Ecological Indicators 78 (2017) 489–501

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Addressing a gap in the Water Framework Directive implementation: Rocky shores assessment based on benthic macroinvertebrates

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ARTICLE INFO

Article history:
Received 22 December 2016
Received in revised form 22 March 2017
Accepted 23 March 2017
Available online 18 April 2017

Keywords:
Benthic communities
Hard bottom
Organic enrichment
Ecological quality assessment
Water Framework Directive

ABSTRACT

A gap in the European Water Framework Directive (WFD) is addressed, aiming for the development of an ecological quality status assessment tool based solely on the Biological Quality Element benthic macroinvertebrates from intertidal rocky shores. The proposed Rocky shore Macroinvertebrates Assessment Tool (RMAT) was tested and validated along disturbance gradients (organic enrichment). During the whole process, the response of widely used metrics (e.g. Hurlbert index, Shannon-Wiener index, AZTI's Marine Biotic Index; Bentix biotic index) and models (i.e., metrics combined) was compared to results provided by the Marine Macroalgae Assessment Tool to the same sampling sites.

The RMAT is a multimetric index compliant with the WFD based on the benthic macroinvertebrates community, combining 'abundance' (Hurlbert index) and 'taxonomic composition' (Bentix index using density and biomass data) metrics. It performed well along anthropogenic disturbance gradients, showing ecological quality increasing from close to far away from the disturbance.

The RMAT is a promising tool for rocky shore ecological assessment in the scope of the WFD or other monitoring activities worldwide.

1. Introduction

The European Water Framework Directive (WFD, 2000) was implemented to 'establish a framework for the protection of inland surface waters, transitional waters, coastal waters and ground waters'. The WFD requires Member States to assess the ecological quality status (EQS) of all water bodies, based on the status of the biological quality elements (BQE) as well as hydromorphological and physical-chemical quality elements. The EQS is determined by the deviation (ecological quality ratio, EQR) that the biological elements exhibit from the expected at undisturbed or nearly undisturbed situations (reference conditions) (WFD, 2000). The WFD specified a five-point scale for water quality, 'Bad', 'Poor', 'Moderate', 'Good' and 'High'; the 'High status' is represented by EQR values close to 1, whilst the 'Bad status' is expressed by values close to 0.

A major issue in the implementation of the WFD is defining reference conditions. This should be done using historical and monitoring data, modelling or, ultimately, resorting to expert judgement (WFD, 2000). This is largely because historical data is scarce on the pressures impacting ecosystems and the consequent long-term changes (Borja et al., 2012). Also, recent monitoring data may not be comparable due to different methodologies (e.g., sampling and processing) and lack of intercalibration among Member States, further slowing the implementation of the WFD (Poikane et al., 2014). In brief, Member States should reach an agreement on quality standards (e.g., set reference conditions and establish boundaries between EQS classes) so that the different methods produce comparable classifications for each BQE (Birk et al., 2013).

Coastal rocky shores extend to over 80% of the coastline worldwide (Emery and Kuhn, 1982; Granja, 2004). They are important marine habitats with great biodiversity, providing valuable ecosystem services, namely provisioning, regulating and cultural services (e.g., Liquete et al., 2013; Galparsoro et al., 2014). The particular environmental conditions (e.g., wave exposure, tidal regime) of rocky shores add challenges to the ecological status assessment.

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http://dx.doi.org/10.1016/j.ecolind.2017.03.044
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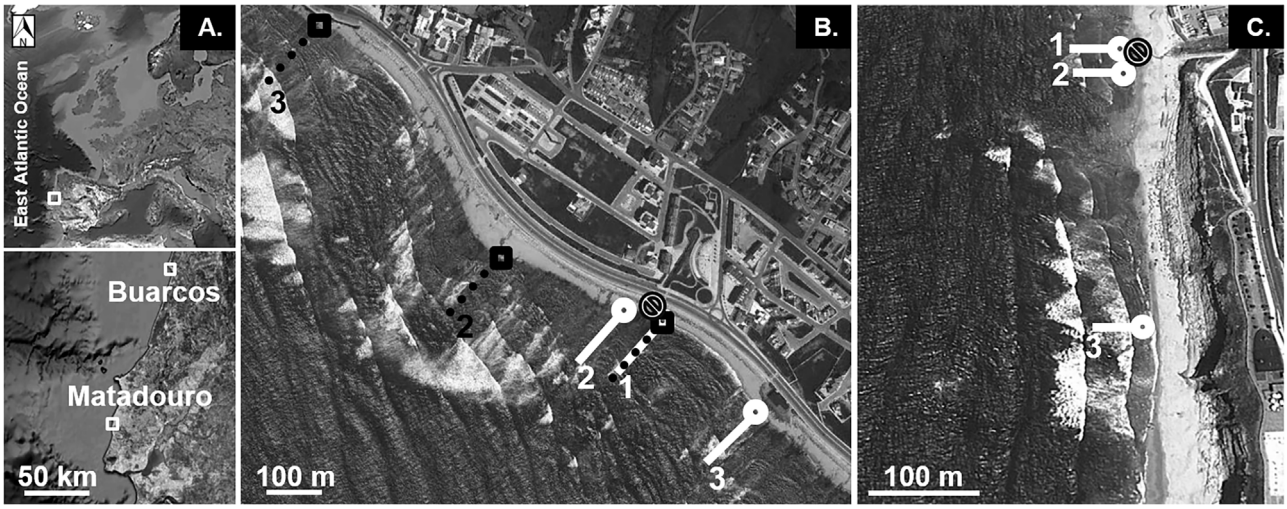

Fig. 1. Study sites location: A. Europe and Portugal. B. Buarcos (40°10′14.2"N, 8°53′26.7"W). C. Matadouro (38°58′31.5"N, 9°25′14.4"W). Sampling sites = white circles full line; Validation sites = black squares dotted line; Source of disturbance=⊘ sign.
Source: Adapted from Vinagre et al., 2016b.

