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Ability of invertebrate indices to assess ecological condition on intertidal rocky shores

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ABSTRACT

The implementation of directives such as the European Water Framework Directive (WFD) and the Marine Strategy Framework Directive (MSFD) has promoted the development of several tools and methods for assessing the ecological health of marine ecosystems. Within the scope of the WFD and in terms of rocky shores, several multimetric tools were developed based on the macroalgae biological quality element (BQE), in addition to those based on macroinvertebrates.

The WFD requires member states to assess each BQE separately. The present work aimed to test the ability of ecological indices to distinguish sites within anthropogenic disturbance gradients caused by organic enrichment, using macroinvertebrate communities on intertidal rocky shores. Owing to the lack of more specific indices (for rocky shore), indices based on abundance, diversity and/or taxonomic composition were selected from several widely used indices in ecological studies and/or developed for soft-bottom macroinvertebrate communities.

Present findings reveal several indices based on diversity and/or taxonomic composition able to distinguish sites within the disturbance gradients, showing increasing quality from the site nearest the source of organic enrichment to that farthest from it, especially indices calculated using biomass data, and in the summer season. Such results open good perspectives for the use of intertidal macroinvertebrate communities from rocky shores, and also help add the perspective of this biological quality element in the ecological quality assessment of coastal waters.

1. Introduction

Over the last 15 years, the implementation of directives such as the Water Framework Directive (WFD, 2000) and the Marine Strategy Framework Directive (MSFD, 2008) in Europe has triggered the development of a great number of tools and methods for assessing the health of marine ecosystems (Birk et al., 2012; Borja et al., 2016).

In coastal waters, subject to the WFD, rocky shores are considered of vast importance. They support high biological diversity and supply a wide variety of ecosystem goods and services including primary productivity, biofiltration, fish nursery grounds, shellfisheries, recreation and tourism (Seitz et al., 2013; Galparsoro et al., 2014). Coastal rocky shores are subject to multiple pressures, ranging from global environmental change to regional and local scale impacts (Thompson et al., 2002) requiring assessment monitoring and management actions in order to improve quality.

Macroalgae and benthic macroinvertebrates seem to be the most suitable Biological Quality Elements (BQEs) required by the WFD to be used, separately, in quality assessments on rocky shores (WFD, 2000). Accordingly, several multimetric indices, combining simpler metrics which provide complementary information on a system (Salas et al., 2006; Marques et al., 2009), have been developed based on macroalgal communities (Ballesteros et al., 2007; Juanes et al., 2008; Neto et al., 2012; Ar Gall and Le Duff, 2014), although such is not the case of benthic macroinvertebrates (however see Hiscock et al., 2005; Orlando-Bonaca et al., 2012; O'Connor, 2013).

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To date, few attempts have been made to develop a multimetric tool compliant with the WFD requirements based solely on rocky shore macroinvertebrate communities. For example, Díez et al. (2012) argued that few invertebrate taxa would correlate with a disturbance gradient and, thus, a multimetric tool for rocky shores should be more reliable with attributes of both macroinvertebrates and algae being taken into account. In contrast, Vinagre et al. (2016) showed that benthic macroinvertebrate communities responded similarly to benthic macroalgal communities along disturbance gradients (organic enrichment) with several opportunistic species being more abundant in sites near the source of disturbance and decreasing farther away from it, with the converse occurring for sensitive species. Therefore, multimetric tools for rocky shores based solely on macroinvertebrate communities were not developed yet, but this is a gap in fulfilling WFD requirements.

The present work tested the ability of several ecological indices, using macroinvertebrate communities on intertidal rocky shores, to distinguish sites within anthropogenic disturbance gradients caused by organic enrichment. For this purpose, available indices based on abundance (density and biomass), diversity and/or composition, were applied to rocky intertidal data. Some had been widely used before in ecological studies while others were developed specifically for soft-bottom macroinvertebrate communities (e.g., Salas et al., 2006; ICES, 2008; Marques et al., 2009; Pinto et al., 2009; Martínez-Crego et al., 2010). Indices were used to measure seasonal and spatial variations within disturbance gradients, and results compared with that of an established multimetric tool, developed for use with macroalgae – the *MarMAT* (Marine Macroalgae Assessment Tool) (Gaspar et al., 2012; Neto et al., 2012). To validate the response of these indices, those showing the best performance were applied to an independent dataset (gathered from different years and sites) and compared with the response provided by the *MarMAT*. The comparison against physical-chemical parameters was not considered here due to the lack of a robust time series of the study areas, and also hydro-morphological modifications cannot be considered significant on open shores where the study site is located. The verification against the BQE macroalgae was selected due to the accumulated effects they can record over long periods from the recent past, which is not possible with putative measuring of physical-chemical parameters. In parallel fashion and as a secondary objective, the suitability of response of a particular index along each shore and in each season was analysed, using data from particular intertidal zones (e.g., upper, mid, lower) separately, to check the concordance of results between the whole intertidal zone and certain sampling levels. This is because rocky shores may not provide the three sampling levels encompassed at this time and some levels may show better response to disturbance than others, which should be taken into account for the assessments.

