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

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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

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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