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Do structural and functional attributes show concordant responses to disturbance? Evidence from rocky shore macroinvertebrate communities

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ABSTRACT

The utility and concordance of application of taxonomic-based (diversity, richness and composition) and functional-based (biological traits analysis and functional diversity indices) metrics to distinguish anthropogenic disturbance or stress gradients (e.g., nutrient enrichment) on intertidal rocky shores were explored using macroinvertebrate communities. Metrics from both approaches showed similar trends in the variation of communities along the gradients, in which higher ecological health was found in less disturbed sites (farthest from the disturbance source), with the converse at more stressful sites (close to the disturbance source). The functional-based approach, using biological traits analysis and functional diversity indices, showed potential to be included in monitoring programmes at rocky shores alongside taxonomic-based metrics.

1. Introduction

How ecosystems respond to natural disturbance and anthropogenic pressures has become a major concern (Piggott et al., 2015). Such understanding is essential for the assessment of the likely resistance and resilience (Tett et al., 2007; Pinto, 2012) of an ecosystem and its subsequent potential for recovery after being impacted (Bremner, 2008; Statzner and Bêche, 2010). Local and regional scale impacts must be considered in the context of natural climate fluctuations and more recent anthropogenically driven climate change (Root and Schneider, 1995; Parmesan, 2006; Firth and Hawkins, 2011; Mieszkowska et al., 2014; Birchenough et al., 2015).

Coastal areas in particular are under the influence of multiple disturbances and stressors, naturally or anthropogenically driven, that impact their biodiversity and functioning (Micheli et al., 2016), thereby compromising their ability to sustain ecosystem services (Worm et al., 2006; Halpern et al., 2008). To manage pressures and impacts, several sets of legislation have been established worldwide over recent decades [e.g., European Water Framework Directive (WFD, 2000) and Marine Strategy Framework Directive (MSFD, 2008); Australia Oceans Policy (Commonwealth of Australia, 1998a,b); South Africa Integrated Coastal Management Act (South Africa Government, 2013); US Clean Water Act (US Environmental Protection Agency, 2002) and Oceans Act (US Congress, 2002); People's Republic of China laws on Water (1988/01/21) and Environmental Protection (1989/12/26)] in order to protect and restore integrity within marine ecosystems, ensuring that human activities are carried out in a sustainable manner (Borja et al., 2008). There is thus a societal demand for robust approaches to evaluate ecosystems status (Borja et al., 2016). This requires in-depth knowledge of the response of communities and ecosystems to anthropogenic impacts (Western, 2001; Hooper et al., 2005).

Traditional approaches to assess anthropogenic disturbance have usually been focused on taxonomically based structural features (e.g., metrics based on species richness, density/biomass, and diversity). Growing awareness that changes in biodiversity may potentially modify ecosystem functioning (Loreau et al., 2001, 2002; Hawkins et al., 2009) led to the recognition of the importance of considering functional attributes when detecting change (e.g., Loreau et al., 2001; Hooper et al., 2005; Elliot and Quintino,

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2007). The biological characteristics of organisms (traits – Violle et al., 2007) determine outcomes of interactions with the physical-chemical environment, population, community and ecosystem processes (Snelgrove, 1998). Thus, a trait-based approach offers useful proxies to investigate ecosystem functioning and the effects of disturbance at the ecosystem-functioning level (Bremner et al., 2006a).

In the past two decades, an interest in functional diversity (FD) has emerged: the functional component of biodiversity usually measured through species traits (Tilman, 2001). A suite of metrics and tools has been developed (Bremner, 2008; Mouchet et al., 2010). Recent approaches to address FD have often included Biological Traits Analysis (BTA; Statzner et al., 1994) and the computation of FD indices (Petchey and Gaston, 2006; Schleuter et al., 2010). BTA is a multivariate approach that combines information on species distributions over space and time, with the multiple traits (life-history, morphological, behavioural) they exhibit (Bremner, 2008). This multi-trait method had its genesis in terrestrial and freshwater ecology, but later it was translated to the marine benthic environment (Bremner et al., 2003) where it has been proved useful to: (i) assess fishing effects on benthic fauna (e.g., Bremner et al., 2003; Tillin et al., 2006); (ii) investigate the effects of climate change (e.g., Neumann and Kröncke, 2010); (iii) use for management and conservation purposes (e.g., Bremner, 2008; Frid et al., 2008; Veríssimo et al., 2012); and (iv) assess functional diversity in different species assemblages (e.g., Bremner et al., 2003; Hewitt et al., 2008; Van der Linden et al., 2016). Two of the most often used FD indices are the Community-Weighted Mean trait values (*CWM*; Garnier et al., 2004) and Rao's Quadratic Entropy (*RQE*; Rao, 1982; Botta-Dukát, 2005). These indices provide complementary information on the changes in the mean trait values (*CWM*), and on the patterns of trait dispersion (*RQE*), within the communities (Ricotta and Moretti, 2011). The *CWM* expresses the trait mean per sample weighted by species relative biomass, and allows investigation of shifting patterns in traits within communities indicating which traits are dominating ecosystems processes (Lepš et al., 2011; Ricotta and Moretti, 2011). The *RQE* expresses the amount of trait dissimilarity between species pairs in the community (Botta-Dukát, 2005).

