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Marine Macroalgae Assessment Tool (MarMAT) for intertidal rocky shores. Quality assessment under the scope of the European Water Framework Directive

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ABSTRACT

The *Water Framework Directive* (WFD) requires European Member States to assess the Ecological Quality Status (EQS) of their water bodies based on Biological Quality Elements (BQEs). A tool called MarMAT (*Marine Macroalgae Assessment Tool*) was developed to implement the WFD in Portugal, which assesses the EQS of Portugal's coastal intertidal rocky shores. MarMAT is a multimetric method that is compliant with the European WFD requirement. It is based on the composition (Chlorophyta, Phaeophyceae and Rhodophyta) and abundance (coverage of opportunists) of marine macroalgae. This study focused on the demands of the WFD to have the assessment methodologies legally accepted by the European Commission. The following factors were examined: (a) the response of MarMAT against anthropogenic pressures; (b) the ability of MarMAT to report all of the five quality classes (bad, poor, moderate, good and high); and (c) the performance of MarMAT, specifically in comparing the RSL (Reduced Species List) methodology with the utility of including the abundance (coverage of opportunists) metric and the necessity of locally adapted reference conditions and boundaries. MarMAT was high inversely correlated ($p < 0.001$) with anthropogenic pressure. MarMAT also successfully reported all of the quality classes (bad to high) and captured the community changes more accurately when using the coverage of opportunists metric. Because MarMAT satisfactorily covered all of the issues examined, MarMAT may be accepted as a compliant assessment methodology in the scope of the WFD requirements.

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1. Introduction

The eutrophication of coastal systems as a result of anthropogenic activities is recognised worldwide as a major pollution threat (Norkko and Bonsdorff, 1996; Valiela et al., 1997; Raffaelli et al., 1998; Sfriso et al., 2001). Frequently, one of the main problems affecting these areas is a spatial shift in primary producers, which often prevails also in time. Undisturbed systems with low nutrient loadings are regularly dominated by slow-growing vegetation (e.g., *Zostera* sp. and *Fucus* sp.), while disturbed systems with enhanced nutrient loadings favour the growth of phytoplankton and opportunistic macroalgae (e.g., *Ulva* sp. and *Porphyra* sp.) (Raffaelli et al., 1998). Nutrients may arrive in the system as water is dissolved or as loose mats decompose after they have been accumulated (Raffaelli et al., 1998). Changes in the composition of primary producers can also lead to changes in associated communities (e.g., macroinvertebrates, fish, and shorebirds) (Raffaelli et al., 1998) and to changes in the materials and services these areas supply to surrounding environments (Jonge et al., 2000). Many management schemes implemented in the past few decades have sought to manage the physicochemical conditions of the water and sediment. These schemes were implemented to reduce the external nutrient loading of coastal systems, but the effective control of its efficiency has only recently been regarded as reasonable, with the implementation of monitoring programmes focused on the ecological integrity of aquatic systems. These programmes correspond to the implementation of recent water policies, such as the European Water Framework Directive (WFD, 2000/60/EC) or the USA's Clean Water Act (CWA, 2002/P.L. 107-303/USA).

The environmental objective of the WFD is to achieve a 'good water status' for surface and groundwater by 2015 and to prevent its deterioration in subsequent years throughout the Europe (WFD, 2000/60/EC) (see Mostert, 2003; Borja, 2005). The WFD requires European Union (EU) Member States (MS) to assess their surface water status by determining each water body's ecological and chemical status (WFD, 2000/60/EC). To assess the ecological quality based on the Biological Quality Elements (BQEs) the reference conditions (undisturbed or nearly so) must be defined, and the deviation of a given system to the conditions that can be measured at any other moment must be estimated. The difference in the quality observed between measurements and the reference conditions is called the Ecological Quality Ratio (EQR), and its values range from 0 (low quality) to 1 (high quality). The EQR is converted into the Ecological Quality Status (EQS); the assessment

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results are expressed as bad, poor, moderate, good, or high (detailed in the Common Implementation Strategy (CIS) documents: WFD CIS, 2003a,b,c,d).

The BQEs outlined by the WFD to assess Coastal Waters (CWs) include phytoplankton, benthic macroinvertebrates, and other aquatic flora, such as macroalgae and angiosperms (WFD, 2000/60/EC). Macroalgae are useful indicators of environmental quality because they can integrate environmental pressures, and they can respond to toxic substances, changes in nutrient concentrations and hydromorphology (Benedetti-Cecchi et al., 2001; Soltan et al., 2001; Panayotidis et al., 2004; Melville and Pulkownik, 2006; Yuksek et al., 2006; Arévalo et al., 2007; Scanlan et al., 2007; Krause-Jensen et al., 2008). These environmental alterations can be quantified through different measurable attributes (metrics), which individually or in combination, can be used to monitor the functioning of aquatic systems and infer their ecological status (Schramm, 1999; Orfanidis et al., 2001, 2003, 2011; Krause-Jensen et al., 2007; Scanlan et al., 2007; Wells et al., 2007; Juanes et al., 2008).

The reference conditions defined for composition and abundance should be considered in the development of assessment methodologies so that they are compliant with the WFD recommendations (WFD, 2000/60/EC). The recommendations regarding macroalgae state that the taxonomic composition should correspond to undisturbed conditions (where all sensitive taxa should be present) and that there should be no detectable changes in macroalgae abundances due to anthropogenic activities. Instead of creating a new assessment index or method, Borja and Dauer (2008) recommended that assessment schemes should integrate well-known metrics, which should create more confidence and yield advantages when interpreting the results.

