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Effects of subtle pollution at different levels of biological organisation on species-rich assemblages

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ABSTRACT

We investigated effects of subtle nutrient enrichment and metal pollution on different levels of biological organization (i.e. whole assemblage, population and individual) of species-rich assemblages. We used rockpools as model system, applying a multi-factorial sampling design to test hypotheses on differences between disturbed and reference locations. Results indicated that disturbed and reference locations supported similar assemblages, as well as individual fitness-related life-traits were ineffective to discriminate between the two conditions. In contrast, assemblages responded to pollution through a reduction of the abundance of sensitive species and a proliferation of tolerant species, although these alterations were detectable only once the influence of dominant taxa was down-weighed by data transformation. Present findings suggest that, contrarily to individual level variables, assemblage structure after data transformation and patterns of distribution and abundance of differently sensitive taxa would be a powerful tool to detect effects of subtle pollution on species-rich assemblages.

1. Introduction

The global increase of human activities has made pollution a major threat to marine biodiversity (Lotze et al., 2006) and a powerful ecological and evolutionary driver structuring coastal ecosystems (e.g. Forbes, 1999; Galletly et al., 2007). Pollutants can directly affect aquatic organisms by reducing their abundance through increased mortality, depressed fecundity, behavioural impairment or physiological stress, whose effects are normally proportional to the intensity and duration of exposure (Fleeger et al., 2003). Moreover, pollutants can alter interactions among affected organisms, an effect considered as indirect or secondary (Fleeger et al., 2003). Both direct and indirect effects can act across the whole range of levels of biological organization (i.e. from genes to individuals, populations, assemblages and ecosystems) and over multiple spatial and temporal scales (Parker et al., 1999). This poses large difficulties to unequivocally assessing the ecological effects of exposures to pollution and their underlying mechanisms, particularly in systems including well structured and diverse assemblages of species themselves largely variable naturally in space and time (Gray, 1989).

In this context, effects of severe pollution are relatively easy to detect as they usually involve drastic modifications of biodiversity through a large reduction of species and the promotion of a dominance of relatively more tolerant species (Gray, 1989; Johnston and Roberts, 2009). In fact, as a result of the concern about such ecological changes and their economical and social costs (e.g. Worm et al., 2006; Halpern et al., 2007), many countries have implemented policies to reduce the environmental impacts of pollution such as the European Water Framework (European Commission, 2000) or the US Clean Water Act (USEPA, 2002), which could considerably limit the amount of pollutants released to the environment and to make very unlikely, in most cases, the worst scenarios (e.g. Bustamante et al., 2012; Azeda et al., 2013). Nevertheless, effects of low concentrations of pollutants are difficult to detect as they hardly cause direct and evident toxic responses. In rich assemblages, in particular, overall changes are usually virtually negligible as only a few species will be very sensitive and potentially driven to local extinction by low concentrations of pollutants, while a relatively large number of species will be able to survive apparently unaffected. In low diversity assemblages, however, responses to low levels of pollution can be most likely detectable only at low biological levels (Rubal et al., 2009) due to the ability of exposed species to buffer the toxic effects through multiple physiological and/or genetic mechanisms (Calow and Forbes, 1998; Rubal et al., 2011a). Measurements of fitness and

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fitness-related life-history traits, such as rates of development and fecundity, have shown that these processes involve energetic costs (e.g. Weis and Weis, 1989; Notten et al., 2006). For example, Lardies et al. (2008) found that a decapod species exposed to high copper concentrations showed significantly lower size than the range observed in areas with no copper enrichment. Analogously, Bedini and Piazzi (2012) found a reduction of density, leaf surface and rhizome biomass of the seagrass *Posidonia oceanica* in disturbed habitats.

The present study was aimed at exploring the effect of nutrient and metal pollution at different levels of biological organisation on North Portuguese intertidal shores. Based on previous studies by Reis et al. (2012a,b, 2013) disturbed and reference rocky shores were identified. Moreover, at each studied location and date we have explored the concentration of chemical pollutants (i.e. metals and nutrients) in order to ensure different pollution profiles between disturbed and reference locations. Intertidal rockpools were selected as model system due to their previous knowledge in terms of patterns of diversity of both macroalgae (Araújo et al., 2006) and invertebrates (Bertocci et al., 2012) and of their natural variability in space and time (Rubal et al., 2011b; Bertocci et al., 2012). In addition, they were considered an ideal case study due to their accessibility and critical position at the interface between the marine and the terrestrial environment, thus being exposed to several anthropogenic disturbances, including the disposal of contaminants. A multi-factorial sampling design was adopted to test hypotheses on differences in the structure of whole assemblages, the total number of taxa, the Shannon Wiener index, the abundance of individual taxa and selected individual traits of a particular species between intertidal locations exposed to anthropogenic disturbance (i.e. associated to urban and port activities) and less disturbed reference locations. In order to test hypotheses on the consistency of the examined effects over time, sampling was done every three months during a year.

