biomasses and the exceptional macroalgal diversity of Brittany (Ar Gall and Le Duff, 2014). Concerning geographic regions, some variations have been observed between 2009 and 2012, even though not significant, with an increase in Eastern Channel and Poitou-Charentes and a decrease in the Basque Country (Table 9).

3.3. Relationship with anthropogenic pressures

Firstly, as suggested by weak multiannual variations of EQRs observed in geographic regions (Table 9), the lack of important changes in anthropogenic pressures may be suspected over the six year sampling period. Types and ratings of pressures have been established in a semi-quantitative composite index (JRC, 2013), which components are displayed in parallel to EQRs in Table 10. A significant, negative correlation has been established between anthropogenic pressures and CCO evaluation, following Spearman's test ($N = 32$, $p = 0.0000$, $rs = -0.8290$, $rs^2 = 0.6872$). CCO may be therefore considered as validated for the implementation of WFD in coastal water bodies. Most sites exhibited no pollution or only diffuse pressure (intermediate eutrophication, fishing on the shore including boulder rolling over, trampling), particularly in Brittany, where high EQRs have been recorded. Sites in Normandy seem to be more impacted than elsewhere but the pertinence of sampling in some of them could be discussed, due to the natural instability of their substrates. On the whole coastline, only two sites were partially impacted by industrial pollution, Dielette, located in the vicinity of the nuclear plant of Flamanville, and Octeville, in front of which industrial residues have been dumped at sea over decades (Port Autonome du Havre, 2007).

Table 10
Anthropic pressures impacting the sampling sites ranked by their CCO rating (EQR).

Sites	Urban discharge	Industrial pollution	Diffuse pressure	Pressure score	EQR
Portsall	0	0	0	0	0.94
Delleg	1	0	0	1	0.88
Bréhat	0	0	0	0	0.87
Molène	0	0	0	0	0.87
Kallot	0	0	1	1	0.83
Malban	0	0	0	0	0.82
Trégunc	1	0	0	1	0.82
Quiberon	0	0	1	1	0.80
Karo	0	0	1	1	0.79
St Briac	1	0	0	1	0.79
Berchis	2	0	0	2	0.79
Le Croisic	0	0	1	1	0.78
Loix (Ré)	1	0	0	1	0.74
Saint Gildas	0	0	1	1	0.73
Herbaudière	0	0	1	1	0.73
Abbadia	2	0	0	2	0.72
Sabia (Oléron)	0	0	1	1	0.72
Bénouville	0	0	1	1	0.70
Chausey	0	0	1	1	0.69
Yeu Sud	1	0	1	2	0.68
Bouin Sud	0	0	1	1	0.67
Tatihou	1	0	1	2	0.67
Audresselles	1	0	1	2	0.65
Grandcamp	0	0	1	1	0.65
Cap Lévi	0	0	2	2	0.64
Brétignolles	0	0	2	2	0.63
Saint Aubin	1	0	1	2	0.60
Dielette	0	1	1	2	0.59
Saint Valéry	2	0	2	4	0.59
Pirou	0	0	3	3	0.56
Hautot	1	0	2	3	0.52
Octeville	0	2	3	5	0.49

4. Discussion

The CCO index has been developed to assess the ecological status of coastal water bodies in the context of the WFD (European Water Framework Directive) implementation, using intertidal macroalgal communities as bio-indicators. The WFD aims at both assessing the good ecological status of all water bodies on the territory of the European Community and compelling member states to restore it where necessary (E.C., 2000, 2008). Developed at first as a derivative of the Spanish CFR (Guinda et al., 2008), the originality of the CCO index is related to a community rather than a global site approach: sampling per topographic level, each corresponding to the potential occurrence of 1–2 dominating species; compensating calculation relative to the extension of each community, in terms of macrophyte-covered surface; lists of characteristic species per level. It does not reflect a global macroalgal diversity per site like the RSL (Wells et al., 2007), neither a global, stretch-based approach of the coastline like CARLIT (Ballesteros et al., 2007), but it has rather been inspired by the assessment of community structure (Ar Gall and Le Duff, 2014). In addition, the use of 0.1 m^2 sampling units rather than transects of tens meters long makes the estimation of taxon covers more precise. The surveillance program of intertidal macroalgal communities included 28 coastal water bodies over a total of 88 along the French Atlantic–Channel coast, following a six year round shared into two periods of three years.

In the prospect of evaluating putative degradations linked to human activities, CCO may be considered as efficient, since a clear relationship has been established between ratings and resulting EQS calculated from macroalgae data on one side, anthropogenic pressures on the other side. Even though the robustness of CCO could be strengthened through a wider pressure–impact study, the correlation level established in our work ($r^2 = 0.6872$) is close to/better than that obtained for other indices based on communities of intertidal macroalgae like CFR, MarMat, several versions of RSL or RICQI (Gaspar et al., 2012; JRC, 2013; Guinda et al., 2014). During the European inter-calibration process, a regression coefficient had been calculated for CCO on the basis of 8 sites on the French coast which was even slightly better ($r^2 = 0.7577$) (JRC, 2013). The pressure–impact relationship displayed by CCO is also comparable to results listed for several BQE and three hundred indicators tested to assess the ecological status of European surface waters (Birk et al., 2012).

