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Quality Index of Subtidal Macroalgae (QISubMac): A suitable tool for ecological quality status assessment under the scope of the European Water Framework Directive

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ABSTRACT

Despite their representativeness and importance in coastal waters, subtidal rocky bottom habitats have been under-studied. This has resulted in a lack of available indicators for subtidal hard substrate communities. However, a few indicators using subtidal macroalgae have been developed in recent years for the purpose of being implemented into the Water Framework Directive (WFD). Accordingly, a quality index of subtidal macroalgae has been defined as a French assessment tool for subtidal rocky bottom habitats in coastal waters. This approach is based on 14 metrics that consider the depth penetration, composition (sensitive, characteristic and opportunistic) and biodiversity of macroalgae assemblages and complies with WFD requirements. Three ecoregions have been defined to fit with the geographical distribution of macroalgae along the French coastline. As a test, QISubMac was used to assess the water quality of 20 water bodies. The results show that QISubMac may discriminate among different quality classes of water bodies.

1. Introduction

According to the United Nations Environment Programme, more than 50% of the global human population is concentrated in littoral areas (less than 60 km from the shoreline). Consequently, coastal areas are impacted by human activities such as industrial and urban discharge, agriculture, natural resource exploitation, and construction. The observed degradation of marine ecosystems led to several policy decisions. In Europe, the Water Framework Directive (WFD, 2000/60/EC) and the Marine Strategy Framework Directive (MSFD, 2008/56/EC) were implemented to evaluate and then maintain or recover good ecological status.

The Water Framework Directive (WFD) requires each member state of the European Union to achieve a good status for their surface and ground water (rivers, lakes, transitional waters, and coastal waters) by 2015 (WFD, 2000/60/EC). According to this directive, both the ecological and chemical status must be assessed. The ecological status evaluation is based on the use of biological quality elements (BQEs) and the definition of reference conditions (undisturbed or nearly so). The deviation between the observed and reference conditions is expressed as a ratio (ranging from 0 to 1), known as the ecological quality ratio (EQR). Finally, the ecological quality status (EQS) is classified into five quality classes (bad, poor, moderate, good and high) on the basis of EQR results.

To assess coastal water quality, the selected BQEs include macroinvertebrates, phytoplankton and aquatic flora such as angiosperms and macroalgae (WFD, 2000/60/EC). Macroalgae are considered to be good indicators for reflecting environmental pressures (Gorostiaga and Díez, 1996) such as eutrophication (Blomqvist et al., 2012; Eriksson et al., 2002), urban or industrial discharge (Guinda et al., 2014), and sediment inputs (Airoldi, 2003). However, very few quality assessment methods based on macroalgae had been developed until recently (Ballesteros et al., 2007). For the purpose of the WFD, subtidal macroalgae were selected to be BQEs in only a few member states, whereas the assessment methods based on intertidal macroalgae are very common. Indeed, the knowledge and available data on subtidal algae are comparatively scarce; essentially because of access difficulties (e.g. limited to diving or remotely operated vehicle access) that imply costly sampling and working difficulties. Subtidal rocky bottom are also sometimes considered as heterogeneous especially when compared with soft bottom. However, various studies that conducted careful sampling (e.g. comparable depth, sampling on flat rock, same sampling surface…) demonstrate the capacity to distinguish communities against environmental factors (Derrien-Courtel et al., 2013; Díez et al., 2003; Georg et al., 2003; Guinda et al., 2012; Kluijver, 1991; Martin, 1999; Martins et al., 2013; Pedersén and Snoeijs, 2001) or to highlight changes in relation to disturbance (Balata et al., 2007; Díez et al., 2014; Gorostiaga and Díez, 1996; Kautsky et al., 1999; Pehlke and Bartsch, 2008; Shepherd Scoresby et al., 2009). Moreover, subtidal macroalgal beds are one of the most represented habitat type in coastal shallow waters. This representativeness, the sensitivity and the functional role of subtidal macroalgae justify the needs of assessment

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method to study the relations between those benthic communities and human activities. However, only Denmark, France, Spain and Sweden designated subtidal rocky bottom macroalgae as BQEs for coastal water bodies in the northeastern Atlantic region (Birk et al., 2012). In France, macroalgae were selected as BQEs for both intertidal and subtidal rocky shores but were studied separately and the results of each evaluation are finally combined. In contrast, they are both included in a single assessment tool in Spain (Juanes et al., 2008).

Here we present an assessment tool adapted to French water bodies based on subtidal macroalgae: the Quality Index of Subtidal Macroalgae (QISubMac). As required by the WFD, the QISubMac assessment method is based on several metrics that consider sensitive and opportunistic macroalgae species. Under degraded environmental conditions (e.g., eutrophication, urban discharge), large perennial macroalgae are replaced by fast-growing opportunistic species (Arévalo et al., 2007; Benedetti-Cecchi et al., 2001; Krause-Jensen et al., 2007; Orfanidis et al., 2001). In such situations, the decrease in perennial algae (notably structuring species such as kelp or *Cystoseira* spp.) can lead to functionality loss (i.e., habitat, nursery or feeding functions) and changes in the associated fauna (Blight and Thompson, 2008; Derrien-Courtel et al., 2013; Eckman and Duggins, 1991; Edwards, 1980; Kennelly and Underwood, 1993; Moore, 1973; Schultze et al., 1990; Sheppard, 1976; Vadas and Elner, 1992).

The QISubMac assessment tool was essentially developed on the basis of the REseau BENThique (REBENT) experience. Launched in 2003, following the Erika oil spill, the REBENT programme is the first French quantitative monitoring network with large-scale data acquisition for macroalgae in subtidal zones (Derrien-Courtel, 2008; Derrien-Courtel et al., 2013). In particular, the REBENT data were used to select metrics and define the reference conditions. The use of documented metrics is in agreement with stated recommendations (Borja and Dauer, 2008).

