Ecological Indicators 12 (2012) 26–36

Contents lists available at ScienceDirect

Ecological Indicators

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

Development of a new index for the assessment of hydromorphological alterations of the Mediterranean rocky shore☆

Martina Orlando-Bonaca[a], Borut Mavrič[a,*], Gorazd Urbanič[b]

[a] Marine Biology Station, National Institute of Biology, Fornace 41, 6330 Piran, Slovenia
[b] Institute for Water of the Republic of Slovenia, Hajdrihova 28c, 1000 Ljubljana, Slovenia

ARTICLE INFO

Keywords:
WFD
Hydromorphological conditions
Benthic invertebrates
New index
BIRS
North Adriatic

ABSTRACT

The assessment of the status of coastal waters is required by the European Water Framework Directive. The aim of the present study was to test the response of benthic invertebrates to hydromorphological (HM) alterations and to develop a new index for the assessment of HM alterations of the rocky shore, based on benthic invertebrates. Fifty samples were collected, 10 from pre-classified HM classes 1, 3, 5; 15 from class 2, and 5 from class 4. Seven HM variables describing habitat conditions were used to test the benthic invertebrate response and to develop the HM stressor gradient: material, texture, structure, belt length, sedimentation, water retention and artificially induced mobility. Abundance, some diversity (Shannon–Wiener, Simpson's and Evenness) and richness (number of taxa) metrics showed low correlation values ($r < 0.5$) against HM variables and HM stressor gradient, indicating that tested metrics have limited value in assessment of the HM degradation impact on coastal benthic invertebrates. On the other hand, significant differences in the structure of benthic invertebrate assemblages among HM classes were observed (One-way ANOSIM global test $r = 0.53$, $P < 0.0001$). In the partial canonical correspondence analyses each of seven HM variables statistically significantly ($P < 0.05$) explained individual portion of the benthic invertebrate taxa variability. HM indicative values ranging from 1 to 9 were defined for each of 229 taxa, according to its distribution along the five HM classes. HM indicative weights (*WHM*) between 1 and 5 were defined according to the valences distribution among HM classes. HM indicative values, *WHM* and log 5 abundance classes were combined in a new Benthic Index for Rocky Shore (BIRS), using the weighted average approach. The combination of all three parameters in the BIRS showed a statistically significant ($P < 0.05$) response of the new developed index to HM stressor gradient, with a high Pearson correlation coefficient ($r = 0.97$). Further work has to be done in order to develop a WFD compliant method with five classes' boundary values. Nevertheless, the new developed index has a good potential to contribute to existing coastal assessment systems. Especially, as impact of hydromorphological alterations on coastal communities was almost neglected so far, despite being one of the main threats to coastal water integrity.

1. Introduction

The European Water Framework Directive (WFD) 2000/60/EC established a framework for the protection and improvement of all waters. For the evaluation of Quality Status (QS) of water bodies (WB) the predominant role was given to Ecological Quality Status (EQS) assessments, with the support of hydromorphology and physico-chemical assessments (EC, 2000). Among Biological Quality Elements to be used in EQS assessment of coastal waters are also benthic invertebrates. Most of the effort was applied on the assessment with soft-bottom benthic invertebrates (Borja et al., 2000; Simboura and Zenetos, 2002; Rosenberg et al., 2004; Muxika et al., 2007). That was confirmed in the first phase of the Intercalibration (IC) process, where EU member states succeed to intercalibrate only assessment methods for soft-bottom benthic invertebrates (GIG, 2008). The reason lies in the fact that the most of the background knowledge and experience was gained on soft-bottom benthic invertebrates. Sampling on soft-bottom is much simpler than on hard-bottom, hard-bottom habitats are usually more complex and in general soft-bottom is more widespread (Chintiroglou et al., 2005). For this reason research on soft-bottom benthic invertebrates was favoured. Another advantage to soft-bottom benthic invertebrates was given by development of

☆ This paper is dedicated to the memory of our wonderful colleague and friend Žiga Dobrajc, who has recently tragically passed away. He was an irreplaceable member of our working team, with his active presence, multitudinous skills, and his unforgettable joyful smile.

* Corresponding author. Tel.: +386 5 923 29 36; fax: +386 5 671 29 02.
E-mail address: mavric@mbss.org (B. Mavrič).

1470-160X/$ – see front matter
doi:10.1016/j.ecolind.2011.05.010

general succession pattern of the macrobenthic biocoenosis of the soft-bottom substrate under the influence of a perturbation factor (of anthropogenic origin), based on the work of Pearson and Rosenberg (1978), and in the Mediterranean by Peres and Bellan (1973). Some sporadic studies have in recent years focused also on assessment using hard-bottom benthic invertebrates (Hiscock et al., 2005; Kalkan et al., 2007). Hiscock et al. (2005) derived a new metric, based solely on the species richness of the reduced checklist present in a defined survey area. At the time of the completion of their report was the metric however still not verified. On the other hand, Kalkan et al. (2007) applied existing biotic index Bentix to hard substrate benthic data adding some new indicative taxa scores. That enables them to assess the impact of the water pollution on benthic invertebrate community.