CCO has been already inter-calibrated with both CFR and MarMat (JRC, 2013) and referenced N° 354 in the WISER (EU-project: Water bodies in Europe: Integrative Systems to assess Ecological status and Recovery) database (http://wiser.eu/). A supplementary inter-calibration exercise should be soon attempted with the British RSL index (Wells et al., 2007), in the logic of the new North East Atlantic classification of coastal waters of Europe based on macroalgal communities (Ramos et al., 2014). Following that typology, Atlantic and Channel coasts of France are split in southern Brittany between A2 biotype, common to both Spain and Portugal, and B21 biotype, with the British Isles and Norway.

As described above, both geographic regions of the Atlantic–Channel coasts of France differ by their environmental characteristics, mainly in terms of substrate quality: (a) extension of hard substrates and shores amenable to the settlement of macroalgal communities; (b) proportion of outcrop bedrock versus unstable boulders and pebbles; (c) composition and particle size of constitutive minerals, since rough, hard rocks make easier the fixation of large holdfasts; (d) occurrence of mobile sand and mud. In that prospect, the coastline of the Armorican Massif, particularly in Brittany, appears more suitable to the development of both large seaweed biomasses and well-structured macroalgal communities (Ar Gall and Le Duff, 2014). Consequently, environmental traits could be invoked to explain that Breton sites obtained the best EQRs/EQSs. In the same way, the degradation of several sites to moderate ecological status in Normandy may be also partially due to environmental factors, in particular to sediment instability. The CCO index has been designed to fit with one to six topographic levels and corresponding macroalgal communities, using a compensating rule of three (cf. results in the Basque Country). However, when less than one half of the levels usually available in a given area is sampled, the resulting CCO evaluation may be somehow impaired by an artificial instability. The pertinence of corresponding sites may be then questioned. In addition, the representativeness of the quality element "intertidal macroalgae" in some coastal water bodies may also be controversial, even though those exhibiting mainly soft bottoms have been previously removed from the surveillance monitoring program (e.g. FRGC05, Bay of Saint-Brieuc in Brittany). Nevertheless, anthropogenic pressures calculated from JRC (2013) gave an average 0.75 in Brittany, versus 1.5 for all sites and around 2.36 in Normandy, so in global agreement with EQR range, outlining the accuracy of CCO ratings at the geographic region level. Whatever our concerns about the understanding of cause (human pressures)–effect (CCO EQRs) relationships, our results (correlation coefficient > |0.7|) suggest that more than one half of the biological variability observed in macroalgal communities, a highly integrative BQE, may be explained by pressure effects (Birk et al., 2012). A better comprehension is required to decide which management actions should be implemented to improve water quality when necessary (in case of moderate to poor EQS). A solution would consist in developing a more complete grid to assess anthropogenic pressures, including for example fertilizer inputs and artificial embanking. In addition, CCO evaluation could be compared with results obtained in the same water bodies by other indicators, in particular by indicators based at least partially on macroalgae, e.g. subtidal communities (Derrien-Courtel and Le Gal, 2011) and green seaweed blooms (Rossi, 2011).

In conclusion, CCO may help select representative sites for the ecological evaluation of coastal water bodies by intertidal seaweed communities, considering the advanced community approach of the index (Ar Gall and Le Duff, 2014). CCO meets globally the requirements described by Borja and Dauer (2008) for environmental indicators following the DPSIR (drivers–pressures–state changes–impacts–responses) approach (Elliott, 2002; Atkins et al., 2011). To assess the sensitivity and uncertainty versus the inherent variability of the index (Borja et al., 2013), further sampling cycles will be probably necessary in the future. The pertinence of the sub-BQE intertidal macroalgae and the representativeness of sampling sites in corresponding water bodies must be taken into consideration. In that prospect, CCO is being tested in supplementary sites located in water bodies not included in the surveillance program in Brittany, on the initiative of the Loire-Brittany Water Agency. Several questions have been also addressed concerning the ecological significance of observed discrepancies, the putative link with environmental factors such as hydrodynamism, hard substrate availability and sedimentology, and the notion of biogeographical gradient. About biogeography, combined latitudinal and longitudinal gradients and suspected evolutions due to climatic global change, some answers may be found in Ramos et al. (2014). About representativeness of the sites and substrates, sixteen sampling sites of our study out of thirty-two were located in water bodies in which soft bottoms dominated, three of them rated high by CCO, twelve good and only one moderate. However, correlation coefficients found between anthropogenic pressures and CCO results on one side, the area related co-distribution of low pressure and high EQR ratings on the other side support the accuracy of CCO to assess the ecological status of coastal water bodies. In addition, the implementation of CCO initiated a collaborative project at the French Channel–Atlantic level, with connections at the European scale (Ramos et al., 2014 and Guinda et al., 2014). At last, even though our index is not aimed at assessing the ecological status of assemblages, biocenoses or ecosystems (Ar Gall and Le Duff, 2014; Personnic et al., 2014), the CCO approach developed here differs from other WFD indices by the integration of the community–habitat dimension.

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