Intercalibration of the QISubMac with the Spanish CFR method was considered during the second phase of the European intercalibration exercise at the North East Atlantic Geographical Intercalibration Group meeting in Lisbon (6–7 April 2011). The Spanish CFR was intercalibrated with the French intertidal assessment tool.

This article reports the first application of this assessment method to the coast of Brittany which is here presented as a case study. This first evaluation gives us the opportunity to test the capacity of QISubMac to distinguish the environmental status of water bodies. The relationship between environmental status and antropogenic pressure are also studied to check the relevancy of QISubMac assessment tool.

2. Materials and methods

At a large scale, the water temperature strongly varies from northern to southern French littoral. Temperature is a key parameter for macroalgae geographical distribution (Birkett et al., 1998; Breeman, 1988; Derrien-Courtel et al., 2013) and many species have their distribution limit on the French coast, such as *Laminaria digitata* (Smale et al., 2013) or *Alaria esculenta* (Dizerbo, 1947). Therefore, three ecoregions characterised by different macroalgal communities were defined. Those ecoregion correspond with the delimitation of biotypes that were defined for the needs of intercalibration of assessment method of vegetation quality elements along the North East Atlantic region (i.e. NEA 1/26-B1, NEA 1/26-B21 and NEA 1/26-A22) (Ramos et al., 2012). Then, opportunistic and characteristic species lists were adapted to correspond with those three ecoregions. We used our own biological database (the marine laboratory of Concarneau Database) and other available data such as macroalgal checklists (Chalon, 1905; Debray, 1899; Giard, 1913), bibliography (Díez et al., 2003; Gorostiaga and Díez, 1996; Juanes et al., 2008) and local expert knowledge (De Casamajor and Gevaert, personal communication).

At a smaller scale, water turbidity and sediment influence are two major factors that strongly modify macroalgal communities (depth penetration and taxa composition) (Derrien-Courtel et al., 2013; Eriksson et al., 2002; Pehlke and Bartsch, 2008). Turbidity is a somewhat complex parameter with natural (e.g., wave action, geological nature) and/or anthropogenic origins (e.g., eutrophication, dredge spoils disposal, coastal construction). Sediment input is another predominant parameter that changes algal composition by favouring silt cover-tolerant species (Airoldi, 1998; Derrien-Courtel et al., 2013; Díez et al., 2003; Gorostiaga and Díez, 1996). We have considered that the degree of exposure and dominating substrate of water bodies were two main factors that influence macroalgal communities. As an example, in very sheltered water, kelp forests disappear and are replaced by other most competitive species (e.g. *Halidrys siliquosa*, *Cystoseira baccata*…). This can affect metrics and therefore, we have created three supertypes (i.e., groups of water bodies) with specific species lists, scoring scales and reference conditions. The objective of including supertype description was to make comparison possible between water bodies with different characteristics. A comparable methodology was applied in other assessment method for intertidal shore (Neto et al., 2012). All the French water bodies type of Channel and Atlantic coast were assigned to a supertype on the basis of the analysis of hydrological parameters (e.g. level of exposure, dominating substrate) database (Creocean, 2003). All those parameters influence subtidal macroalgae composition (Derrien-Courtel et al., 2013) and then justify the definition of supertypes for the ecological status evaluation. Thus, supertype A corresponds to water bodies exposed to wave action with rocky dominating substrate, whereas supertype B groups water bodies exposed to wave action with soft bottom dominating substrate and finally, supertype C gathers water bodies characterised by sheltered condition and soft bottom dominating substrate (Table 1).

2.1. Study sites

The QISubMac was designed for the evaluation of the quality status of the water bodies along the French Chanel and Atlantic coast. This 4700 m length coastal zone (Eurosion database, 2005) is included in the North East Atlantic (NEA) region (WFD, 2000/60/EC). This coastal zone is characterised by a wide range of physical features: meso to megatidal regime, rocky sandy or muddy dominated shore, sheltered or exposed shore, homogeneous or stratified water, and shallow or deep water. The 74 water bodies of the French Chanel and Atlantic coast were characterised (DCE, 2005/11) using physical features (depth, tidal regime, current speed, level of exposure, water residence time, level of water mixing, percentage of water body occupied by the intertidal zone, and dominating substrate). Then, 33 water bodies were selected for an evaluation of their quality status. The QISubMac method was first tested on 20 water bodies from NEA 1/26-B21 biotype grouped into the 3 supertypes A, B and C. The QISubMac method was applied on 25 sampling sites (23 from Brittany WFD monitoring network and 2 additional sites) (Fig. 1) to assess the ecological status. Sampling sites were selected on the basis of their representativeness of the water body (position in the water body, presence of rocky substrate, and depth). The maximum depth was between −4 m and −40 m chart datum (C.D.). The large water bodies with rocky dominating substrate were assessed using two sampling sites, whereas one site was considered as sufficient to evaluate most of the water bodies. Moreover, results of QISubMac assessment is aggregated with other biological quality elements as intertidal macroalgae, angiosperms and opportunistic macroalgae blooms.

To represent reference conditions, seven sites characterised by a high biological status (i.e., under very low anthropogenic pressures) were selected. The lack of historical data (particularly quantitative data) on the subtidal hard substrate made the definition of this reference condition difficult. We used sites with minimally disturbed conditions (REBENT data), defined on the basis of expert judgement and an available data comparison (Derrien-Courtel et al., 2013), to represent reference conditions. Furthermore, we assume that all coastal water