The WFD incorporates the polluter pays principle through a review of measures for charging for water use, including full environmental cost recovery, and for this reason developed indices should be as pressure specific as possible. A review of 252 WFD-compliant assessment systems of four main water categories (rivers, lakes, transitional and coastal waters) published on www.wiser.eu/results/methods-db (Hering et al., 2010) revealed that 46% of these systems target various forms of water pollution (acidification, eutrophication, heavy metals, pollution by organic compounds, pollution by organic matter), the next is general degradation targeted by 19% of the systems, than hydromorphological degradation (10%), habitat destruction (8%), riparian habitat alteration (5%), catchments land use (4%), flow modification (4%) and impact of alien species (4%). Looking on the pressures that are covered by developed indices for coastal water, the most dominant are organic enrichment and mixed or general pressure (GIG, 2008). The response of organisms to hydromorphological pressures are less known and used in EQS assessment (GIG, 2008), although the hydromorphological degradation along the coast is very pronounce (Chapman and Bulleri, 2003). It is a direct consequence of high human concentration on the coastal areas accompanied by high urban and industrial development and coastal modification, which is still increasing (Benedetti-Cecchi et al., 2001; Chapman and Bulleri, 2003), and represents one of main threats to the ecological integrity of the coastal sea. This is true for the Mediterranean Sea as well, in Slovenia for example only around 18% of the coastline remains in the natural state (Turk, 1999), and on the coast of Barcelona only 22% of the rocky littoral remains free of artificial structures (Pinedo et al., 2007). Therefore, assessment methods using hard-bottom benthic invertebrates and addressing hydromorphological degradation, which were left aside in the past, should be developed and used in monitoring according to WFD. This need is even more pronounced in countries with a high percentage of hard bottoms or rocky coastline.

The aim of our study was to (i) test a response of some in the assessment widely applied richness and diversity metrics to hydromorphological alterations and (ii) to develop a new hard-bottom benthic invertebrates based index for the assessment of hydromorphological alterations of the rocky shore.

2. Materials and methods

2.1. Study area

The Gulf of Trieste, which represents the northernmost part of both the Adriatic and the Mediterranean seas, is characterized by the largest tidal differences (semidiurnal amplitudes approach 30 cm) and the lowest winter temperatures (below 10 °C) in the Mediterranean Sea (Boicourt et al., 1999). The Slovenian coastal sea, a shallow semi-enclosed embayment, covers the southern part of the Gulf of Trieste (Fig. 1). The rocky substratum of the coastline, which is approximately 46.7 km long, consists mainly of Eocene Flysch layers, with alternating solid sandstone and soft marl (Ogorelec et al., 1991). The sediments of the two main bays of Koper and Piran are mainly composed of silty clay (with about 60% of clay), while in the central part of the Gulf the sand fraction prevails, consisting of about 80% of biogenic detritus (Ogorelec et al., 1991). A gradual increase in the grain size towards to open part of the Gulf of Trieste is clearly evident also from previous works (Ranke, 1976; Faganeli et al., 1984; Ogorelec et al., 1991).

The general water circulation pattern in the Gulf of Trieste is predominantly counter clockwise in the lower layer and clockwise in the surface layer. This circulation can be modulated by prevailing winds, mostly Bora (Stravisi, 1983).

In recent decades the Slovenian natural shoreline was modified by many human activities, like urbanisation, intensive farming and massive tourism. Nowadays, less than 18% of the coastline is in near-natural state (Turk, 1999). The coastal sea has suffered also from many anthropogenic impacts such overfishing, sewage outfalls and mariculture (Francé and Mozetič, 2006; Mozetič et al., 2008; Grego et al., 2009).

Among the six water bodies of the Slovenian sea (Fig. 1), four are defined as coastal waters (Ministry of Environment and Spatial Planning of the Republic of Slovenia, 2005). Two CWs were characterized as “rocky shallow moderately exposed” (SI5VT2, SI5VT4), one as “sedimentary shallow moderately exposed” (SI5VT5), and SI5VT3 as a candidate to be defined as a “heavily modified water body” (for typology see, Orlando-Bonaca et al., 2008).

Ten different sampling sites on hard bottom were chosen (Fig. 1) and classified into hydromorfological (HM) classes according to the WFD, from pristine conditions to very heavily stressed zones. They were chosen through evaluation of coastal modification due to the abiotic stressor gradient (see Section 2.4). Two sites were initially identified for each class, but during sampling *in situ* observations and sampling difficulties caused the modification of the status of two of them. As a result only one site correspond to class 4, and three sites correspond to class 2. As reference sites were chosen the Natural Reserve of Strunjan (SITE1) and the coast under Piran natural cliffs (SITE2). Slightly stressed sites were Cape Madona Nature Monument (SITE3), a segment of the coast between Koper and Izola (SITE4), and the Police seaside resort of Debeli Rtič (SITE5). Moderately stressed sites were located in the Youth Health and Holiday Center Rdeči Križ (SITE6) and at the external breakwaters of the Marina of Izola (SITE8). The only heavily stressed location was the Customs’ dock in Izola (SITE7), while very heavily stressed sites were inside the small ports of Bernardin (SITE9) and Piran (SITE10).

2.2. Fieldwork

The fieldwork was carried out in June 2008. Samples were collected during the period of high tide, in order to capture also vagile organisms, such as active crustaceans (crabs, isopods, amphipods) and gastropods (fam. *Trochidae*). Fifty samples were collected, 10 from pre-classified hydromorphological (HM) classes 1, 3, 5; 15 from class 2, and 5 from class 4. Each benthic sample consisted of three subsamples of 400 cm^2 size, collected in the upper-mediolittoral, lower-mediolittoral and upper-infralittoral belt. The vertical and horizontal extension, and the distinction among the upper- and lower-mediolittoral and the upper-infralittoral belt were done mainly through the identification of sessile organisms, according to Specchi (1966), Gamulin-Brida (1967), Pérès (1967) and Bellan-Santini et al. (2002). The presence of two species of Cirripedia (*Chthamalus stellatus* and *Chthamalus montagui*) marks the highest limit of the upper-mediolittoral. The abundance of these species drastically decreases in the lower-mediolittoral, were the characteristic species are mainly the bivalve *Mytilus galloprovincialis* and the brown alga *Fucus virsoides*. The lower limit of the