2. Material and methods

2.1. Study area

Two shores on the western Portuguese coast (Fig. 1A), Buarcos (40°10′14.2"N, 8°53′26.7"W) and Matadouro (38°58′31.5"N, 9°25′14.4"W) (exposed and moderately exposed Atlantic Coast typologies, respectively; TICOR project, Bettencourt et al., 2004; available at http://www.ecowin.org/ticor), were studied. The sampling areas were subject to a point source of pollution (SOP) discharging almost directly into the upper intertidal zone (Figs. 1B, C). On each shore the discharge is low but continuous throughout the year, crossing urban centres and agricultural land before reaching the shore (Vinagre et al., 2016).

2.2. Sampling design

Three sites (sites 1–3) were selected in the intertidal area at Buarcos and at Matadouro to characterise the disturbance gradients at about 30–40, 50–60 and 300 m from the SOP (Figs. 1B, C). At each site three horizontal zones were identified, naturally defined by tides – upper intertidal (submersed for ~25% of the tide period, ~6 h day^{-1}), mid intertidal (submersed for ~50% of the tide period, ~12 h day^{-1}) and lower intertidal (submersed for ~75% of the tide period, ~18 h day^{-1}). Four random replicates (12 cm × 12 cm squares) were collected from each zone. Samples were taken twice in summer (S1 and S2, in August and September 2011, respectively) and twice in winter (W1 and W2, in February and March 2012, respectively), during low water of spring tides. Open, freely draining rock was sampled avoiding pools and crevices. The samples (144 from each shore) were immediately preserved after sampling in neutralised 4% formalin solution (prepared with sea water).

Parallel to biological sampling, water samples were collected at each site and at the SOP for quantification of chlorophyll a (Chl.a) ($mg\,m^{-3}$) (Strickland and Parsons, 1972), total suspended solids (TSS) ($g\,L^{-1}$), particulate organic matter (POM) ($g\,L^{-1}$), and determination of dissolved nutrient concentration ($mg\,L^{-1}$) [$N\text{-}NO_3$, $N\text{-}NO_2$, $N\text{-}NH_4$, $P\text{-}PO_4$ (DIP) and silica]. Nutrients were analysed by colorimetric reaction using a Skalar San++® Continuous Flow AutoAnalyzer (Skalar, 2010). Dissolved inorganic nitrogen (DIN) was determined as the sum of $N\text{-}NO_3$, $N\text{-}NO_2$ and $N\text{-}NH_4$. Simultaneously to sampling, water temperature (°C), conductivity ($\mu S\,cm^{-1}$), oxidation-reduction potential (ORP) (mV), salinity, dissolved oxygen (DO) (%) and pH parameters were measured *in situ* (using a YSI Professional Plus handheld multiparameter probe). For complete details of the laboratory procedures see Vinagre et al. (2016).

This first dataset was used for all statistical analyses and for the calculation of ecological indices. A second dataset was used to validate indices performance. It included independent data from Buarcos, gathered in September 2009 (henceforth designated as "summer") and March 2010 (henceforth designated as "winter") from different sites (except site 1) within the disturbance gradient (using the same methodology as for the first dataset) (Fig. 1C).

2.3. Statistical analysis

All statistical analyses were done with PRIMER 6 + PERMANOVA© software (Clarke and Gorley, 2006; Anderson et al., 2008), with the exception of the principal component analyses (PCA) and corresponding ordinations, which were performed using CANOCO 4.5 for Windows (Ter Braak and Šmilauer, 2002).

2.3.1. Environmental data

The environmental parameters (Env.) were used to place the sampling sites within the disturbance gradients by performing principal coordinate (PCO) analyses. The Euclidean similarity measure was used in the calculation of similarity matrices, after square root transformation of data (except for DIN, Chl. a and Silica, 1/X was used in these cases) to approach normality, followed by normalisation. Statistically significant differences between shores, between sampling sites within shore and between seasons were tested using permutational multivariate analysis of variance (PERMANOVA; Anderson, 2001). This included three fixed factors, 'Shore' (two levels: Matadouro and Buarcos), 'Site' (nested in Shore; four levels: SOP and sites 1, 2, and 3) and 'Season' (two levels: summer and winter). The above-mentioned similarity matrices were used. The statistical significance of variance components was tested using 9999 permutations and unrestricted permutation of raw data, with a significance level of $\alpha = 0.05$.