The intertidal rocky shore is a very harsh environment and biotic communities there are naturally highly variable (Thompson et al., 2002). Difficulties in distinguishing natural from anthropogenic disturbance (e.g., organic enrichment) have often been highlighted (e.g., Crowe et al., 2000; Thompson et al., 2002; Elliot and Quintino, 2007). This hampers the WFD implementation with regard to rocky shores, namely in the development of an ecological assessment tool (e.g., defining reference conditions, setting boundaries between EQS classes). Despite that, rocky shore communities have also often shown to respond to different levels of disturbance (e.g., Bishop et al., 2002; Kraufvelin, 2007; O'Connor, 2013; Cabral-Oliveira et al., 2014; Vinagre et al., 2016a).

For assessment of coastal and transitional waters, several multimetric ecological tools have been developed based on the different BQEs (Birk et al., 2012), combining complementary, metrics to summarize the ecosystem health into a single, and comprehensible value. Also, several biological elements (e.g., macroalgae, phytoplankton) have been intercalibrated among Member States (Poikane et al., 2014). For benthic macroinvertebrates, however, the intercalibration exercise has been undertaken only for the soft sediment habitat, while for hard substratum (i.e., rocky shores) that has not been the case (Borja et al., 2009a). This is because, despite macroalgae and benthic macroinvertebrates being the most suitable BQEs for rocky shore assessment, the tools available are exclusively (Ballesteros et al., 2007; Juanes et al., 2008; Neto et al., 2012; Ar Gall and Le Duff, 2014), or in part (Hiscock et al., 2005; Díez et al., 2012; O'Connor, 2013) based on the macroalgae. Although macroinvertebrates are widely recognized as good indicators of water quality and pollution, to date, attempts to develop an index based exclusively on this BQE (Hiscock et al., 2005; Díez et al., 2012; Orlando-Bonaca et al., 2012) were not totally successful. This was possibly because of the approaches widely used by rocky shore ecologists (e.g., using non-destructive percentage cover instead of destructive samples of density or biomass, or using a low taxonomic resolution). Therefore, a method based specifically on the benthic macroinvertebrates from hard substratum constitutes a gap in the WFD implementation (Birk et al., 2012).

The overall aim of this work was to address that gap in the WFD implementation, and to propose a multimetric index based exclusively on rocky shore macroinvertebrates, the *Rocky shore Macroinvertebrates Assessment Tool* (*RMAT*). The RMAT seems promising for WFD rocky shore quality assessments, and may be a valuable indicator in the scope of other European Directives (e.g., Marine Strategy Framework Directive).

In parallel to the RMAT, an alternative index (alt-RMAT) is presented; this is not as accurate as the former but is quicker and less expensive to apply when time or resources are limited.

2. Methods

2.1. Study sites

The Buarcos (40°10′14.2"N, 8°53′26.7"W) and Matadouro (38°58′31.5"N, 9°25′14.4"W) rocky shores are located in the western Portuguese coast (Fig. 1A) and classified as Exposed and Moderately Exposed Atlantic Coast typologies (TICOR project, Bettencourt et al., 2004; available at http://www.ecowin.org/ticor), respectively.

Along this coast the prevailing current direction is from West-Northwest, and the most frequent wave period and wave height are in the range of 8–12 s and of 1–3 m, respectively. Tide is semidiurnal and the extreme spring tide ranges from 3.5–4 m (Boaventura et al., 2002; Bettencourt et al., 2004).

Both shores are subject to moderate impact from continuous throughout the year runoff of waters crossing urban centres and agricultural land before reaching the shore (Vinagre et al., 2016a,b, 2017).

2.2. Data collection

Eleven ecological indices based on macroinvertebrates were selected from Vinagre et al. (2016b). These were those that performed best along the disturbance gradients at both shores, especially during summer. Summer data (collected during August and September 2011) was used as it was previously found as the better season (comparing to winter) for monitoring activities on rocky shores (Vinagre et al., 2016b, 2017). The indices were calculated using macroinvertebrates' density (ind m^{-2}) and biomass (g AFDW m^{-2}) data, estimated from samples collected at three sites distancing gradually along the disturbance gradient (site 1 closest to the disturbance, site 3 farthest from the disturbance) (Fig. 1B, C). Each site was divided into three intertidal zones: upper intertidal (submersed for ~25% of the tide period, ~6 h/day); mid intertidal (submersed for ~50% of the tide period, ~12 h/day); and