2. Material and methods

2.1. Study system

This research was carried out between February and November 2012 at four locations along the north coast of Portugal. The studied rocky shores are characterized by typically granitic substrate and the area presents a semidiurnal tidal regime, with the largest spring tides about 4.0 m. The wave regime is dominated by swells from the NW (73%) with those from the W contributing 16%. The mean wave height varies strongly among seasons, with typical wave heights during the spring–summer period between 1 m and 3 m and most storms occurring during autumn–winter months (October–March) when waves often exceed 7 m height (Dias et al., 2002). Concerning nutrients, the main change in their availability is closely related to upwelling events that increase the nutrient concentration particularly from April to September (Lemos and Pires, 2004).

Sampling was done at mid intertidal shore level, where emerged substrate is dominated by the mussel *Mytilus galloprovincialis* and the barnacle *Chthamalus stellatus*. The most common grazers are limpets (*Patella* spp.) and snails (*Gibbula umbilicalis*). However, at this tidal level rockpools harbour more diverse assemblages than emerged substrate. Macroalgal assemblages from rockpools include canopy-forming (e.g. *Sargassum muticum*, *Bifurcaria bifurcata*), turf-forming (e.g. *Gelidium pulchellum*, *Ceramium* spp.) and encrusting species (e.g. *Lithophyllum* spp.) and invertebrates are also very diverse (e.g. *Gibbula* spp., *Sabellaria alveolata*, *Mytilus galloprovinciallis*) with sea urchins as the most important grazer.

2.2. Sampling design

The study was done at a total of four locations in north Portugal: Âncora (A), 41°49′27.49″N; 8°52′28.51″W and Forte do Cão (FC), 41°47′44.32″N; 8°52′27.71″W as reference locations and Leça (L), 41°12′8.96″N; 8°42′54.17″W and Cabo do Mundo (CM), 41°13′31.36″N; 8°43′3.55″W as disturbed locations (Fig. 1). Disturbed locations are indirectly exposed to multiple diffuse pollution sources as harbour and industrial activities, river runoff, and urban sewage. Disturbed and reference sampling location could not be interspersed, but previous studies by Reis et al. (2012a,b, 2013) and specifically collected data indicated clear differences in pollution profiles between the locations assigned to each condition in the present study. Moreover, Veiga et al. (2013) found no significant variability among macroalgal assemblages among locations separated by a similar spatial scale as disturbed and reference locations (10 s of km) in north Portugal. Therefore, any possible confounding factor due to the spatial segregation of disturbed and reference locations was likely irrelevant compared to the specific effects under examination. Finally, with the aim of testing hypotheses on the consistency of the examined effects over time, sampling was done every three months (February, May, August and November 2012) with an

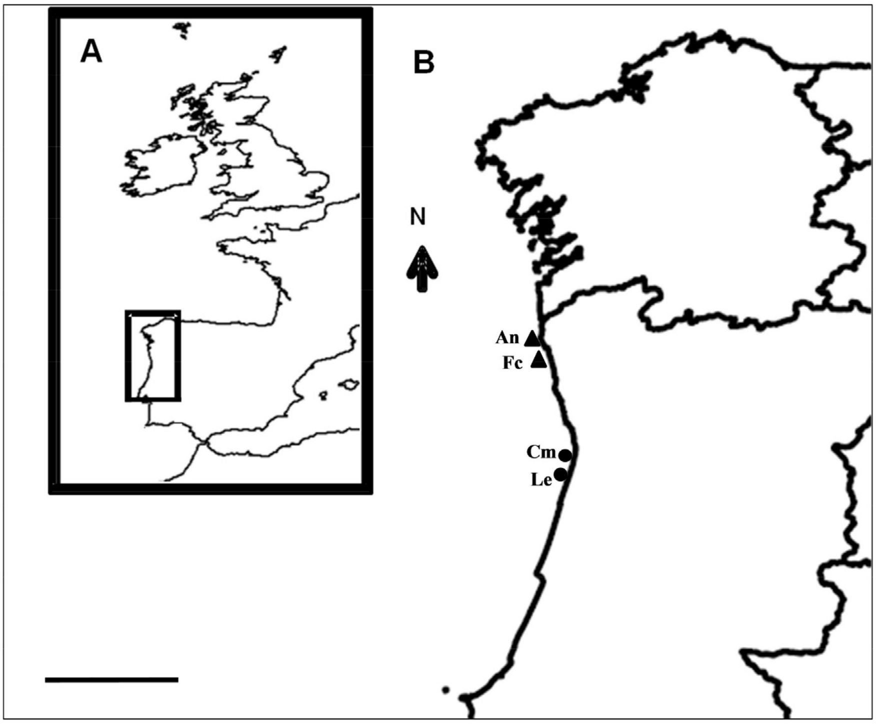

Fig. 1. Map of the studied locations. Full dots indicate reference locations Âncora (A), Forte do Cão (FC), full triangles indicate disturbed locations Leça (L), Cabo do Mundo (CM). Scale bar 50 Km.