In this paper, the Marine Macroalgae Assessment Tool (MarMAT) is presented. The MarMAT was developed to assess the ecological status of a system based on the macroalgae found within a system's intertidal rocky shores. The MarMAT combines the philosophy of assessment tools that have already been tested and are being used around EU countries, such as the RSL (Wells et al., 2007), the CFR (Juanes et al., 2008), the EEI (Orfanidis et al., 2001, 2003), and the opportunistic macroalgae assessment method (Scanlan et al., 2007; Patrício et al., 2007). The first version of the MarMAT (the P-MarMAT) was intercalibrated with the CFR (Spanish tool) during the first phase of the European Intercalibration (IC) Exercise. The P-MarMAT achieved an excellent agreement value with the Spanish tool (0.89 from a Kappa analysis) (E.C., 2008; Carletii and Heiskanen, 2009). Gaspar et al. (2012) defined the ecological reference conditions and the quality classes for several indicators of macroalgae. Following this, the MarMAT was updated, both for the metrics and for the reference conditions. The MarMAT fulfils the WFD requirements for abundance and taxonomic composition because the selected metrics are based on macroalgal attributes, such as species composition; diversity among Chlorophyta, Rhodophyta, and Heterokontophyta (Phaeophyceae); and the biomass or coverage of some taxa that allow these communities to be characterised.

Although species composition is expected to vary successively over time (e.g., days, seasons, and years) as a result of environmental changes (e.g., natural or anthropogenic disturbances) or of natural differences between sites (Addessi, 1994; Keough and Quinn, 1998; Lindberg et al., 1998; Panayotidis et al., 2004; Arévalo et al., 2007; Krause-Jensen et al., 2007, 2008; Gaspar et al., 2012) species richness remains approximately constant in the absence of environmental modifications (Wells and Wilkinson, 2002, 2003; Gaspar et al., 2012). Variations in composition are mainly due to changes in transient taxa, and species richness in intertidal rocky shore communities remains approximately constant under constant environmental conditions (Wells and Wilkinson, 2002, 2003).

Under environmental degradation (i.e., water transparency, nutrient enrichment) macroalgal communities decrease in diversity (e.g., elimination of sensitive species) and increase in biomass of opportunist species due to environmental stimulation (Orfanidis et al., 2003; Arévalo et al., 2007; Krause-Jensen et al., 2007; Scanlan et al., 2007; Patrício et al., 2007; Gaspar et al., 2012). When exposed to nutrient-enriched waters, opportunist species can dominate the community at the expense of larger and perennial algae (Schramm, 1999; Orfanidis et al., 2003; Krause-Jensen et al., 2007, 2008). During such occasions, a shift in marine ecosystems' structure and function from a pristine to a degraded state may occur; the replacement of late succession seaweeds by opportunistic species is a reliable signal of increasing eutrophication (Orfanidis et al., 2001, 2003). Orfanidis et al. (2001, 2011) considered two Ecological Status Groups (ESGs): ESG I (late succession or perennial to annual taxa) and ESG II (opportunist or annual taxa). ESG I includes seaweeds with thick or calcareous talus, low growth rates and long life cycles, whereas ESG II includes sheet-like thin simple tissue and filamentous species with high growth rates and short life cycles (usually annual) (Orfanidis et al., 2001, 2003). The ratio between these two groups of species has been used as a measure of environmental degradation; lower values correspond to deteriorating ecological conditions (Orfanidis et al., 2001, 2011).

Another factor influencing species richness is the morphology of rocky shores. Wells et al. (2007) demonstrated statistically that substrata can influence variations in species richness observed among shores. Rock ridges, outcrops and platforms have a significantly higher number of species than shores consisting predominantly of boulders, pebbles and vertical rock. The shore description, with different scores attributed to different shores' morphology, constitutes an important factor to include (as a species richness correcting factor) in assessment methodologies.

The present study aims to (a) select a group of relevant metrics to include in an assessment tool (i.e., the MarMAT method); (b) test the tool's response against different anthropogenic pressure levels; (c) analyse its performance; and (d) compare its performance to the performance of other assessment tools currently in use by EU countries.

2. Materials and methods

2.1. Study site

The study area is located along the western coast of Portugal (Fig. 1). It is located inside the EU North-East Atlantic (NEA) region, typology NEA 1 (WFD, 2000/60/EC) which is equivalent to the Portuguese type A5 (Bettencourt et al., 2004). This region of the coast is an open and exposed euhaline and mesotidal (1–3 m amplitude) coastal area that is frequently turbid and nutrient-enriched due to coastal upwelling (Ambar and Dias, 2008).

During the summer, the Canary Current, which has a strong southward flow (12 $cm\,s^{-1}$) originating from the north, and the Azores Current, which enters the region from the south and has a west-to-east circulation, affect the Portuguese coast. During the winter, the Azores Current has twice the velocity it has in the summer, and there is little circulation of seawater in the region. The circulation of seawater along the Iberian Coast flows predominantly south to north with a velocity of approximately 1.6 $cm\,s^{-1}$ (Ambar and Dias, 2008).

Sampling was conducted at nine intertidal rocky shore sites located along the study area: the Vila Praia de Âncora (VPA), Montedor (M), Viana do Castelo (VC), Cabedelo (Ca), Lavadores (La), Aguda (Ag), Buarcos Bay (BB), São Martinho do Porto (SMP) and Peniche (P) shores (Fig. 1). These sites experience different levels of anthropogenic pressure; eight of these sites (Table 1) were selected to test

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