Rocky shores are an important system which, in common with other coastal habitats, provide valuable ecosystem supporting (e.g., primary production), provisioning (e.g., seaweed and shellfish collection and aquaculture, fish nursery grounds), regulating (e.g., water quality by biofiltration, sea defence), and cultural services (e.g., aesthetics leading to amenity use and tourism) (Thompson et al., 2002; Sugden et al., 2009; Galparsoro et al., 2014). Moreover, rocky shores have been recognized as warning systems for climate change (e.g., Southward et al., 1995; Sagarin et al., 1999; Thompson et al., 2002; Hawkins et al., 2003; Helmuth et al., 2006; Mieszkowska et al., 2014).

The basic descriptive ecology of distribution patterns rocky shores has been long-studied (e.g., Stephenson and Stephenson, 1949; Lewis, 1964). The processes involved in setting distributions, driving population dynamics and structuring communities are well understood from a long history of field experimental studies on the interactions of the physical environment with biota and amongst the organisms themselves, including the role of recruitment in driving fluctuations (Connell, 1961; Menge, 1976; Paine, 1994; Raffaelli and Hawkins, 1996; Menge, 2000; Underwood, 2000).

There has been much attention to the responses of rocky shore organisms and assemblages to acute (e.g., oil spills: Southward and Southward, 1978; Hawkins and Southward, 1992) and/or chronic (harvesting: Addessi, 1994; runoff pollution: Kinsella and Crowe, 2015; Vinagre et al., 2016a, b; sewage pollution: Littler and Murray, 1975; Bishop et al., 2002; O'Connor, 2013; Zubikarai et al., 2014; Tributyl tin pollution from anti-foulants: Bryan et al., 1987) anthropogenic impacts (reviews of several acute and chronic impacts: Hill et al., 1998; Crowe et al., 2000; Thompson et al., 2002; Mearns et al., 2014). Despite this attention, in contrast to other coastal habitats (soft-bottom), few ecological tools are currently available for the ecological quality assessment of rocky shores, the existing ones being exclusively (Ballesteros et al., 2007; Juanes et al., 2008; Neto et al., 2012; Ar Gall and Le Duff, 2014) or in part (Díez et al., 2012) based on the macroalgae. Furthermore, the use of functional trait approaches on rocky shores has focussed nearly exclusively on macroalgae (e.g., Littler and Littler, 1980, 1984; Orfanidis et al., 2001; Martins et al., 2016), rather than on macroinvertebrates (but see, e.g., Törnroos et al., 2013; Bustamante et al., 2014; Vinagre et al., 2015) or the whole community considered together.

This work is, as far as the authors are aware, the first to assess impacts on rocky shore intertidal macroinvertebrate communities using a functional traits, coupled with a traditional taxonomically based approach. In particular, communities were assessed along anthropogenic disturbance gradients (organic enrichment) on two shores using trait-based descriptors (BTA and FD indices) as well as taxonomically based analyses (e.g., species composition, richness and diversity indices). For this purpose, (i) differences in the expression of biological traits across sites within the disturbance gradients were analysed; (ii) changes in FD over those gradients were investigated; and (iii) results obtained using trait-based descriptors were compared against those of taxonomic-based ones.

This study will contribute to a better understanding of the structure and functioning of intertidal rocky shore communities in the context of the future design of assessment tools. Such approaches will aid development of suitable management and conservation actions preventing further degradation, and where necessary enabling restoration.

2. Materials and methods

2.1. Study sites

Two rocky shores were monitored, Buarcos (40°10′14.2″N, 8°53′26.7″W) and Matadouro (38°58′31.5″N, 9°25′14.4″W), located on the western Portuguese coast (Fig. 1A) and, respectively, classified as Exposed and Moderately Exposed Atlantic Coast typologies (TICOR project, Bettencourt et al., 2004; available at http://www.ecowin.org/ticor/). Along this coast the prevailing current and wave direction are from West-Northwest with episodic occurrence from the Southwest (Ambar and Fiúza, 1994; Bettencourt et al., 2004). The most frequent wave period and wave height are in the range of 8–12 s and of 1–3 m, respectively. The tides are semi-diurnal and may reach 3.5–4 m during extreme spring tides (Boaventura et al., 2002; Bettencourt et al., 2004). Surface sea temperature ranges between 13–15 °C during winter and 20–22 °C during summer, with surface salinity varying between 35 and 36 (Boaventura et al., 2002).

On both shores the rocky surface is situated among narrow sandy areas limited landward by seawalls fronting promenades. The sampling areas are moderately impacted by continuous runoff throughout the year of water (crossing urban centres and agricultural land before reaching the shore) close to the upper intertidal zone creating disturbance gradients across the shores. These gradients on both shores were characterised by Vinagre et al. (2016a,b) showing differences in several physical-chemical parameters among sites [e.g., higher nutrient concentrations – dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphate (DIP), chlorophyll *a* and particulate organic matter (POM), closer to the source of pollution (SOP)], thus confirming the hypothesized gradients away from the SOP. Within these gradients, higher numbers of opportunistic macroalgal and macroinvertebrate species were found at the more stressed sites (close to SOP), and more sensitive